THE FISCAL IMPLICATIONS OF CLIMATE CHANGE ADAPTATION

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PART I

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List of abbreviations

A	Adaptation (in mathematical formulas)
ADAM	Adaptation and Mitigation Strategies: Supporting European Climate Policy (a research project under the 6^{th} Framework Programme)
AT	Austria
AWG	Working Group on Ageing Population and Sustainability
B	Benefits (the mathematical function)
BE	Belgium
BG	Bulgaria
AD-DICE model	A modification of the DICE model (see below) that takes into account adaptation to climate change
BAU	Business as usual
BLOC	Backing, loss sharing, open and central & uniform
C	Costs (the mathematical function)
CAP	Common agricultural policy
CBS	Cost-benefit analysis
CCS	Carbon capture and storage/sequestration
CGE	Computable general equilibrium
CO_2	Carbon dioxide
CY	Cyprus
CZ	Czech Republic
D	Damages from climate change (in mathematical formulas)
DE	Germany
DG	Directorate-General of the European Commission
DICE model	Dynamic Integrated model of Climate and the Economy
DK	Denmark
E	A negative externality – a cost that must be borne by others (in mathematical formulas)
EE	Estonia
EEA	European Environment Agency
EL	Greece
ES	Spain
EPC	Economic Policy Committee
ESV	*Elementarschadensversicherung* [supplementary natural hazard insurance]
EU	European Union
EU25	The EU member states until the end of 2006 (excluding the current members Bulgaria and Romania)
EU ETS	EU Emissions Trading Scheme
EUSF	EU Solidarity Fund
FOC	First order condition
FI	Finland
FINSKEN	A regional climate model for Finland

FR	France
G8	Group of eight (France, Germany, Italy, Japan, the United Kingdom, and the United States, Canada and Russia)
G5	A group of emerging countries consisting of Brazil, China, India, Mexico and South Africa
GDP	Gross domestic product
GDV	German Insurance Association
GHG	Greenhouse gas
GRACE	A general equilibrium model used in ADAM
HU	Hungary
IE	Ireland
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IT	Italy
JRC	Joint Research Centre of the European Commission
LV	Latvia
LT	Lithuania
LU	Luxembourg
M	Maintenance costs (in mathematical formulas)
MC	Marginal costs (in mathematical formulas)
MB	Marginal benefit (in mathematical formulas)
MNP (currently PBL)	The Netherlands Environmental Assessment Agency
MPI	Max Planck Institute
MT	Malta
NL	The Netherlands
NO_x	Nitrogen oxides
NPV	Net present value
OECD	Organisation for Economic Cooperation and Development
PESETA	Projection of Economic Impacts of Climate Change in Sectors of Europe based on Bottom-up Analyses (a research project funded by the European Commission)
PL	Poland
PPP	Public–private partnership
ppp	Purchasing power parity
PT	Portugal
R	Emissions reduction = mitigation (in mathematical formulas)
R&D	Research and development
REMO	Regional Climate Model (Regionales Klimamodell)
RO	Romania
SCC	Marginal social costs of carbon
SE	Sweden
SI	Slovenia
SK	Slovakia

SLR	Sea-level rise
SRES	Special Report on Emissions Scenarios (by the IPCC)
TC	Total costs of climate change (in mathematical formulas)
tCO_2	Metric tonnes of carbon dioxide
TSO	Transmission system operator
UBA	The Federal Environment Agency of Germany (Umweltbundesamt)
UK	United Kingdom
UKCIP	United Kingdom Climate Impacts Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
WETTREG	Weather-based Regionalisation Method (Wetterlagen-basierte Regionalisierungsmethode, a regional climate projection model)
WHO	World Health Organisation
WIAGEM	World Integrated Assessment General Equilibrium Model
WRI	World Resource Institute (a Washington-based think tank)
WRMA	Weather Risk Management Association
ZÜRS	Zonierungssystem für Überschwemmung, Rückstau und Starkregen – an electronic database system developed by GDV
a_i	Amount of adaptation committed by individual *i* (in mathematical formulas)
f, *g*	Symbols for a mathematical function
d	Change (in mathematics)
∂	Partial derivative (in mathematics)
$\sum$	Summation (in mathematics)

Executive summary

Climate change will have an effect on the European Union. The repercussions will be regionally varied, with impacts on several sectors in the economy. Climate change has the particularity of being global with respect to the sources of emissions and local in the consequences (whether positive or negative). The sources of emissions are linked to the most basic aspects of human activity, from energy consumption to farming, while the impact of climatic changes are broader, affecting inter alia economic activities, land use, biodiversity, public health and water systems. This means that for the first time in history there is a need to align large parts of fiscal and regulatory policy with environmental concerns, from the local to the national and supranational levels.

Weather impacts will hit agricultural production, the tourism industry and public health, be it negatively or positively; they will also increase or reduce the risks of river floods and droughts, as well as affect the hydroelectric power stations and the cooling systems of other generators. Rises in sea levels will also pose considerable threats to many coastal areas. Studies on these large impacts abound, and show sizable differences in the quantification of impacts and their time scale. Now that we are starting to perceive some contours in the picture of impacts, a number of fundamental questions emerge: What should be the response of planners to these events? What are the costs of action or inaction to the economy and the state, and in particular the fiscal implications of the costs?

This report seeks to provide guidance on how to answer these questions. It is divided into two parts. PART I is dedicated to the conceptual framework, while PART II focuses on impact studies and data analysis to bring together the latest knowledge in this area. PART I of the report includes the following elements:

1) a theoretical framework that uses cost-benefit analysis tools to analyse the autonomous response to climate change impacts by individual economic actors, i.e. autonomous adaptation. It studies the potential market failures that may contribute to a suboptimal adaptation by individual agents. It addresses the reasons why autonomous adaptation alone cannot reach a socially optimum adaptation level. Finally, it also studies the response of individuals to various kinds of policies along with the role of insurance markets and combined, public–private partnership intervention through the insurance markets for extreme events;

2) a description of the driving factors of the fiscal impacts, listing the areas of concern depending on the level of exposure, existing infrastructure, fiscal capacity, etc.;

3) policy options to reduce the level of exposure to important fiscal impacts;

4) a summary of case study results on the fiscal implications for Germany, Italy and Finland; and

5) a summary of the knowledge gaps and required future work.

PART II of the report covers these elements:

6) a literature review of the existing cost estimations of climate change;

7) case studies for Germany, Italy and Finland on the impacts and their associated costs, with an analysis of the implications for budgetary costs and state fiscal balances; and

8) a knowledge gap analysis identifying the areas in which studies are missing and the adaptation costs and fiscal implications are still unknown.

The theoretical framework

The theoretical framework studies the behaviour of economic agents and how to alter it to reach a social optimum level of adaptation. It centres on rational economic decision-making in the face of climate change by individual agents, taking into account their profit-maximising objectives, the existence of market failures and uncertainty.

We thus distinguish two types of adaptation to climate change, autonomous and planned adaptation, which can furthermore be either anticipatory or reactive. Autonomous adaptation is defined as the unaided and unguided actions of private individual agents; this type may also entail collective action as long as it does not emerge through public policy intervention. Planned adaptation involves the intervention of the state to address market failures in the adaptation process, including the issues of equity and the security of supply of public goods or essential goods and services. Anticipatory actions are those that prepare for future impacts, while reactive actions are taken at the time of or after the climatic effects.

Policy interventions to assist adaptation should take place when autonomous adaptation is suboptimal and social costs are higher. This may be because the optimal adaptation for a profit-maximising individual is lower than the adaptation required for a social optimum or simply because the individuals do not have the means to cover the adaptation costs they have to bear. Other causes of suboptimal adaptation are imperfect information and moral hazard, which lead individuals to adapt insufficiently.

The study presents a theoretical framework that analyses the complex relationship between climate change impacts, socio-economic repercussions and fiscal policy implications. From a fiscal and economic policy perspective, the objective of a planner is to maximise social welfare while minimising the negative fiscal effects. This requires an understanding of the autonomous adaptation that is taking place, alongside the market and policy failures that emerge from such actions as well as other potentially unacceptable consequences for society (affecting equity, for example). The theoretical framework concentrates on the use of cost-benefit analysis tools for climate change adaptation. The theoretical framework develops the steps needed for policy-makers to address the fundamental questions about where, when and how to intervene.

For the policy-maker, the most difficult issue to address is the uncertainty of the timing and magnitude of impacts and how these factors translate into fiscal effects. Policy intervention may lead to an inefficient result with negative ramifications for the economy if adaptation measures are either too paltry or too ambitious. Different options also have different implications for fiscal costs and government revenues. The potential impacts of extreme events are seen in the study as important and presently underestimated, and policy-makers need to consider the kinds of actions needed for events of very low probability but very high cost. Such events are difficult to predict and generally absent from studies on climate change impacts, which often only look at gradual changes and average effects.

We determine that one of the most complex issues in the analysis of climate impacts is timing. When should an adaptation measure take place? Models diverge widely on both the extent of impacts and their timing. The study presents the theoretical treatment of time in a cost-benefit analysis, where the net present value of an action is estimated taking into account the value of the action under different risk levels, the costs and benefits of early or delayed action and the influence of maintenance costs.

Given the uncertainty of the expected regional effects of climate change, the benefits of the investment – by both private or public actors – in an adaptation project have to exceed the costs by a positive amount (the so-called 'hurdle rate') in order to justify the investment. The amount above the investment cost is called the 'option value' of not investing but waiting and delaying the project. In other words, the classic rule according to which the present value has to cover at least the cost of the investment does not hold under these circumstances. The optimal solution to this problem involves comparing investment costs and present values at all possible time slots, i.e. it must be taken into account that the investment is possible at different time slots. Using the option to wait, an investor can possibly gain new information about future benefits (but also about better adaptation techniques that may reduce costs) and can adapt his behaviour to changed conditions. Real option effects can work in the opposite direction, too: cheap options for adaptation or mitigation may disappear or become more costly as climate change intensifies over time. Therefore, appropriate analysis of an adaptation strategy has to incorporate this aspect as well.

One of the cornerstones of the report is the analysis of insurance markets. Functioning insurance markets are central to limiting the liability of the state and ensuring optimal adaptation. Public authorities need to explore further the use of insurance markets and the potential of public–private partnerships, such as state guarantees for excessive uninsurable damages. This could also include the creation of supranational reinsurance markets to support, at the EU level, national insurance schemes in cases of extensive damage across large territories. The way insurance is offered will be crucial to avoiding moral hazard, which is clearly present across a number of countries, whenever state guarantees provide a disincentive to take private insurance and thus shift private insurable costs unnecessarily to the state budget. Local government authorities may also avoid taking the necessary precautionary actions because they anticipate compensation for damages from the state or even from the EU.

The report presents a palette of options for insurance systems that could be efficiently deployed. Member states and the EU have to review their policy frameworks in this respect, to make certain that the private–public insurance combination is the most appropriate and least costly to the economy and the public finances.

Drivers of fiscal costs

While the theoretical framework studies the behaviour of agents, it does not directly address the question of what will drive the level of fiscal impacts. This study dedicates a large section to identifying and presenting the main drivers behind fiscal impacts:

1) the degree of exposure to gradual and extreme climate events;
2) the level of protection already in place in areas at risk, i.e. preparedness;
3) the state's liability for damages;

4) the potential and impacts of autonomous adaptation and remedial actions;
5) the cross-border effects of climate change; and
6) the fiscal capacity of the member states and the role of the EU.

There has not yet been any study that satisfactorily addresses the way in which these factors affect the state budget and in particular its stability. This study offers a first attempt at classifying the fiscal risks involved. From the case studies and other literature reviews, it is clear that the fiscal consequences are not negligible. A number of predicted climate changes and in particular extreme events could severely affect the fiscal stability of some member states.

In general, the gradual changes caused by climate change are considered manageable from the point of view of direct budgetary costs. Yet in relation to the costs arising from extreme events, along with the related indirect effects on growth and thus government revenues, the impacts are not necessarily manageable. Furthermore, the indirect effects of gradual climate change and the impacts in other countries can also threaten fiscal stability. A few impacts have been identified as having negative fiscal implications that are particularly significant. These are primarily related to the risks of floods owing to rises in sea levels, increases in sea surges and changes in river flows. For example, the annual costs of maintaining the necessary protective infrastructure for rivers and reacting to damages from extreme river flood events has been calculated to exceed 1% of GDP in some member states. This being an average, it is clear that the costs in any given specific year can be much higher.

After highlighting the main drivers, the study presents a number of recommendations for how to reduce the negative fiscal implications, which can be summarised as follows:

- selecting the right level of protection using appropriate, cost-benefit analysis tools;
- investing in research and development;
- providing a high level of public information;
- limiting state liability through innovative public–private partnerships with the insurance industry;
- adopting appropriate regulations on land use and on the use of other natural resources;
- using appropriate mixtures of legal and fiscal instruments to guide autonomous adaptation;
- reinforcing coordinated action across Europe; and
- ensuring that appropriate assistance is provided to countries whose internal fiscal resources are insufficient to undertake the necessary adaptation measures or to react to catastrophic events.

Literature review and case studies

PART II complements PART I. It presents the current state of knowledge about adaptation costs to climate change in Europe and presents a country-level impact analysis based on existing knowledge. Adaptation to climate change will predominantly take place at the regional and local levels, and it is at these levels that adaptation needs and costs can be assessed. Three case studies have been performed on climate impacts and adaptation needs in three representative EU member states, namely Germany, Finland and Italy. The analysis of climate change impacts in the three countries reveals that climate change is a multi-faceted phenomenon in Europe and that although in both northern and southern Europe temperatures are expected to rise, other physical outcomes and consequences of this temperature rise are by no means the same. While precipitation is projected to rise in Finland, in Italy severe droughts in summer may occur more often. In Finland, the expected climate-related damages are small and in some sectors climate-induced gains are even possible. In contrast, in Italy and in some economic sectors in Germany, climate change may entail high economic costs, such as capital losses due to floods and other extreme weather events. Some sectors, such as the tourism sector in Germany, call for more detailed regional studies, because climate change provokes economic losses in one region while it creates opportunities for other regions.

Concerning adaptation, the analysis distinguishes between planned centralised adaptation and autonomous adaptation. In the analysis of the countries studied, it becomes clear that some sectors are particularly prone to autonomous adaptation, but most autonomous adaptation measures need a supportive framework set by the government. Among the different actions, the most cost effective and influential is information provision on the expected regional impacts of climate change. But information provision is far from sufficient. For some adaptation actions, the state is the central provider of protective infrastructure and provider of assistance in catastrophic events. The state also takes on the main burden of maintaining transport and other public infrastructure.

The detailed, country case studies lay the groundwork for a more systematic approach to a literature-based review of adaptation costs. The results of the case studies, complemented by top-down cost estimates of adaptation measures in Europe, are listed in an adaptation cost matrix. The purpose is two-fold: first, the knowledge gaps become visible at a glance, as the cost estimates available in the literature are sorted by region, underlying scenarios, time periods and affect sectors. The matrix shows that to date most research has been done in the field of coastal protection, while little is known about public health impacts or the potentially costly adaptation measures in the transport sector. Furthermore, the adaptation of infrastructure in response to the increasing severity and frequency of extreme weather events may be relatively expensive, but detailed estimates of costs in the EU are mostly missing. The second purpose of the matrix is the systematic review and classification of various literature sources. Taking into account time periods, scenarios and methodologies, one can – inter alia – approximate total adaptation costs through the compilation of various sectoral assessments. So far, this application has mainly been hypothetical – there are very few studies that are comparable in terms of regional and temporal coverage, scenarios and assumptions; hence transferring the results of one bottom-up study to another time frame, region or climate scenario is largely a speculative exercise. Nevertheless, the cost estimates in the matrix show relatively high adaptation costs for agriculture, coastal protection and transport infrastructure (and possibly high negative costs in energy demand).

The theoretical framework for government intervention in adaptation is used to develop rough estimates for the direct public costs of adaptation. Therefore, sector-specific shares of public costs and the total adaptation costs are estimated. Coastal protection and transport infrastructure remain those aspects for which the impacts would entail the highest public costs; adaptation in the agricultural sector does not play a major role for public budgets, as the measures can mostly be assumed to be taken and funded privately, while support will generally be channelled by restructuring existing subsidies. Savings from the reduction of heating energy demand may provide for significant decreases in public expenditures, albeit only in some regions of the Union (northern Europe) and under uncertain assumptions regarding the technical developments.

It has been possible to estimate to a certain extent the direct costs to the state budget of gradual climate change (approximately €5 to 15 billion a year depending on the scenario), but the far more serious impacts from extreme events and indirect effects through ramifications on the economy are missing. Based on just one estimation for Germany by Bräuer et al. (2009), the indirect effects of climate change on public costs will amount to 87% of all public costs. Thus there is a signal that yearly average costs can treble to around €60 billion a year, i.e. 1% of total public expenditure for the EU, and not be evenly distributed territorially. For extreme events, there are very few indications of the expected costs, but studies by Costa et al. (2009), the IMF (2008) and the Dutch Deltacommissie (2008) on the protection of the Dutch coast give some flavour of the serious costs of damages from flood events in the event of insufficient adaptation.

The review of the case studies and the literature revealed a considerable lack of data and quantitative cost analyses. Research on adaptation costs is still in its infancy, so statements concerning the budgetary burdens related to adaptation are necessarily very uncertain. Still, the present analysis identifies the sectors with potentially high public costs and the sectors for which more research is necessary.

What emerges from PART II is the need to increase the number of bottom-up studies with cost-benefit analyses of alternative adaptation options, with a clear identification of the direct costs of the infrastructure, the level of state liability and the long-term costs to the economy, and the consequences of inaction.

1. Introduction and overview

Evidence suggests that the impacts of climate change are already being felt and will be increasing in significance over the years. Large uncertainties exist as to the nature of the impacts and the consequences for the European Union. Some trends are relatively clear, however, along with the fact that the effects will hit different regions in the EU in different ways. While not all regions will be adversely affected, the negative impacts will be larger on average and, as the Commission's Region 2020 (EC, 2009) and the JRC's PESETA report (2009) clearly indicate, the largest negative impacts are expected to fall principally on the already economically weakest or financially most vulnerable regions of the EU.

What also emerges from the studies is that there will be many impacts regardless of the mitigation efforts undertaken, as the stock of greenhouse gases already in the atmosphere will have an effect. The potential trade-off between mitigation and adaptation is therefore limited in the short term, and many adaptation actions are already unavoidable. Unfortunately, the exact nature of the impacts is shrouded by uncertainties, but the potential costs of inaction on adaptation measures are expected to be too substantial to ignore.

1.1. Potential types of adaptation and their fiscal implications

Adaptation is not an exclusively public responsibility, nor will it always create negative fiscal implications. There are different types of adaptation responses. There is *autonomous* adaptation, where agents adapt their behaviour as a response to climatic changes without intervention by the state. In contrast, there is *planned* adaptation, which is assisted by the intervention of public authorities. Each of these adaptation responses can be either anticipatory or reactive. Anticipatory adaptation is based on agents taking steps to avoid expected costs in the future, while reactive adaptation occurs as a response.

Autonomous adaptation alone by individual agents will play a central role, but it will likely lead to socially suboptimal results. There are many reasons for this. Many required actions have a large public good aspect, and individual costs will not reflect social costs, so steering adaptation to achieve a socially optimal level is thus necessary. In addition, climate impacts are complex and uncertainties hamper appropriate actions by individuals, again leading to the need for the government to enhance the availability of information for the economic agents concerned. An OECD (2008) study notes that many regions and sections of society remain poorly adapted to the current climate even if in line with historical trends. This is due to market failures, asymmetric information, policy failures and particularly a different private-to-public discount rate of the value of anticipatory action. Climate change poses new risk factors and these have to be incorporated in private and public decision-making.

Adaptation is expected to have manifold fiscal effects. These effects depend partly on the ability of private actors to autonomously adapt to changing climate conditions and partly on how much governments engage in the adaptation process. Below we explore the rationale for government interventions, namely the existence of market failures, equity concerns and the need to ensure security of supply. Since for the latter two issues additional political and social value judgements are required, from an economic point of view it is difficult to predict where and to what extent governments will actually intervene.

1.1.1. Autonomous adaptation

Much of the burden of financing the reallocation of resources to adapt to climate change will fall on the private sector. Negative or positive effects on the productivity of the private sector (e.g. higher energy expenditures, higher or lower crop yields in agriculture) will also have fiscal effects, for example owing to increasing or decreasing tax revenues. Autonomous adaptation (both domestically *and* globally) may also cause changes in the relative prices of goods and services, not only in the sector where adaptation takes place but also in other sectors of the economy (Aaheim and Aasen 2008). Therefore, fiscal effects may be observed in sectors for which adaptation to climate change does not have direct relevance.

The following potential kinds of fiscal pressures may be caused by autonomous adaptation (Heller 2003):

- financing for private adaptation in the production sector. A high degree of vulnerability, particularly in the agricultural sector, may create a demand for subsidies or transfers to facilitate adaptation (e.g. financing technological innovations and management practices). The extent of political pressure will also depend on the adaptive capacity of the farming sector.

- financing for private adaptation in the private sector, especially for low-income households (see section 2.3 on equity aspects and section 2.4 on security of supply). It is important to note that the prices of basic goods such as food or energy will probably increase because of climate change and adaptation policies.

- risks to the tourism industry, which may differ substantially within a country. In Germany, for example, summer tourism in the northern regions is expected to become more important while winter tourism in the mountains will become less so (Matzarakis and Tinz 2008). While on average the fiscal effects may be negligible, *regional* fiscal effects may be significant. Claims for transfers may be one reaction to impaired incomes from tourism.

- increasing or decreasing tax revenues from changes in the earnings or expenditures of private agents. A country's trade balance, the development of commodity world prices and changes in relative prices will play an important role in determining the fiscal implications.

Autonomous adaptation, without any intervention by the state, may thus create considerable costs to society and ultimately to the state. Autonomous adaptation may involve a suboptimal level of adaptation, resulting in higher overall social costs than under different levels of planned adaptation (which in economic terms would reflect a permanent fall in GDP as well as adverse effects on other indicators, such as life expectancy, health costs or biodiversity loss). The impacts of extreme events or events for which the extent of autonomous adaptation is too low because of uncertainty, moral hazard, adverse selection or the under-provision of public goods could be mitigated by planned adaptation. Appropriate planning for adaptation is also necessary to avoid the doubly negative fiscal effect of a fall in growth and thus fiscal revenues and an increase in public expenditure for reactive public intervention for adaptation. In countries especially vulnerable to climate change, growth may be adversely affected, putting additional pressure on the economy. Such growth impacts are going to have the most damaging effect on national welfare, rather than any direct fiscal costs arising from direct expenditure.

The results of no state intervention – even in cases where it would be optimal in pure efficiency terms – could also be unacceptable, based for example on equity considerations. In cases where planned adaptation is deemed necessary, it should consist of actions that maximise welfare and minimise fiscal costs. This does not imply minimising public expenditure, as a scenario with higher growth and increased public revenues can allow for more public expenditure and be fiscally beneficial overall.

1.1.2. Planned adaptation

In planned adaptation, government intervention is used for the provision of specific public goods as well as to correct for market failures and impacts that violate accepted standards of social equity. The costs of intervention may be very different depending on the kind and level of autonomous adaptation taking place and the kind of instrument used to correct for insufficient or socially suboptimal adaptation levels.

The objective of the planner, i.e. public authorities, should be to minimise the costs of climate impacts, while maximising the net benefits of intervention, more specifically maximising economic welfare and minimising fiscal costs. Planned adaptation may be anticipatory or reactive and may take many forms, such as information provision, regulation, taxation, subsidies and emergency support, as well as the state acting as a guarantor for insurance or financial engineering schemes.

Planned adaptation will need appropriate funding, which has to be financed for example through taxes. Thus, the overall economic costs comprise not only the tax itself but also the excess burden, which depends on the market conditions. The type of fiscal instrument used to raise the necessary resources will also be an influential factor.

Areas of public sector involvement will include outlays on infrastructure (urban water control, irrigation systems and public health systems) and subsidies (to facilitate the population resettlement). Planned adaptation may also involve preventing or regulating adaptation measures that generate negative external effects (e.g. uncontrolled flood protection measures in an upstream river segment or increasing water discharge from an aquifer). In this regard, the fiscal effects may differ significantly from the support for adaptation measures that generate positive external effects (e.g. the greening of city areas in order to mitigate the heat island effect). Taxing activities (such as water usage in heat periods) that generate negative externalities would have positive fiscal effects, while subsidising activities with positive externalities (like the planting of trees) have negative effects on the public budget.

With respect to planned adaptation, the following types of fiscal pressures are important (see also Heller 2003):

- requirements for building up or relocating infrastructure to address potential risks in coastal zones, notably for long-term infrastructure (bridges, ports). The requirements include the costs of coastal protection, building dykes, beach nourishment and maintenance. The fiscal effects in this regard will mainly depend on a country's coast length and the extent of development of the coastal areas (population density, tourism, biodiversity). The fiscal effects will also depend on the timing of adaptation measures;

- required regulatory policies to deal with land use and settlement management, especially in coastal zones and areas prone to flooding. These policies may have minor effects on the public budget but in terms of opportunity costs the effects may be consequential;

- required regulatory policies to adjust standards and prescriptive limits (e.g. environmental standards, construction guidelines);

- requirements for redistribution within the EU and development policies to avoid moral hazard by national or subnational jurisdictions arising from a failure to undertake adaptation activities. Again in terms of opportunity costs, the fiscal effects may be relevant (Heller 2008b);

- the fiscal component of costs to restructure and reform energy systems. Adaptation may cause effects on the demand side as well as on the supply side of energy markets. Additionally, changes in the energy grid may have fiscal effects;

- costs of adapting all publicly-owned buildings, facilities and infrastructure; and

- costs of providing information and monitoring early-warning systems, which are mainly relevant in the public health sector.

Another field of governmental intervention, the provision of basic information on the climate system and on expected local effects, may be of minor fiscal relevance but quite important in terms of facilitating autonomous adaptation.

It is also crucial to take into account the fiscal pressures already expected in the member states as a result of demographic ageing, chiefly with respect to public health and mobility. Adaptation considerations need to be taken into account in assessments of fiscal sustainability.

Planned adaptation actions should of course concentrate on the costliest and most probable events, but should also consider extreme but rare events, for which meeting the costs could result in considerable social harm. There are, however, also a large number of cheap and easily implementable actions even for smaller impacts, for which the benefits exceed the costs and which should be implemented quickly. The fiscal and regulatory policies in place should be reviewed and adapted based on the growing information on possible expected impacts. Fiscal and regulatory instruments have generally not been designed to ensure that private behaviour matches the need for climate mitigation and adaptation. Some of the policies may provide negative incentives in this respect. Climate change has the particularity of being global in relation to the sources of emissions and local in the consequences (whether positive or negative). The sources of emissions are linked to the most basic aspects of human activity, from energy consumption to farming, while the impact of climatic changes are broader, affecting inter alia economic activities, land use, biodiversity, public health and water systems. This means that for the first time in history there is a need to align large parts of fiscal and regulatory policies with environmental concerns, from the local to the national and supranational levels.

In addition, owing to the existing fiscal pressures, public authorities should concentrate on achieving cost effectiveness and maximising leverage effects, i.e. using private mechanisms in conjunction with public policy in the most efficient configuration. For adaptation, the role of insurance mechanisms will be crucial.

For policy-makers, one of the most complex barriers to formulating effective policies is the high degree of uncertainty surrounding the impacts of climate change. This brings considerable complexity to the planning process, thus entailing a risk of generating too much or too little adaptation; similarly, time considerations further accentuate the complexity of the decision process. Optimal adaptation to uncertain events may require early preparation. Some events, whose probability appears to be low in the medium term, may also occur earlier than predicted by the models (or later or never). For political decision-makers, events with a low probability of occurrence but very large costs associated with them will pose difficult dilemmas. Presently, contradictory claims on the speed and severity of some climate impacts just increase the uncertainty about optimal timing.

It must be emphasised, however, that climate change will not only bring negative impacts, but also benefits to some regions. There are areas that are expected to suffer less from river flooding for example or areas previously uncultivable that will become available for farming. It is important for governments to be reactive to not only negative but also positive effects, and to alter policy instruments to facilitate adaptive behaviour on the part of agents to avoid negative impacts as well as benefit from potentially new opportunities.

This report aims at providing policy-makers with conceptual criteria and guidelines on how to approach the issue of the fiscal implications of climate change.

1.2. Overview of the study

This report is divided into two parts. PART I presents a theoretical framework that analyses the complex relationship between climate change impacts, socio-economic impacts and fiscal policy implications. From a fiscal and economic policy perspective, the objective of a planner is to maximise social welfare while minimising the negative fiscal implications. This requires an understanding of the autonomous adaptation that is taking place and the market and policy failures that emerge from such action, as well as other potentially unacceptable consequences for society, affecting for example equity. The theoretical framework concentrates on the use of cost-benefit analysis (CBA) tools for assessing measures for climate change adaptation. The report discusses in section 2.2 the treatment of adaptation as a public or private good. This is important for determining when and to what extent public intervention, referred to as planned adaptation, is required. Based on the economic theory of social vs. private costs, this section looks at the potential market failures emerging from private autonomous adaptation leading to socially suboptimal results. It also gives an overview of the potential causes of suboptimal results, which may actually stem from perverse incentives under existing policies that could easily be altered. Apart from the correction of market and policy failures, efficient markets can entail consequences for social equity or for the security of supply (sections 2.3 and 2.4) of vital public or semi-public goods, which may justify some sort of policy intervention to cushion impacts or compensate for damages. Even after determining the need for action, acting to address potential adaptation needs through public policy instruments involves complex uncertainty and timing considerations. Generally, public policy-makers are uncertain about the size, frequency of recurrence and the expected timing of climate change developments or extreme weather events. The study presents a theoretical approach to these issues in sections 2.6 and 2.7 and concludes with a lengthy discussion of the potential uses of insurance markets (section 2.8).

Chapter 3 analyses the drivers influencing the fiscal implications. It describes the transmission of climate impacts to fiscal impacts. For each driver it proposes policy options to mitigate the negative fiscal implications, concentrating on those actions that have low fiscal costs but large benefits, from the basic provision of information to the use of fiscal instruments (such as taxes and subsidies) to change the behaviour of individuals and improve autonomous adaptation.

Chapter 4 presents a summary of the areas for which autonomous or planned adaptation will need to take place in the case study countries examined in PART II.

Chapter 5 outlines the potential fiscal implications derived from the case studies in PART II.

Chapter 6 discusses the results of a knowledge gap analysis discussed in PART II, indicating the areas of research required to assess the fiscal implications.

Chapter 7 presents the overall conclusions of the study, including those of PART II, which provides examples of the implementation of the theoretical framework in case studies and the structure for applying the methodology in European regions.

PART II accompanies PART I and presents a literature review on adaptation costs, three case studies (for Germany, Finland and Italy) and a list of knowledge gaps on the impacts and adaptation costs of climate change at present and in general equilibrium modelling.

The literature review in chapter 2 of PART II identifies the knowledge gaps concerning data and methodologies and ends with a note on modelling adaptation costs using computable general equilibrium (CGE) models. Chapters 3 to 6 of PART II present the implementation of the theoretical framework in three case studies, based on a bottom-up approach. Chapter 3 gives an overview of the existing work on National Adaptation Strategies in the case study countries. In the strategies and in the case studies, the focus is mainly on those critical sectors and fields considered particularly exposed and vulnerable to climate change developments. Thus, besides water resources, water supply and health, economic sectors such as agriculture and forestry, energy, transportation and tourism are examined. Adaptation measures – those realised as well as potential ones – are indicated for each sector and country and the fiscal implications are derived as far as possible.

2. Theoretical framework of adaptation policy

In this chapter, we focus on the key aspects that a theoretical framework for adaptation has to consider. Cost-benefit analysis is a basic tool in economic policy and can serve as the starting point for analysis. Then we examine several aspects that may help to identify the driving forces of the costs and benefits and the appropriate level of adaptation. In particular we discuss i) adaptation as a public or private good, ii) equity aspects, iii) security of supply, iv) the role of markets and collective action, v) the timing of adaptation, vi) uncertainty and irreversibility, and vii) adaptation of insurance markets.

2.1. Cost-benefit analysis

Starting from a global perspective, adaptation and mitigation are – to a certain extent – policy substitutes as both policy strategies reduce the impact of climate change, albeit with very different time dimensions and with considerable differences in the certainty that is associated with policy actions. Therefore, a joint analysis is necessary. From an economic point of view, cost-benefit analysis (CBA) is the appropriate tool in order to answer the questions how much adaptation and how much mitigation, respectively, is necessary. The question to be answered is, "If the world were ruled by a benevolent dictator, a philosopher-queen who is in control of the entire planet and is up to speed with the latest scientific insights, what would she do about climate change?" (Tol 2005, p. 573). Since real politics cannot possibly deliver a better result, global CBA provides a useful benchmark for evaluating real policies.

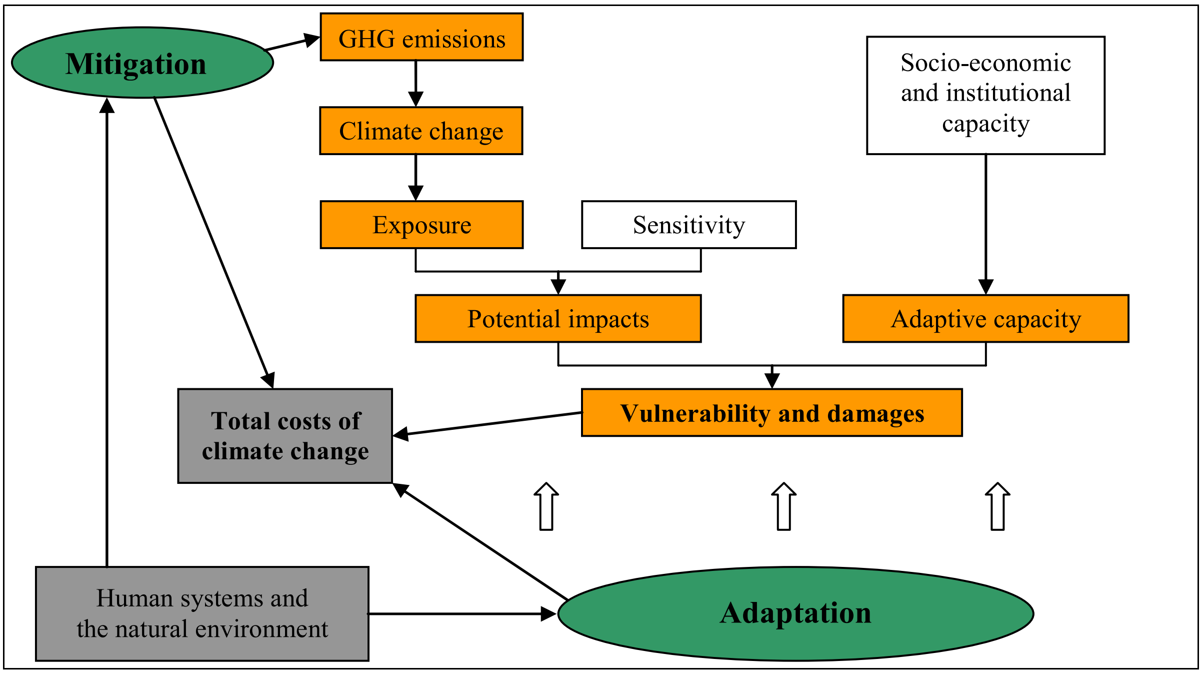
In a first step, we ask which factors determine the total costs of climate change. Three cost factors can be identified: i) mitigation, ii) adaptation, and iii) residual damage. How mitigation, adaptation and residual damages influence the total costs of climate change is depicted in Figure 2.1. Countries' mitigation efforts marginally influence GHG emissions and the extent and impacts of climate change. The resulting impacts depend on the sensitivity of regions and the actual economic activities exposed to the various physical effects of climate change. Human systems and the natural environment are furthermore characterised by their *adaptive capacity,* which in turn depends, respectively, on existing socio-economic and institutional capacities as well as on the responsiveness of fauna and flora in the ecosystem. Adaptive capacity is the ability of a system to provide the requisite resources to i) adjust to climate change (including climate variability and extremes), ii) moderate potential damages, iii) take advantage of opportunities, or iv) cope with the consequences (IPCC 2007b). Both potential impacts and adaptive capacity, determine a country's vulnerability and, finally, the climate change *damages*. Adaptation – as the second available policy strategy – is the direct response of human systems and the natural environment in order to reduce potential impacts (e.g. change in land-use policy), damages (e.g. building higher dykes) or to enhance the adaptive capacity (e.g. increase the level of education).

The task for the benevolent dictator, therefore, is to decide whether to invest in adaptation (*A*) or mitigation (denoted as emissions reduction *R*) in order to minimise the total costs of climate change, i.e. to minimise

$$TC = C_R(R) + C_A(A) + C_{\mathrm{Res}}(A, R) \qquad (1)$$

whereby TC are the total costs of climate change, $C_R(R)$ are the costs of emission reduction, $C_A(A)$ are the costs of adaptation measures and $C_{\mathrm{Res}}(A, R)$ are the residual costs of climate change damages. All costs are discounted value terms. The third cost term, $C_{\mathrm{Res}}(A, R)$, depends negatively on both adaptation and emissions reduction.

Figure 2.1: Mitigation, adaptation and damages



Source: EEA (2008).

The costs of emission reduction include, inter alia, costs for higher energy efficiency, fuel switching or the development of carbon-free technologies such as CCS. It is reasonable to assume increasing marginal costs of abatement.[1] The costs of adaptation comprise, for example, the climate-proofing of infrastructure, measures against sea level rise and higher expenditures for air conditioning. There may also be some benefits, for instance in the form of less heating or more agricultural production. We assume that marginal costs of adaptation are an increasing function of adaptation efforts – and are likely to rise over time, particularly if mitigation efforts fail to prevent an increase in climate change in the second half of the century and beyond. The reason for this increase is simply that cheaper and more effective adaptation measures will be realised first, and more expensive and less effective measures will be implemented later (de Bruin et al. 2007). There also exist some links between adaptation and mitigation costs, for example, more air conditioning increases emissions. Finally, the residual costs of mitigated climate change include damages caused by extreme weather events and other climate impacts despite mitigation and adaptation measures.[2]

The minimisation problem (1) results in two FOC, which are

$$R: \qquad \frac{\partial C_R(R)}{\partial R} + \frac{\partial C_{\text{Res}}(A,R)}{\partial R} = 0 \Leftrightarrow \frac{\partial C_R(R)}{\partial R} = -\frac{\partial C_{\text{Res}}(A,R)}{\partial R} \qquad (2)$$

---

[1] See, for example, the meta-study of Dannenberg et al. (2008).

[2] Tol et al. (1998) estimate the relation of adaptation costs to residual damages. Depending on the study, residual damages are 4 to 14 times higher than adaptation costs for a doubling of the atmospheric concentration of carbon dioxide. Using the AD-DICE model (a modification of the DICE model developed by Nordhaus) de Bruin et al. (2007) report residual damages for the year 2100 which are about 10 times higher than adaptation costs and mitigation costs respectively. Thus, residual damages seem to be much higher than the other costs components.

$$A: \quad \frac{\partial C_A(A)}{\partial A} + \frac{\partial C_{\text{Res}}(A,R)}{\partial A} = 0 \Leftrightarrow \frac{\partial C_A(A)}{\partial A} = -\frac{\partial C_{\text{Res}}(A,R)}{\partial A} \tag{3}$$

Avoided marginal costs can be written as marginal benefits, i.e.

$$-\frac{\partial C_{\text{Res}}(A,R)}{\partial R} = MB(R) \qquad \text{and} \qquad -\frac{\partial C_{\text{Res}}(A,R)}{\partial A} = MB(A)$$

Then, from (2) and (3) we get

$$\frac{\partial C_R(R)}{\partial R} = MB(R) \tag{4}$$

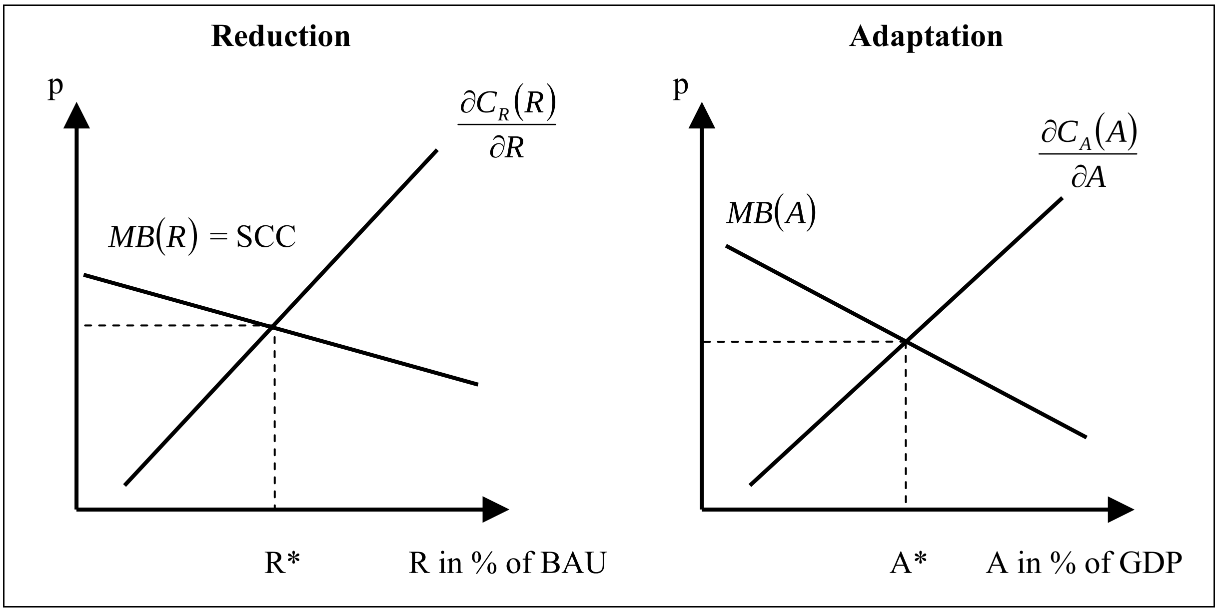
$$\frac{\partial C_A(A)}{\partial A} = MB(A) \tag{5}$$

In order to attain a total cost minimum, the marginal costs of emissions reduction should equal the marginal benefits of emission reduction (i.e. the avoided marginal residual costs of climate change) (see also Nordhaus 1991). Condition (4) delivers the optimal amount of emission reduction, $R*$. The term $MB(R)$, the marginal benefit of not emitting one additional ton of GHGs, is also called the *marginal social costs of carbon* or SCC (Stern 2007, Tol 2008), i.e. the total damage from now into the indefinite future of emitting one extra ton of GHGs now. Thereby, one has to take into account that the $MB(R)$ curve for a given period depends on future emissions (Stern 2007).

The second FOC states that adaptation should be realised up to the point where the marginal benefits of adaptation equal the marginal costs of adaptation. From condition (5) we get the optimal level of adaptation, $A*$.

Therefore, based on the costs minimisation problem (1) we get the optimal levels for reduction and adaptation, $R*$ and $A*$ (see Figure 2.2 for a graphical presentation). For both policy strategies, the marginal benefits (avoided marginal costs) have to equal the marginal costs. Thereby, emission reduction is depicted in percentage of business-as-usual emissions (BAU) and adaptation costs and benefits in percentage of GDP.

Figure 2.2: Cost-benefit approach to reduction and adaptation



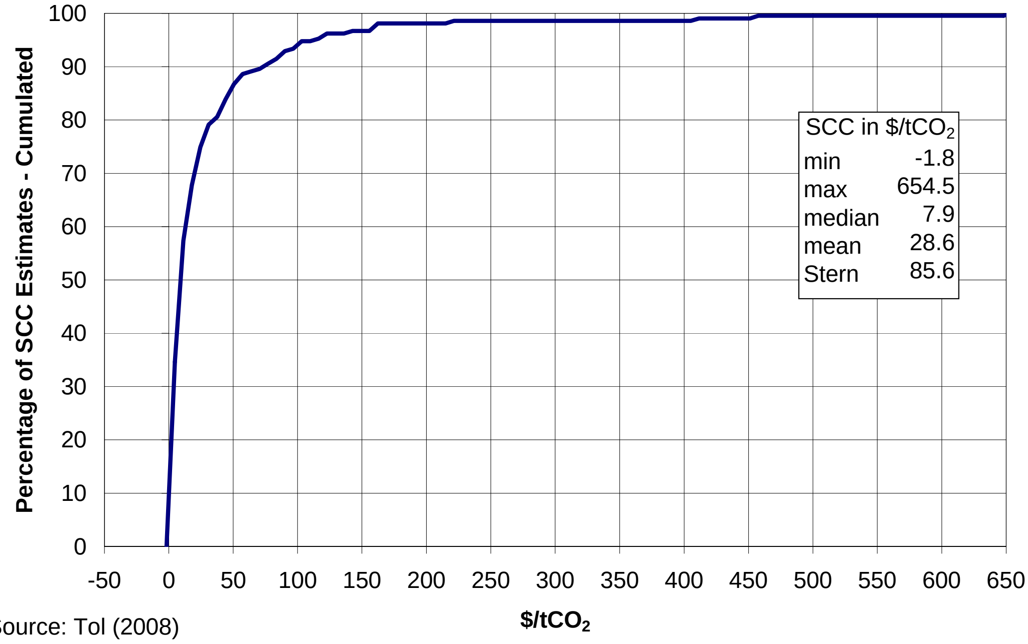
Given the costs curves in Figure 2.2, a simple comparative static analysis can give some insights how the optimal levels of both policy strategies react to changes in the economic systems. In particular, two aspects should be considered. First, a new technology which enables abatement at lower costs leads to a downward shift in the marginal abatement costs curve, $\partial C_R(R)/\partial R$, thus leading to more abatement in the optimum. On the other hand, more abatement makes less adaptation necessary as the marginal benefits of adaptation shift downwards.[3] In other words, there is a *trade-off* between mitigation and adaptation in this case. Second, if better information about future climate damages indicates that the expected damages of climate change will be higher, marginal benefits of mitigation as well as marginal benefits of adaptation will move upwards. In this case more mitigation and more adaptation will be necessary. The magnitude of the increase, however, will depend on the ascent of the marginal costs functions. An increase in risk aversion should have the same effects. In this case, the weight of the uncertain bad outcome increases leading to higher expected marginal damages.

If the SCC is computed along a trajectory in which the marginal costs of emission reduction equal the SCC, the SCC is the Pigou tax, which internalises the negative externality caused by GHG emissions. In order to get an idea of the magnitudes for SCC, Figure 2.3 depicts recent estimates, which are evaluated in a meta-analysis by Tol (2008). This analysis includes 211 estimates of the social cost of carbon. The median (mean) SSC value is $7.9/t$CO_2$ ($28.6/t$CO_2$). The estimate of the Stern Review is $85.6/t$CO_2$ and higher than 90% of all estimates available. The right tail of the SCC distribution is strong, i.e. there is a low but positive probability of very high SCC values. An important result of Tol's study is that equity-weighted estimates of the SCC are substantially higher than estimates without equity-weights. Higher SCC values would lead to more mitigation. From the viewpoint of the global decision-maker equity weighting is necessary because climate change will affect people with

[3] Remember that both adaptation and mitigation negatively influence the residual damage costs. More mitigation leads to a downwards shift in the marginal residual costs of adaptation and therefore also to a downwards shift in the marginal benefits of adaptation.

disparate incomes in different regions of the world (Anthoff et al. 2009). Economic theory assumes a declining marginal utility of consumption, i.e. the same absolute consumption change results in a smaller welfare change for a rich person than a poor person. Looking for the welfare effects of climate change one has to take into account this difference.

Figure 2.3: Cumulated relative frequencies of SCC estimates



Source: Tol (2008)

The global perspective above may not be appropriate for real politics for at least three reasons. First, as mentioned above there is no benevolent dictator who may enforce a global cost-benefit analysis. Second, emissions reduction is a global public good and the prospects for a global agreement – where industrialised and developing countries commit to binding reduction targets – are rather dim (Helm 2008). The December 2009 Copenhagen Accord represents proof of the difficulties in reaching any binding agreement. Despite the defined objective of limiting climate change to 2ºC the Accord is based on voluntary pledges for reductions to greenhouse gas emissions without enforcement mechanisms, which according to the IPPC already fall 50% short of the required cuts[4]. Therefore, the socially optimal approach to climate change may not be realistic and even more may not be helpful in order to analyse the potential fiscal effects of adaptation measures. Third, as is pointed out by Tol (2005), adaptation and mitigation are done by different people operating at different spatial and temporal scales. This hampers theoretically possible trade-offs between adaptation and mitigation.

Given this background the following nationally oriented perspective seems to be more appropriate in order to analyse adaptation from an economic point of view. From the perspective of a single (small) country the amount of global mitigation (R) is given, because this country has no influence on the global level of mitigation and on climate change in general. This is also largely true for the EU as a whole, as its emissions are estimated to be 'only' around 22% of global emissions (2004 data from the IEA). However, as adaptation has many private good properties at the national level, this country has a strong incentive to

[4] See http://www.climateactiontracker.org/.

provide this good efficiently (see Box 2.1 for an example at the regional level). Therefore, as reduction R is given for a single country, only $A*$ has to be determined by the social planner in this country (following condition (5)).

Box 2.1: CBA for hurricane protection system in the City of New Orleans

The proposed national perspective for a CBA of adaptation projects is also relevant for single local projects. A prominent example for this approach is the question whether and how the city of New Orleans should be rebuilt after the Hurricane Katrina. There has been a controversial debate about this question (Hahn 2005, Schwartz 2005). Hallegate (2006) implements a CBA with respect to the issue whether the additional costs of a category 5 hurricane protection system (Katrina was category 4) for New Orleans are lower than the benefits from reduced flood damages. This study is remarkable because on the one hand it demonstrates the applicability of CBA to a large-scale and climate related disaster protection project and on the other hand the key elements determining the results are identified. A first standard CBA rules out category 5 hurricane protection. The additional costs of category 5 protection are \$27 billion. Using an annual 1/500 probability of having a category 5 hurricane, the expected present benefit of a category 5 protection system in New Orleans is between \$1.5 billion (with a 7% discount rate) and \$6 billion (with a 3% discount rate). This calculation clearly rules out an upgrade of the protection system to make it able to cope with category 5 storms. However, taking into account effects such as climate change related effects to the environment, indirect impacts of large scale-disasters, and possible changes in the discount rate might still make such a hurricane protection a rational investment. Hallegate's study also emphasises the importance of the difference between direct costs (such as costs evaluated by insurance companies) and indirect cost. Direct costs may be amplified in the case of large-scale events, for instance by production losses during the reconstruction phase or by negative long-term effects on tourism.

There are the following potential limitations to the above presented cost-benefit approach. First, possible interactions between adaptation and mitigation are not considered. The IPCC (2007b, pp. 759-760), in discussing this issue, comes to the result that such interactions are of minor importance. However, more in-depth studies are needed to estimate the magnitude of interaction effects. The most important example for an interaction between both climate policy strategies is agriculture (Rosenzweig and Tubiello 2007). Some very specific adaptation practices may not be conducive to mitigation. For instance, increased or new cultivation due to a longer growing season may lead to losses of organic carbon in the soil, i.e. the reduced sequestration of atmospheric carbon in agricultural soils. Furthermore, with respect to the livestock production levels, warmer conditions in the coming decades may trigger the implementation of enhanced cooling and ventilation systems, which would increase energy use and (possibly) CO_2 emissions. Discussing those and other interactions between adaptation and mitigation, which may lead to increased CO_2 emissions from adaptation efforts we have to bear in mind that economic (cost) efficiency requires setting an equal price on all emissions sources in an economy. Therefore, in the case of increased GHG emissions in agriculture due to changing cultivation or livestock production techniques, one should set a price on the emissions (or at the production level) in this sector. Furthermore, the increased energy use due to enhanced cooling systems *in Europe* does *not* increase the CO_2 emissions. The reason for this is the existence of the EU emissions trading scheme (EU ETS), which sets an overall cap on the emissions of the regulated sectors. Since the electricity sector is under the EU ETS cap, higher electricity use does not increase CO_2 emissions but has only price effects on the emissions market. Actually, adaptation in Europe may even lead to a decrease of total CO_2 emissions. Higher winter temperatures will lead to a lower level of carbon intensive heating (mainly based on oil and gas) which is currently not under the EU ETS cap. The empirical evidence is quite clear: De Cian et al. (2007) estimate temperature elasticities of demand for different countries. For most European countries, the temperature elasticity of demand for electricity is positive while it is negative for gas and oil. On the other hand, increased need for air conditioning due to higher summer temperatures will lead to more electricity consumption, which is CO_2 neutral because the electricity sector is under the EU ETS cap. Thus, anticipating the final consequences of adaptation and mitigation measures, one has take into account the existing institutional framework.

Second, uncertainty about climate sensitivity and economic impacts may pose a serious challenge to CBA. Recent studies (e.g. Tol 2003 and Weitzman 2007, 2008) suggest that uncertainty about low-probability-high-impact events may limit the applicability of a cost-benefit framework. The reason is that – due to the possibility of a catastrophic event – there may be situations where society's expected marginal rate of substitution between current and future consumption is indefinite. On the other hand, Lange and Horowitz (2009), Tol and Yohe (2005) and Howarth (2003) show that even in cases where the economic value of avoiding a catastrophic event is infinite, the criterion of maximising expected present-value net benefits is operational.[5]

Given this scope of theoretical explanations, we analyse the *institutions* that can facilitate the provision of the efficient adaptation level at the national level, recognising both the governance challenges that might arise and the potential difficulties that can arise in the interaction of the government with the private sector (and even across levels of government). In particular, the importance as well as the limitations of markets with regard to the provision of adaptation measures will be analysed.

2.2. Adaptation as a public or private good

From an economic point of view, the distinction between adaptation as public or private good is essential because this procedure determines who should be responsible for providing the adaptation measure (see e.g. OECD 2008). In this section we show with a simple theoretical model how different adaptation measures may be characterised as private or public good. Thereby we closely follow Mendelsohn (2000). Furthermore, we analyse the role of government in this context.

Private adaptation

We start with a simple model of an economic sector that is climate sensitive. We assume that individuals or firms can engage in some expenditure that will tend to reduce the damages or increase the benefits from climate change. Furthermore, there is no market failure. The question is to what extent private adaptation leads to a social optimum.[6]

Reduced damages and increased benefits are defined in terms of a benefit function that depends only upon the amount of adaptation, *A*:

$$B = f(A) \qquad (6)$$

[5] Sections 3.7 and 3.8 discuss uncertainty with respect to adaptation.

[6] Mendelssohn (2000) refers to *private* adaptation, which is here equivalent to *autonomous* adaptation.

where $dB/dA > 0$, and $d^2B/dA^2 < 0$.[7] Benefits are non-linear. They are assumed to increase at a decreasing rate with adaptation. That is each monetary unit invested in adaptation reduces the residual climate change damage but the reduction is decreasing with more adaptation. The reason for this assumption is that adaptation measures that generate high benefits are first implemented.

Adaptation is not free. There are costs associated with adaptation, from either lost opportunities or explicit outlays. The cost function has the following properties:

$$C = g(A) \tag{7}$$

where $dC/dA > 0$, and $d^2C/dA^2 > 0$. Thus, also costs are non-linear. They are assumed to increase at an increasing rate. This cost curve reflects rising production costs due to a potentially higher demand for resources. Furthermore, if several adaptation options are available the low-cost measures are first implemented. For example before a house owner insulates her house from heat she may decide to use an air conditioning system.

The first order condition (FOC) implies

$$\max_A \; B(A) - C(A). \tag{8}$$

The FOC delivers an optimal level of A^* where the marginal benefits equal the marginal costs:

$$MB = MC \tag{9}$$

It is commonly assumed in economics that marginal benefits and costs are linear (see Figure 2.4). Although the real costs and benefits may jump at certain threshold levels, in particular in case of adapting infrastructure, this assumption seems to be a good approximation due to the potentially available adaptation measures the create different costs. For example, if people wish to respond to rising sea levels, they may decide to either build a new sea wall or raise the height of the old one. If the expected benefits from the new sea wall exceed the additional costs then the landowners should choose the new sea wall. This is what condition (9) implies.

If the individual must pay all the costs and yet enjoys all the benefits, then it is individually rational to choose the optimal amount of adaptation. Individually rational behaviour leads to a social optimal solution. Of course, if the strong assumptions of the above model are violated, efficient adaptation may not be selected. For example, if some of the costs of the adaptation are not paid by the individual, then the person may make the wrong choice from the social point of view. For example, what would happen if the government subsidises adaptation by an amount, γ, equation (8) will change to

$$\max_A \; B(A) - (1-\gamma)C(A) \tag{10}$$

The individual will choose an amount of adaptation where marginal benefits are equal to marginal costs:

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[7] The effect of temperature on benefits – which could be positive or negative – is not modeled here, because this does not generate an added value at the moment.

$$MB = (1-\gamma)MC \qquad (11)$$

The result will be too much adaptation. Although it is an individually rational behaviour, the subsidy encourages the individual to invest more than the efficient amount.

Another and perhaps more relevant example of incorrect costs occurs when there is an externality from an adaptation decision. For example, suppose that a forester switches tree species in order to take advantage of a warmer climate. Suppose that the forester only considers the timber benefits against the cost of encouraging the species switch. However, suppose that wildlife species dependent on the old species cannot survive with the new species in place. If the wildlife is valued by others, but the landowner does not consider this effect, the switch in species introduces a negative externality, $E(A)$, a cost which must be borne by others. The landowner will make the decision based only on his own costs and benefits (such as in (11)). However, society would face the choice below:

$$\max_A \; B(A) - C(A) - E(A) \qquad (12)$$

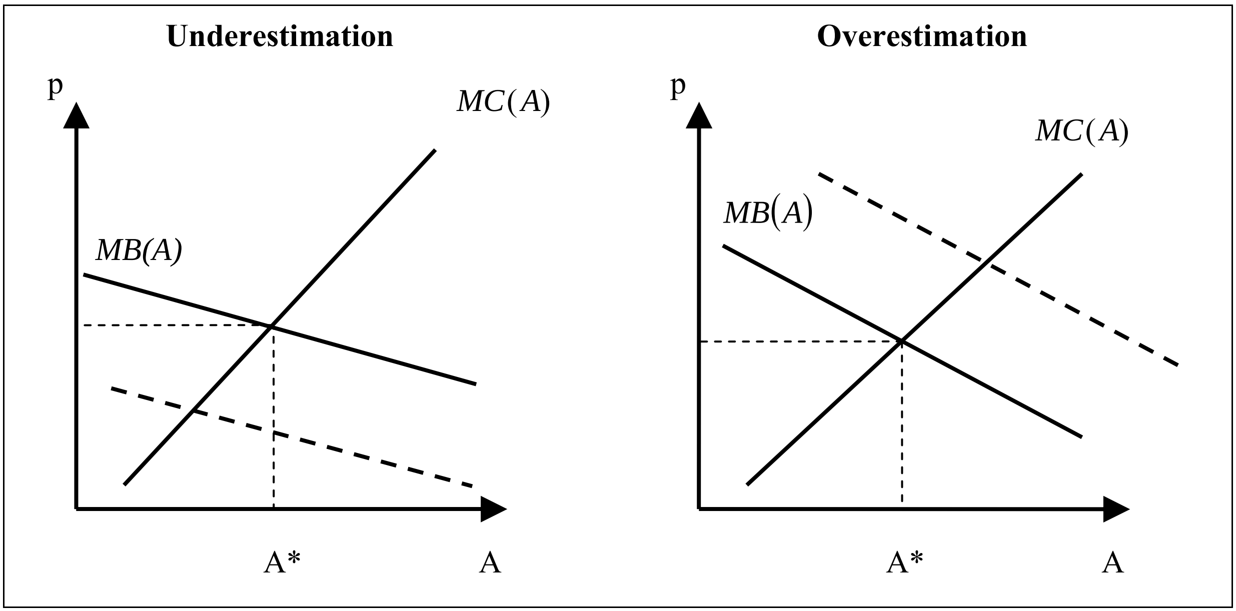
whereas the landowner would choose a level of adaptation that dealt with only the first two terms above as in (8), the optimal choice would now be the following:

$$MB = MC + ME \qquad (13)$$

The optimal choice would weigh the wildlife effect as well as the cost of the conversion against the benefits of the new species. The landowner, in this case, would be too eager to make the change. Private adaptation can be inefficient if it involves substantial externalities.

The analysis can easily extended to the case that individuals underestimate or overestimate marginal benefits of adaptation. If there is substantial uncertainty about the future benefits of adaptation but the current costs are reasonably clear, people may make poor decisions about private adaptation. The result will be too little adaptation if people underestimate marginal benefits (left panel of Figure 2.4) and too much adaptation if people overestimate marginal benefits (right panel).

Figure 2.4: Uncertainty about the benefits of adaptation



Joint adaptation

Joint adaptation involves responses to climate impacts where there are many beneficiaries to each action. From an economic point of view, joint adaptation resembles a public good (Samuelson 1954).

The general model of joint adaptation reveals that the benefits of actions are shared across more than one decision-maker:

$$\max_{a_i} \quad \sum B_i(a_1, a_2, ..., a_n) - \sum C(a_i) \tag{14}$$

where a_i is the amount of adaptation committed by individual *i*. With joint adaptation, the benefits to individual *i* depend not only on what individual *i* chooses but also on what many other individuals choose as well. The fact that the benefits of individual actions are shared by others is the defining characteristic of joint adaptation. This interpersonal complexity explains why joint adaptation is more difficult to manage efficiently.

In the social optimum, the sum of all marginal benefits from adaptation is equal to the marginal costs:

$$\sum_{j=1}^{n} dB_j / da_i = MC_i \tag{15}$$

The adaptation a_i^*, which would result from (15), would be efficient as it would maximise (14).

In contrast, if the individual only considered the effect of his expenditure on himself, then the individual would use a more limited definition of marginal benefits:

$$dB_i / da_i = MC_i \tag{16}$$

This would result in a level of adaptation a^0. Since $\sum dB_j / da_i > dB_i / da_i$, then it follows that $a^* > a^0$. The selfish individual would spend too little on joint adaptation.

In theory, a collective action through the government could solve the problem of joint adaptation by supplying protection levels based on an efficient allocation (15). The government, acting on behalf of society at large, would choose the efficient level of adaptation that maximised the group's net benefits. Total benefits and costs would be considered in every decision. Thus, government decisions, in addition to being concerned about direct group benefits, could also take into account externalities. In the remainder of this report, collective action, joint adaptation, planned adaptation and government intervention are used as synonyms, that is collective action is assumed to always involve some form of government regulation. However, other forms of collective action apart from government intervention could play a role in adaptation. Firms of the same branch may cooperate in a national or international association in order to share information or business strategies. For example, the German Insurance Association currently funds a research project on climate change and adaptation and their implications for the German insurance market. As these forms of collective action do not involve government regulation they belong to private or autonomous adaptation in this report. In other words, the fact that some firms or individuals may choose to respond to climate change the same way does not make it joint adaptation (Mendelsohn 2000). In contrast, public–private partnerships (PPP) belong to collective action because they imply some form of government intervention.

To sum up, the market will not always lead to efficient levels of joint adaptation, i.e. in the case of adaptation measures, which are public goods or at least have strong positive externalities. Joint adaptation will be efficient only through collective action. In general, governmental intervention is necessary if there is market failure and if the costs of the intervention are lower than the welfare loss due to market failure. Negative externalities due to private adaptation are another kind of market failure (such negative externalities can also arise from planned adaptation measures where there are negative cross-border effects). In this case governmental action is necessary to reduce the amount of private adaptation measures. Two examples can illustrate this issue. First, building dykes in order to prevent river floods up-stream increases the risk of floods downstream. In a non-cooperative environment, an up-stream decision-maker will not take into account the negative externality for the down-stream region generated by the dyke. Second, adaptation measures such as changes in mobility behaviour may increase emissions of pollutants such as CO_2 and NO_x. Again, rational and selfish subjects will neglect the negative externality leading to a social dilemma situation.

Facilitating autonomous adaptation

Besides the provision of adaptation measures with strong public good properties, there is a second important aspect of governmental intervention: autonomous adaptation to climate change may need to be 'facilitated' by governmental action. Politicians may i) help economic agents to better understand the nature and impacts of the expected climate change, i.e. to produce and distribute information, and ii) create an institutional framework where autonomous adaptation can be successful (Heller 2008b).

Rational subjects need information in order to adapt efficiently. *Information* on the expected regional effects of climate change, however, has strong public good characteristics. Given the non-rivalry, the marginal costs of information dissemination are close to zero. Furthermore, excludability of information on the expected climatic effects is difficult to enforce. Therefore, private agents will not be able to provide sufficient information on the expected regional impacts. In other words, governmental action is necessary in order to provide the efficient amount of information about the expected regional effects of climate change.

The importance of the institutional framework will be illustrated by property rights. Without a functioning property rights system, long-term investments, which are crucial for several adaptation strategies, will not take place (see Box 2.2). The absence of such facilitating adaptation may ultimately lead to inadequate autonomous adaptation and a higher level of necessary planned adaptation in the future.

Box 2.2: Property rights in Finland

Property rights systems are the basis for efficient long-term adaptation. Hilden et al. (2005) give a good example. The current legislation in Finland restricts the land tenancy period to ten years only, while in many other EU countries such short tenancy periods are exceptional. The short tenancy period in Finland results in land tenure insecurity and provides little incentives for investments in drainage systems of fields or in improving soil quality. While the proportion under lease farming has increased up to 35% in Finland in the last ten years, the investments in drainage systems, as well as lime application on land, have decreased. The projected increase in annual precipitation by 30-40%, and an increasing probability of heavy rainfall and storms due to climate change require efficient drainage systems. Hence, farmers need appropriate economic incentives and a suitable institutional setting for making investments in drainage systems whose operating time is typically 50-100 years, if properly installed.

Another important point is that autonomous adaptation actions may not only be induced by governmental incentives, but also may be influenced by *planned* adaptation efforts by the government (Heller 2008b). This arises from the potential for 'moral hazard' effects. As has been discussed by Wildasin (2008), Goodspeed et al. (2007), and others in the context of recent US terrorist and hurricane events, the amount of autonomous adaptation to some climate change-related events may be lower if there is a perception that ex post, the government will reimburse economic agents for much of the damages arising from such events. Even with the recognition that there may not be full compensation, the ex ante precaution would not reach the efficient level. In other words, planned adaptation by a government may deter autonomous adaptation actions by private economic agents.[8]

Such moral hazard effects have mostly been discussed in relation to the effects of US Federal Governmental actions after Hurricane Katrina. These may have led *state and local governmental units* to invest less in future climate change preventive adaptation measures. But the issue is equally relevant to the extent that governmental action – whether reactive or anticipatory – may also discourage the *private* sector from engaging in autonomous adaptation efforts. There is a similar situation in Germany (Schwarze and Wagner 2003). The German flood disaster in summer 2002 highlighted a dilemma concerning insurance against damages caused by natural forces. On the one hand, owing to the rising incidence of natural disasters, private insurance companies are increasingly withdrawing coverage of floods. On

[8] See also section 3.8 for the effects governmental intervention may have on the natural disasters insurance scheme.

the other, the availability of emergency relief funded by the state and private donations in case of a natural catastrophe is systematically weakening the incentive for potential private victims to implement preventive measures, i.e. the contracting of insurance that can reduce the risk of damages. Local authorities may also believe that the government will cover the cost of repairs and decrease their efforts towards risk prevention.

Thus, in trying to characterise what might be required in the form of governmental adaptation actions (and in assessing their fiscal consequences), it becomes important to assess how such actions might affect autonomous adaptation of nongovernmental agents (or even adaptation by lower levels of government). Indeed, some might argue that governments should not intervene in the case of extreme events other than for basic welfare-provision in order to avoid provoking such moral hazard problems.[9]

2.3. Equity aspects

Another justification for governmental intervention to facilitate private autonomous adaptation is equity. We propose the following structure for analysing equity issues: i) equity issues within countries, ii) equity issues between EU member states, and iii) equity issues between industrialised countries and developing countries.

Let us first consider equity issues in the national context. Although private adaptation may be efficient, it may not be considered as just (Mendelsohn 2000). Here, both vertical and horizontal equity (Atkinson and Stiglitz 1980) matter for public policy, i.e. aspects of redistribution between high and low income households and the equal treatment of individuals by the law. With respect to vertical equity, low-income households may not be able to afford adaptation measures and equity concerns may thus motivate the need for governmental action. The intense debate about the introduction of lower energy prices for fuel- or energy-poor households[10] in order to protect these households against adverse effects is an example for this kind of distributional problem. In the future, there may be a similar discussion about the 'right' prices for adaptation measures or prices for inputs for such measures. Essentially, society has to decide which human needs it considers to be elementary and deserve insurance by public authorities if a citizen cannot provide for himself. Adaptation may require new answers to this old question of social policy. Economic policy has to find measures to ensure these entitlements without excessive efficiency losses. In principle, the preferable solution from an economist's viewpoint is to give lump-sum transfers to low-income households. Thereby relative prices will not be distorted and the governmental support is transparent. The case of health insurance shows, though, that in some cases satisfying entitlements may require more complex answers, in particular when moral hazard and adverse selection render first-best solutions impossible. These can arise in the case of energy poverty, too: poor households tend to live in rented rather than self-owned homes and will thus have little influence on the insulation. Real estate companies, on their part, will rather not invest into insulation when they cannot charge higher rents. This may justify government handling of social housing.

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[9] See, for instance, Epstein (1996).

[10] See for example "Barroso urges lower energy prices to help poor", 6 July 2008, http://www.eubusiness.com/news-eu.

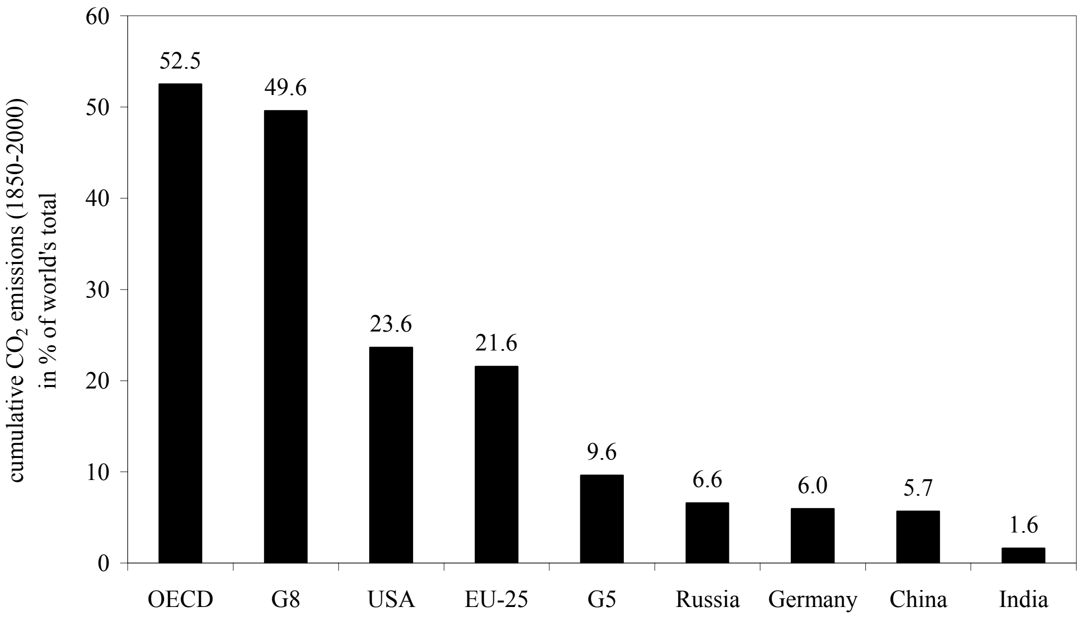
The matter of horizontal equity may well prove to be trickier. For example, it may well be efficient to shelter one agglomeration from flooding while giving up another agglomeration, depending on the relative costs and benefits. Clearly, however, such a policy decision has very different impacts on real estate property rights. If taken by a central government, the unequal treatment would surely provoke lawsuits. In the future governments will have to develop rules (and limits) for compensation for households whose property is not protected. Federal states will have to device a framework of local, regional and national responsibilities for adaptation. Given the huge fiscal consequence of both collective adaptation and compensation, this is a great challenge.

Second, since climate change damages will vary among regions (EEA 2008), in particular between southern Mediterranean and northern European states, the question arises to what extent the EU will provide *intergovernmental transfers* from the winners to the losers (Heller 2008b). The EU has to decide whether it has a responsibility to help finance adaptation actions that would reduce the burden of climate change to citizens of a negatively affected country. Thereby, a moral hazard issue arises, because loser countries may anticipate the help of the EU and therefore reduce their adaptation efforts in order to get more financial assistance.

Third, the equity argument seems to be especially powerful in an international context where climate change is currently being caused by relatively wealthy northern countries and yet the victims may well be largely poorer southern countries.

As shown in Figure 2.5, both OECD and G8 countries are responsible for approximately half of the world's cumulated CO_2 emissions between 1850 and 2000. On the other hand, G5 countries represent only a fraction, viz., 9.6%. In terms of individual countries, the largest emitters are the US (29.3% of the world's emissions), the EU-25 (26.5%), Russia (8.1%) and Germany (7.3%). China, which recently became the world's largest CO_2 emitter (MNP, 2008), is only responsible for a fraction of 7.6% of the world's cumulated CO_2 emissions (WRI estimates for emissions 1850-2002). These numbers underline in which ways groups of countries and individual countries are responsible for causing the climate change problem.

Figure 2.5: Cumulative CO_2 emissions

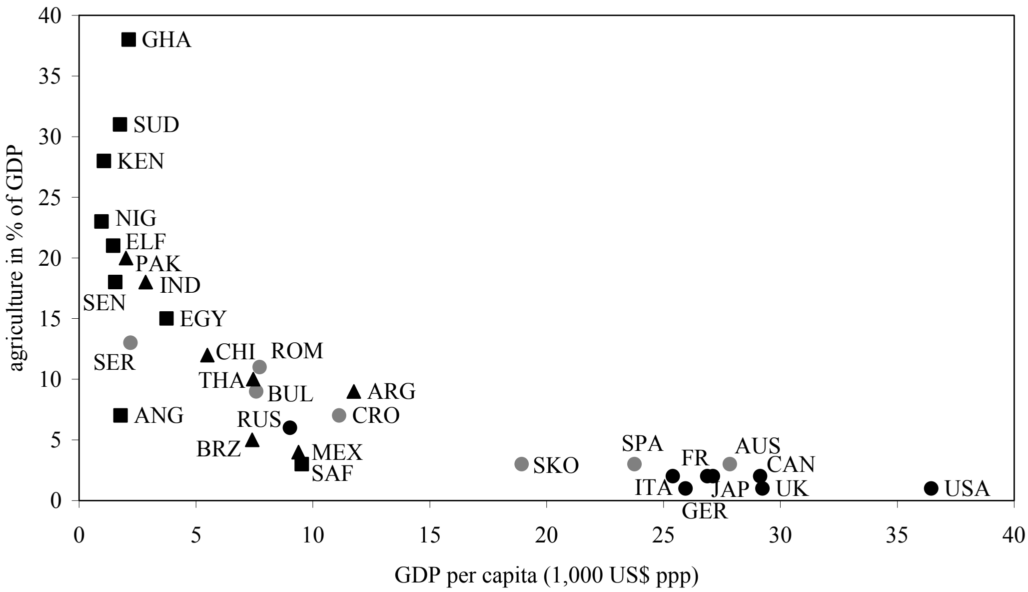


Source: World Resources Institute.

While developed countries bear the main responsibility for the strong increase in CO_2 emissions during the last century, climate change damages are expected to be higher for developing countries. According to Parry et al. (2005), who evaluated the implications of climate change for food production and risk of hunger, the region most at risk is Africa. In order to compare the vulnerabilities of different countries, a comprehensive vulnerability index would be helpful, which encompasses all the possible impacts on a country's economy, society, and nature. Creating such an index is not an easy task, for at least two reasons: a) there are multiple concepts of vulnerability in the different sciences and schools; and b) vulnerability often refers to a particular situation which is hardly comparable to other countries or societies (Füssel 2007b, O'Brien et al. 2004, Vincent 2004). An example of a fully described vulnerable situation would be "the vulnerability of the energy sector along the river Rhine to climate change up to 2050" (Füssel 2007b). Therefore it is difficult to construct a comprehensive vulnerability index that allows a comparison of climate change vulnerability between different countries on different continents. Figure 2.6 is an attempt to illustrate the different vulnerabilities of selected countries. The figure shows a scatter plot where the fraction of GDP that is generated by agriculture is plotted versus GDP per capita. In addition to African countries (depicted as black squares) and G8 countries (black dots), emerging countries in Asia and South America (black triangles) and other developed or European countries (grey dots) are displayed. Since for abovementioned reasons comprehensive indicators quantifying the climate change vulnerability of a country are lacking, we display the fraction of GDP originating from agriculture. Agriculture is the economic sector that is probably most climate dependent, and the fraction it contributes to the GDP may at least provide a first order approximation to what extent the GDP may directly be affected by the climate. GDP per capita on the other hand indicates the average ability to pay, for example in order to buy food at increased world market prices or to invest in climate-change adaptation measures to prevent climate damage. The figure shows that for most African countries the GDP per capita is much lower than in the developed countries while at the same time agriculture plays a major role in those nations' economic systems and accounts for as much as a third of some countries' welfare. While this welfare contribution is at risk in case of extreme weather events, the GDP per capita of these countries is often below $2,000. This is less than a tenth of developed countries such as Germany or Spain, and the difference is even greater with regard to Great Britain or the United States. Vincent (2004) proposes more indicators as determinants of a country's vulnerability: economic well-being and stability, demographic structure, institutional stability and strength of public infrastructure, global interconnectivity, and natural resource dependence (which is solely included in Figure 2.6). Although her analysis focuses on African countries, at least some of the indicators are also applicable in the EU. A proposal for a vulnerability index particularly for EU countries can be found in European Commission (2008c). The variables used here are the change in population affected by river floods, population in coastal areas below 5 m, potential drought hazard, and the regional shares of agriculture, fisheries and tourism in gross value added. However, for illustrating the global equity aspects of climate change, Figure 2.6 gives a reasonable approximation for a global comparison of vulnerabilities.

In short, the bulk of carbon emissions in the past that have caused the man-made part of global warming are due to the activity of industrialised countries, which have fuelled their economic development by burning fossil fuels. Since the heaviest burden due to climate change will be borne by the least developed countries, it is evident that climate change also poses severe distributional problems. Consequently, to break deadlocks in future international climate policy, equity and justice will inevitably play an important role in addition to the efficiency considerations outlined above.

Figure 2.6: Vulnerability and ability to pay



Source: World Resources Institute, The World Bank (2008).

For Europe, in particular, the situation in North Africa and the Middle East is relevant (Heller 2008b). The effects of climate change in terms of heightened summer temperatures and extreme water shortages, coupled with continued high population growth rates in these countries, may result in pressures for migration to Europe that could be an important source of tension.

2.4. Security of supply

Security of supply is one of the stated goals of energy policy in the EU (e.g. COM 2009). While mostly discussed in relation to energy, arguments of security of supply are also – directly or indirectly – used in debates on food and water supply. All these sectors face considerable challenges by climate change, and thus security of supply matters for the debate of adaptation, too.

From a theoretical economic perspective, the issue is odd at first sight: energy carriers, food and water are private goods in the economic sense of the word, and efficiency of markets in their provision should be guaranteed by the basic welfare theorems of economics. In the case of energy and water, transport provides an economic argument for government intervention: electricity grids, gas pipelines and water sewage systems are typical examples of natural monopolies. Their provision of the transport service is characterised by increasing returns to scale, i.e. the larger the network, the lower per-unit costs of transport (this is also called a 'network externality'). Therefore competition between several providers of transport service is inefficient because a single network can provide the service at lower cost. This gives an economic rationale for network regulation, since a monopolistic provider is likely to overcharge his service.

However, the argument for government intervention on grounds of security of supply goes beyond regulation of networks. Rather it is based on the presumption that the good in question is indispensable for economic production and individual welfare: indeed a prolonged shortage of drinking water in a certain region would have devastating effects on public health.[11] Similarly, albeit to a lesser extent, public welfare and economic production are vulnerable to blackouts of the electricity system.

The policy issue arises because companies providing water or energy in a free market are not likely to insure their consumers sufficiently against interruptions of the supply: given the short-term inelastic demand for the goods, markets are likely to clear at very high prices in the case of a shortage – an efficient outcome, but unacceptable from the viewpoint of public welfare, at least for some basic human needs. Private supply of drinking water is likely to be profitable during a drought period, but – given the elementary needs of the population – the government's objective would be to ensure that there are sufficient provisions for such a situation.[12]

The same reasoning applies to the energy sector, where security of supply is viewed as an important pillar of energy policy (Helm 2002, Abbott 2001). This does not imply, though, that the provision of the good has to be organised by public authorities: in the case of liberalised electricity markets, in many countries the grid is operated by a private monopolist that is regulated by a public agency. In particular, the grid company is obliged by law to ensure the security of the network, i.e. the security of electricity supply. The costs are incorporated into

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[11] Northern China is an example – contamination of surface water and desertification endangers the drinking water supply and consequently the health of the population, in particular, rural areas (World Bank 2007). This is widely perceived as a public policy issue, both in China and outside.

[12] While water is certainly not a public good – its consumption is rival – economists refer to it as a common-pool resource, justifying regulation on grounds of negative external effects (McGuiness 1999, Hardin 1968). Given the basic need for drinking water, the regulation of water supply may in practice be governed by both efficiency and equity concerns.

the usage fees. In other words: Specific regulation can be used to enforce security of supply in otherwise free markets, carefully trading off security against efficiency.

Apart from problems to be discussed in a national context, security of supply can be a geopolitical issue: the supply of gas from gas-exporting countries with a monopolistic position may lead to political pressure on the importing countries. Similarly, in some world regions access to drinking water is seen as a right enforceable by political and – if necessary – military means. However, this problem is beyond an economic welfare analysis, because any market rule or property right in this context is vulnerable to political manipulation. Economists may contribute to a positive analysis of these aspects of adaptation to climate change by the study of international negotiations. These may for example arise in the context of access to scarce water resources or agricultural land with disputed property rights.

As in the case of equity issues, adaptation to climate change sheds a new light on old questions of security of supply: Which goods and services are elementary, so that government intervention should guarantee their security of supply? What are the costs of such a policy? What is an acceptable level of security of supply, for instance in the case of drinking water? Public policy on adaptation will have to find answers to these questions.

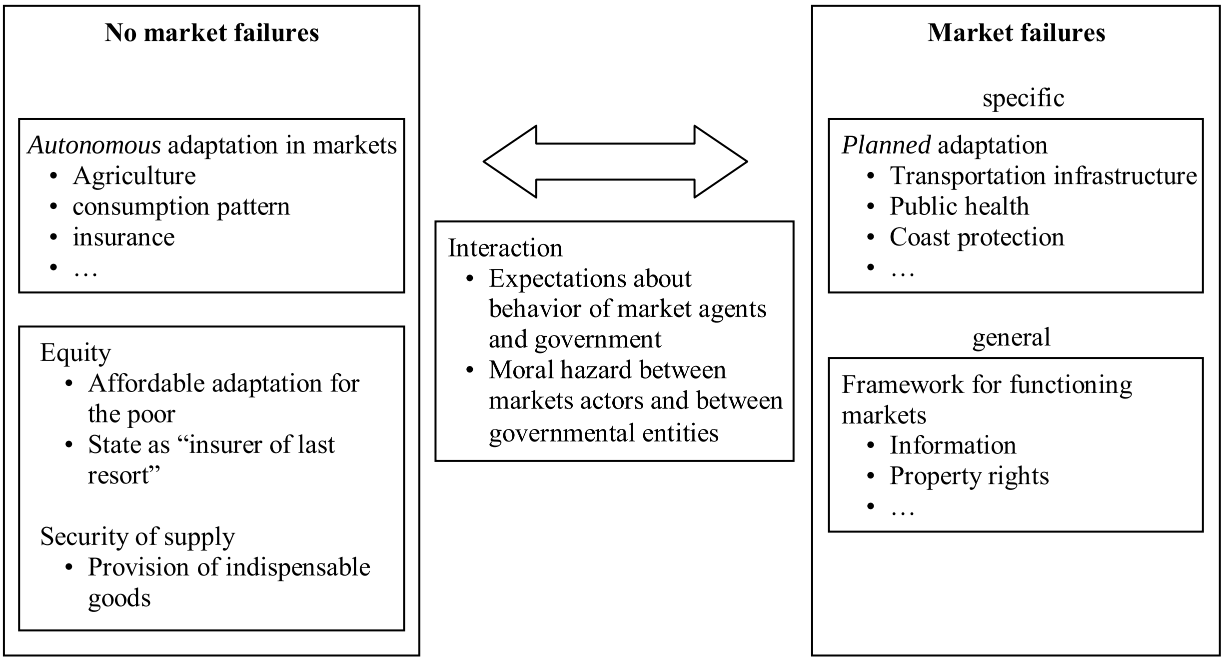
2.5. Role of markets and collective action

The central question in the previous sections was about the role of markets and collective action, i.e. governmental intervention, in order to ensure an efficient adaptation to global climate change (see also OECD 2008). Figure 2.7 summarises the results of our discussion. The economic concept of market failures is the central tool in order to structure adaptation measures. If no market failure can be detected, autonomous adaptation is the appropriate choice. Typical examples are change of crops and cultivation methods in agriculture, changing consumption pattern and the emergence of new insurance products. Equity considerations and security of supply do not constitute a market failure. However, collective action in order to redistribute income and to ensure the provision of indispensable goods is generally seen as task for the state.

In case of market failure, two different types can be distinguished. First, 'specific' market failures directly related to adaptation, which has to be planned centrally. Adaptation in transportation infrastructure, public health system and coastal protection are examples for this. Second, 'general' market failures concern the framework for functioning markets such as information or property rights.

The interaction between autonomous adaptation and planned adaptation is an important and often neglected aspect. More planned adaptation (or expectations of such projects) may lead to less autonomous adaptation and vice versa. The interaction between planned and autonomous adaptation can be influenced by moral hazard issues between market actors but also between governmental entities.

Figure 2.7: Adaptation and market failures



2.6. Timing of adaptation

Climate change is a long-term issue. Therefore, one key question is *when* adaptation measures should be undertaken. As the opportunity costs as well as direct investment costs and benefits may differ over time, this is an important issue. Below we analyse theoretically which facts determine the optimal timing of adaptation (Fankhauser 2006). Conceptually, the analysis applies as much to the considerations relevant to autonomous adaptation as to planned adaptation.

Considering the optimal timing of adaptation, the net present value of the costs of adaptation now (NPV^N) have to be compared with the net present value costs of adaptation at a later period (NPV^L).[13] Let us assume that adaptation now ($t = 0$) costs A^N. Annual maintenance costs amount to M^N over time. Thereby we assume that there are no maintenance costs in the first period, i.e. $M_0^N = 0$. Adaptation will reduce annual climate damages to D^N over the lifetime of the project. If the damage is discounted by the rate δ, the net present value costs of *adapting now* can be written as

$$NPV^N = A^N + D_0^N + \sum (D_t^N + M_t^N)\delta^t \qquad (17)$$

If adaptation is undertaken a period later (e.g. say a decade later), the costs of adaptation are discounted, but climate impacts in the initial period will not be avoided. That is, they reach a

[13] Here one also needs to recognise that i) there may be choices among projects, with some involving longer longevity than others. For the shorter-lived ones, the decision-maker may be faced with the issue of whether the costs of a new project that would carry you to the same time frame as the longer lived project, may prove greater; and ii) that many projects have only a limited time scale so that the decision-maker will be forced to initiate new projects in the future and that (like the subsequent discussion on later adaptation), may lead to a very different situation in terms of the cost and damages averted.

level of $D_0^U > D_0^N$, where D_0^U are the climate damages now when adaptation is undertaken later (U – *unadapted*). It is also possible that adaptation costs (A^L), maintenance costs (M^L), and subsequent damage costs (D^L) will change. This may be the case because of innovations in adaptation techniques (see Box 2.3). The net present value costs of *adapting later* can be written as

$$NPV^L = A^L\delta + D_0^U + \sum (D_t^L + M_t^L)\delta^t \qquad (18)$$

The difference between the two value streams, (17) and (18), represents the net benefit of early adaptation, which is as follows

$$\underbrace{\left(NPV^N - NPV^L\right)}_{\substack{\text{Net benefit of}\\ \text{early adaptation}\\ \text{if} < 0}} = \underbrace{\left(A^N - A^L\delta\right)}_{\substack{\text{Difference in}\\ \text{adaptation}\\ \text{costs over}\\ \text{time}}} + \underbrace{\left(D_0^N - D_0^U\right)}_{\substack{\text{Short-term}\\ \text{benefits of}\\ \text{adaptation}}} + \sum\Big(\underbrace{D_t^N - D_t^L}_{\substack{\text{long-term}\\ \text{effects of early}\\ \text{adaptation}}} + \underbrace{M_t^N - M_t^L}_{\substack{\text{Difference in}\\ \text{maintenance}\\ \text{costs}}}\Big)\delta^t \qquad (19)$$

The expression (19) shows that the optimal timing of adaptation depends on four cost components. *First*, adaptation costs may change over time,

$$A^N - A^L\delta \,.$$

Discounting would generally favour a delay in adaptation measures (because $\delta < 1$). Similarly, the prospects of potentially cheaper and more effective adaptation techniques to be developed in the future would support a delay of adaptation (i.e. $A^L < A^N$).

Box 2.3: Technical innovations reducing adaptation costs

A recent example for the fact that R&D may lead to lower adaptation costs is the development of a new synthetic material that can be used to strengthen dykes. The material (called Elastocoast® developed by BASF) is able to bind crushed stone (which is the basis for dykes to protect coast and river banks) in order to enhance the strength of dykes. This procedure is already in practice, for instance at the river Elbe near Hamburg and at the coast of the island Sylt in Germany.

Source: http://www.basf.com/group/corporate/de/content/news-and-media-relations/science-aroundus/imperiled-dykes/index.

However, there are also adaptation measures where *early action* is cheaper. This class of adaptation measures includes long-lived infrastructure investments such as water and sanitation systems, bridges and ports. In each of these cases, it will be cheaper to make adjustments early, namely in the planning phase of the project, rather than incur the costs and inconvenience of expensive retrofits (i.e. $A^L > A^N$). In these cases it is therefore necessary to anticipate future changes in the climatic conditions, because given the long-life cycle of investment the flexibility to adapt is very low.

The *second* component in expression (19) concerns the short-term benefits of adaptation

$$D_0^N - D_0^U .$$

Early adaptation will be justified if it has immediate benefit effects (i.e. $D_0^N < D_0^U$), for example by mitigating the effects of extreme weather events, i.e. adaptation to climate variability. This cost component also includes adaptations that have strong ancillary benefits, such as health investments or poverty alleviation.

The *third* component includes the long-term effects of early adaptation

$$\sum \left(D_t^N - D_t^L\right)\delta^t .$$

Early adaptation is justified if it avoids long-lasting or even irreversible damages, for example to ecosystems.

Worth mentioning is that the analyst's expectations of D_t – damages in some future time period t – are a function of *when* the cost-benefit analysis is done and the specific expectations of how climate change will eventuate in the future (reflecting what we assume about which climate scenario, like the SRES scenarios by the IPCC, is likely to prevail and how future mitigation will modify that scenario). If we delay adaptation to the future, our views on how climate change will eventuate may be very different at that point in time.[14]

The *fourth* costs component considers the maintenance costs

$$\sum \left(M_t^N - M_t^L\right)\delta^t .$$

Many adaptation measures not only consist of expenditures now but also entail maintenance costs spread over time. If these costs are likely to decrease over time due to technological change ($M_t^L < M_t^N$), then a delay of that adaptation measure may become preferable.

To sum up, early adaptation is useful if i) adaptation costs will not decrease over time, ii) there are strong short term benefits of the adaptation project, iii) the project will avoid long-term and irreversible damages, and iv) maintenance costs will not decrease over time.

2.7. Adaptation strategies under uncertainty and irreversibility

So far we have neglected the aspect of uncertainty in climate change. Clearly, uncertainty matters for climate change: there is scientific uncertainty concerning the expected regional effects, assessment uncertainty concerning the economic impacts, and policy uncertainty (Heal and Kriström 2002). In this section we describe the framework to analyse optimal strategies of adaptation under uncertainty.[15] The next section will discuss another aspect of

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[14] Also, the analysis could be extended to contain a possible relationship between the level of *A* and the level of *D*. Presumably, the higher *A*, the lower will be *D*, though, the sensitivity of the *D*(*A*) function in future periods will depend on what is assumed about how the climate is changing in future periods.

[15] We refer to Arrovian uncertainty only – i.e. uncertain events where the probability distribution is known. There has been little to no study so far how to assess Knightian uncertainty in the context of climate change, i.e. uncertainty over events with unknown probability distribution.

uncertainty, namely adaptation of insurance markets to changing climate conditions and a higher likelihood of extreme weather events.

Uncertainty and the option to wait for better information may have an effect on the optimal adaptation behaviour, in particular if decisions are irreversible. This is the topic of real option theory (Dixit and Pindyk 1994), which studies optimal behaviour under irreversibility, uncertainty and learning. Uncertainty about the exact nature of climate change impacts at the local and regional level makes it difficult to fine-tune adaptation measures. However, private actors and the government are likely to learn more about local impacts as time proceeds (see Box 2.4). Adaptation benefits (avoided climate damages) occur in the future – so they should be interpreted as expected benefits. In contrast costs for long-term adaptation projects, such as investment in climate-proof infrastructure (e.g. for transportation or energy networks) are certain and typically irreversible (i.e. after the investment costs are sunk). At the same time, the timing of the investment is for the investor to choose and can be delayed if appropriate – for instance, instead of building a dyke now the policy-maker can wait for better information regarding the likelihood of flooding in his agglomeration. Real option theory studies the effect of flexibility on optimal action.

In the case of adaptation measures – both by private or public actors – given uncertainty with respect to the expected regional effects of climate change, the benefits of the investment in an adaptation project have to exceed the costs by a positive amount (so-called 'hurdle rate'), in order to justify the investment. This amount is the 'option value' not to invest but to wait and to delay the project. In other words, the classic rule according to which the present value has to cover at least the costs of investments does not hold under these circumstances. The optimal solution to this problem includes the comparison of investment costs and presents values at all possible time slots, i.e. it has to be taken into account that the investment is possible at different time slots. Using the option to wait, an investor can possibly gain new information about future benefits (but also about better adaptation techniques that may reduce costs) and can adapt his behaviour to changed conditions. Real option effects can work in the opposite direction, too: cheap options for adaptation or mitigation may disappear or become more costly as climate change intensifies over time. An appropriate analysis of an adaptation strategy has to incorporate this aspect as well.[16]

Box 2.4: Regional climate projection models for Germany

Germany has made considerable progress in enhancing regional climate projections for its territory. Currently Germany's Federal Environmental Agency uses two main approaches of regional climate models: WETTREG (UBA 2007) and REMO (MPI 2008). 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). The climate scenarios are calculated with a resolution of 10 km x 10 km, which is significantly higher than the available scenarios of the IPCC (used in EEA, 2008).

[16] See Fankhauser (2006) for a discussion of incentives for early investments in adaptation projects when climate change damages in the near future can be avoided.

To sum up, as far as our knowledge about climate change impacts at the regional level will become better in the future, there may be a good reason *to wait* for better information, in particular when adaptation costs will be sunk after the investment. In other words, there is an 'option value' to wait for better information or better adaptation techniques and *to delay* costly adaptation measures. This incentive is opposed to the incentives for early adaptation measures in the case of long-lived infrastructure mentioned above (see section 2.6).

2.8. Adaptation of insurance markets

This section analyses the theoretical framework of insurance markets and their relevance for adaptation. Climate change tends to increase the frequency and severity of extreme weather events (IPCC 2007a). That is, the probability of extreme weather events is not only uncertain but also changes with global warming (Müller-Fürstenberger and Schumacher 2008). Worldwide damages from extreme weather events have clearly increased in the last decades. Schmidt et al. (2009) calculate that even if controlling for effects such as population changes, inflation, increased wealth or changes in settlement behaviour, there is a significant positive correlation between natural disasters and global temperature.

The insurance sector can play an important role in addressing the uncertainty with respect to local effects of climate change (OECD 2008). Principally, insurance markets are able to provide protection against climate-induced losses. The transfer of risk from risk-averse subjects to risk-neutral insurance companies leads to welfare improvements and, if well designed, an efficient level of precaution. Given an appropriate institutional framework – in particular a property rights system and functioning credit markets – insurance markets will find an efficient reaction to climate change. The effectiveness of insurance markets for climate adaptation may be hampered, though, by informational problems (*adverse selection* and *moral hazard problems*), covariate risks, uncertainty, and a lack of demand. In the following we briefly discuss all these issues and the implications thereof.

Let us briefly recall the basic paradigms of insurance markets, as studied by the theory of expected utility (Schoemaker 1982, Gollier 2000). The theory of insurance generally assumes many risk-averse customers facing independent risks who pay premiums to a risk-neutral insurer in exchange for protection against possible future losses. Using the law of large numbers and knowledge about the distribution of risk an insurance company in principle takes a risk-neutral position – the total expected value of damages is equal to the total value of expected revenues. When customers have no real influence over risks, insurance policies are relatively simple and parties frequently purchase complete coverage, which is the socially optimal outcome. More often, however, customers can influence risks – think of settlement behaviour that can influence the risk of flood damages or the construction of a building that can influence the risk of storm damages. This type of problem in insurance markets, which arises from the impossibility to completely control the behaviour of the insured, is labelled *moral hazard problem* (Arrow 1963). Most often, the socially optimal outcome – perfect insurance and sufficient precaution – cannot be achieved under these circumstances, but only a second best insurance contract with varying premia and partial coverage, trading off the insurance motive and the reduction of moral hazard. The degree of moral hazard will depend on the ability of the insurance company to gather information. In principle it is free to control the construction or the site of a building and incorporate the information in the insurance contract. Yet at least in some cases the individual risk evaluation may prove to be too costly and the company will offer standard contracts with partial coverage only. The incident of moral hazard can also arise from public intervention: many natural hazards have shown that politicians as well as the private sector provide financial aid for victims (see Box 2.5). The effort to help the victims of natural disasters is an act of emergency and humanity. As in the case of private insurance anticipation of loss compensation by the government may lead to insufficient precaution and – as mentioned above – to the crowding-out of private insurance. Therefore, ex-post emergency relief should be limited to most elementary protection (see Box 2.5 for an example).[17]

Box 2.5: Moral hazard and insurance in Germany

Moral hazard may lead to an insufficient demand for insurance coverage. One possible solution may be the recent approach of the Bavarian state government for natural hazard insurances for private homes (Bayerische Staatsregierung 2009). The government of this federal state in southern Germany currently runs an information campaign in order to sensitise private households to the risks of natural hazard damages on homes and contents. Effectively, this campaign is a publicly financed marketing campaign for private insurance. In this context the government emphasises that state relief is only possible in exceptional cases where private insurance is not applicable (less than 2% of Bavarian private households). Although this specific approach of the Bavarian state government targets only the market of insurance for private homes, a comparable strategy may also hold for government intervention in other sectors.

The second type of informational problem is commonly known as *adverse selection* (Rothschild and Stiglitz 1976): as an insurance company cannot distinguish between high-risk and low-risk customers – the risk may be partly private information – it has to offer one insurance contract to all, pooling all risks. The implicit redistribution of such a scheme from low to high-risk type may lead to the breakdown of the insurance market when low-risk types find the premium too high and withdraw. Generally, we can say that distortions of insurance markets occur if insurance takers or insurance companies have incomplete information or if they misperceive risks, i.e. information is distributed asymmetrically. Sometimes insurance is not offered because risks are hard for insurance companies to estimate. In particular this is the case if the probability of a catastrophic event is very low so that the law of large numbers can no longer be applied.

Another problem arises if the risks faced by different insurance takers are *non-independent,* which is likely to be the case with climate change damages. For example, the risks of flood damages are positively correlated within one area. Insurance companies then cannot be confident of meeting their costs and they will therefore tend to charge higher premiums, presuming some degree of risk aversion on their part. In this case, the insurance takers' expected utility will be maximised if they obtain less than full coverage of damages (Shavell 1987). This effect could be alleviated if (international) re-insurers pooled the risks facing different (national) insurers.

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[17] As has been discussed by Wildasin (2008) and Goodspeed et al. (2007) in the context of recent US hurricane events, the amount of autonomous adaptation to some climate change-related events may be lower if there is a perception that ex post, the government will reimburse economic agents for much of the damages arising from such events. Even with the recognition that there may no full compensation, the ex-ante precaution might not reach the efficient level.

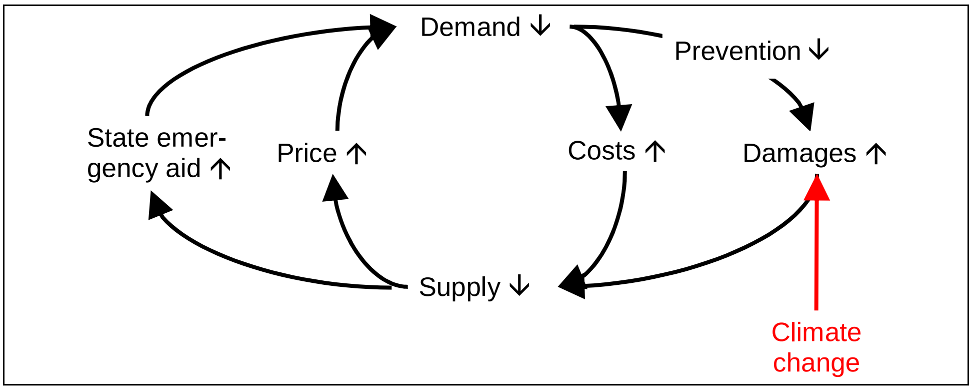
The next issue concerns *uncertainty*. Extreme weather events are uncertain, i.e. they occur with a certain probability, but it may be that also this probability is unknown. If the insurance overestimates the risk then it will charge too high premiums and request too much precaution. In contrast if the insurance underestimates the risk then it will demand premiums and precaution that are below the efficient level. This problem should lessen over time as the parties gather more information about the true risk.

Finally, one often observes that the free market produces a rather low insurance density (Schwarze and Wagner 2002). The example of Germany (Box 2.6) indicates that the low level of natural hazard insurance coverage is mainly due to a *lack of demand*. There are several possible reasons why the demand for insurance coverage may be too low: i) lack of information about risks, ii) potential victims underestimate risks, iii) anticipation of ex-post emergency relief, and iv) interaction effects between distorted demand and insufficient supply. The last aspect is graphically presented in Figure 2.8. It shows the interconnection between demand and supply. The two factors mutually escalate each other's effects. A lower demand for insurance coverage leads to higher costs due to less risk pooling. As a consequence the supply decreases and the price increases which further decreases the demand.

Box 2.6: Natural hazards and insurance in Germany

In Germany, storms cause most of the natural disaster damages (64%) followed by floods (19%), hail (15%), and earthquakes (1%) (Schwarze and Wagner 2002). Only a few natural disaster damages are covered by insurance. With the exception of windstorm and hail, the insurance density is less than 10% in the exposed areas. Therefore damages caused by natural forces are often compensated by public emergency relief and private donations. For example, Schwarze and Wagner (2003) estimate that the emergency relief and reconstruction programmes for the flood damages of summer 2002 in Germany (approx. €9.8 billion) have exceeded the actual damages (approx. €9.1 billion). This results not only in an unnecessarily large withdrawal of private purchasing power and government investment but also systematically reduce the incentive for potential victims to take precautions and to buy insurance coverage.

Figure 2.8: 'Disaster syndrome' in natural hazard insurance markets



Source: Schwarze and Wagner (2006).

State intervention does not necessarily resolve all these problems but all issues have to be taken into account in order to provide an efficient regulation of the insurance market. As people are likely to underestimate and highly discount the full extent of the risk of rare events (Kunreuther 1996, Schwarze and Wagner 2006) the acquisition and distribution of information about risks could be spotted as a task of governmental action, leading to an increase in the demand for insurance coverage. As the example of the federal state Bavaria in Germany (Box 2.5) shows, the government can take the role of an information provider. Running such campaigns will imply some expenditures for the government and therefore have some fiscal effects, but they are not expected to be high. Given that natural disasters are mainly local phenomena, because of the geographical situation, the provision of information should especially be the task for local and regional authorities.

The distribution of information about risks could increase the demand for insurance coverage but the anticipation of ex-post emergency relief could still prevent potential victims to buy full coverage. Therefore, ex-post state aid should be limited to a minimum (see Box 2.5).

The anticipated ad-hoc emergency relief involves private and public donors. Private charitable giving could decrease the expenditure of the government but at the same time it influences the insurance market. Schwarze and Wagner (2003) claim that an overcompensation of losses as well as an overestimation of the actual costs of damages are often the result of such interventions. The governmental relief is two-fold: first is direct financial help for the victims of a disaster and second is the provision of emergency help, which includes technical and administrative assistance. The European Commission reregulated the rules for state aid (EC No. 1857/2006) to agricultural producers in the event of natural damages. The restriction for ad-hoc aid came into effect on 1 January 2010. The limitation to the offered compensation is reduced by 50% (EC No. 1857/2006).

Funds

The governmental aid could be financed by funds. Within the European Union the European Solidarity Fund (EUSF), which was founded in 2002, provides emergency relief and reconstruction aid. There are two main disadvantages of disaster funds compared with an insurance-based system: first the existence of a fund could lead to the wrong market signals. The potential victims have nearly no incentive to take any prevention measures, if they can count on governmental help by funds (Schwarze and Wagner 2003). In the case of EUSF there are two main restrictions to overcome this problem. The payments are in principle restricted to non-insurable damages (EC No. 2012/2002 Article 3(3)), which are not further defined. Furthermore, the annual budget of the EUSF is only €1 billion for all possible natural disasters of the member states or countries in EU accession negotiations (EC No. 2012/2002 Article 1), which guarantees that in case not the whole damage costs are taken by the fund. These limitations ensure to some extent the motivation to reduce the risks in advance. Another drawback of funds is that previously negotiations are necessary. Within this process the countries will try to impose their own interests. This could not only lead to extensive negotiations but also to costly lobbyism (Schwarze and Wagner 2003). For that reasons not only the payments into the fund have to be taken by the countries but also further costs for the negotiation process before implementing the fund. Additionally, decision-making in case of a disaster will also cause expenditures. In case of EUSF the affected country has to apply for a funding (EC No. 2012/2002 Article 4(1)), which has to fulfil criteria defined by the EC Council Regulation. After that the EC is responsible to decide whether a country gets help and to which amount (EC No. 2012/2002 Article 4(2)). Since the establishment of the EUSF in 2002, Germany has received €610.9 million against a damage amount of €13,850 million. The damages were caused by flooding in 2002 and a storm in 2006 (EUSF, 2009 (annual report 2008)).

Types of insurance

Because of the disadvantages of funds compared with insurance-based solutions, different possible designs of insurance for natural disaster damages are presented. The focus is on Germany, but in principal can be transferred to other countries as well.

German insurance market concerning natural hazard

Within the purely private insurance system of Germany it is possible to insure against storm and hail. For an overall coverage against the main natural hazards, a supplementary, natural hazard insurance (*Elementarschadensversicherung*, ESV) is available. The risk differentiation is based on a system called ZÜRS, which was developed by the German Insurance Association (GDV) to classify the risk. Four different risk groups – low to high risk – provide the indication for insurance restrictions. The insurance density against storm and hail is with 95% on a very high level (Schwarze and Wagner 2009). According to the Annual report of the German Insurance Association over 20% of the buildings are insured by an ESV (GDV 2009).

Mandatory natural hazard insurance

On that account, mandatory natural hazard insurance has been suggested (Schwarze and Wagner 2003). As opposed to emergency relief, a mandatory insurance scheme would allow the insurance companies to calculate the amount of compensation based on a large pool of customers and distributions of risks, because it would guarantee comprehensive demand for and supply of insurance coverage, thus reducing the premiums and provide certainty to the insured on what the compensation level is. Moreover, appropriately designed policies would provide incentives to exercise the optimal level of precaution. At the same time, the scheme could be open to new domestic and foreign insurance companies and permit competition within the industry.[18] Furthermore, it should be monitored whether (international) re-insurers offer coverage for the insurance companies so that they can handle covariate risks. However, also in designing the insurance mandate, the government has to trade off likely insurance benefits and possible moral hazard costs that arise whenever private precautions against damages are influenced by the presence of insurance.

In Germany the proposal for a mandatory insurance for natural disasters was rejected. According to Schwarze and Wagner (2009) four main reasons were decisive: the failure to recognise the role of state guarantees in enabling private insurance, the mistaken legal objections against mandatory insurance, the distributional conflicts between central and state governments and the re-election considerations of politicians. A European-wide solution is not to be expected, because the insurance system differs not only from country to country but also within regions, as the example of the federal state Bavaria in Germany (Box 2.5) shows.

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[18] For detailed discussion of mandatory natural hazard insurance, see Schwarze and Wagner (2003).

Index-based insurance

Climate change tends to cause more frequent and severe extreme weather events (IPCC 2007a). Therefore the losses of the past cannot serve as criteria for the risks of future damages.

Especially in the agricultural sector developing an index-based insurance is on the agenda. Traditionally insurance payments are based on the average of former output yields, which serve as a basis for anticipating future crop outputs. This system is also called 'loss-adjusted insurance', because the assumption is based on the loss of expected outputs, whereas an index-based mechanism provides verifiable data. The indices are mainly measurable weather variables like temperature and rainfall. These weather variables are used to make estimates for yield. To get reliable predictions a complex index is needed. Such systems require expenditures to get the necessary measured values. Furthermore, the data is only for small local areas and is not applicable to different regions or cultures. The advantages of such index-based solutions could be seen in the independent assessment of variables, which cannot be influenced by the farmer. Therefore moral hazard and adverse selection problems could be reduced. Furthermore, the ascertainment of damages is straightforward, because the data only have to be compared with *a priori* defined threshold value. Moreover, costly field visits can be eliminated and therefore expenditures are reduced. Along with these possible advantages the measurable factors can make it easier to reinsure the risks.

The implementation of an index-based insurance system might be possible for property/building insurances. In Germany ESV is already based on geo-information provided by the ZÜRS system, where areas of different risks are determined. The input of further data could provide more precise risk projections and in case of damage an index-based mechanism can lead to faster decision-making.

Agricultural insurance solutions

Within the agricultural sector of the EU ad-hoc payments by the governments are common. This practice leads to different problems such as lack of transparency, no guarantee of payment, dependence of availability of a governmental budget, high administrative expenses and the damage being only partly covered (Munich RE 2007). To overcome the disadvantages of anticipated governmental relief, insurance-based mechanisms could be used. One possible solution might be the limitation of governmental reliefs only to damages that are not insurable (see Box 2.5). Such a strict course of action might be difficult to get through especially in the agricultural sector. There are other aspects like food security and saving the artificial landscape that are reasons to provide ad-hoc reliefs.

Another incentive for farmers to insure is the partnership of the government in form of proportional payments of the insurance premium. This option was also offered by the European Commission to launch a broad discussion on the common agricultural policy (CAP) to deal with the risks in agriculture (EC 2005, SEC(2005) 320). There the governmental financial participation should not exceed 50% of the total premium. Poland, the Czech Republic, Slovakia and Austria offer such subventions for premiums of crop insurance (Munich RE 2007 and 2009), whereas in Germany crop insurances are available but none with a public–private partnership design.

Box 2.7: SystemAgro by MunichRE

The Munich RE suggests an agricultural insurance concept on a national level, which includes public–private partnerships. It is called SystemAgro and is based on four basic factors called BLOC, standing for backing, loss sharing, open and central and uniform. The backing is the subsidy of the premiums by the government, which should give an incentive for the farmers to insure. Furthermore, the government should take a share of insured damages within years of extreme losses. In contrast to the current governmental relief aid, this loss-sharing mechanism includes a legal claim for the farmers to financial support, which is a further motivation to insure. The openness to every farmer should secure a high market penetration. The central and uniform structure should guarantee the sustainability and observing the legal rules and the public expenditures. This suggestion includes incentives to insure but on the other hand the government is involved on three levels: first to introduce a law and rules for provision, second the regular payments of the premium share and third still to help out in case of extreme damages. If the subventions are as high as the current ad-hoc payments, like the Munich RE demands (Munich RE, 2007), the public expenditures could even be higher as in the existing mechanism at least on the short run. Therefore the current suggestion is to cut other agricultural subventions and use them instead for financing the shares of the insurance premiums. This might lead to rejections by the agricultural lobby.

Source: Munich RE (2009).

Especially the use of public–private partnerships should be carefully reconsidered. Concerning insurance in the agricultural sector, the practical experience in the US and the literature about these schemes can provide valuable insights.

The Federal Crop Insurance Act of 1980 was introduced to replace disaster programs by subsidised crop insurance. It was amended by the Agricultural Risk Protection Act 2000, which main aim is the increase of insurance coverage.

Although the coverage of acreage has been increased (Babcock and Hart 2005), the government still provides supplemental disaster aid (Glauber and Collins 2002, Glauber 2004). Moral hazard and adverse selection problems are affecting the US scheme. The former may appear in changed planting decision or changing the application of inputs like fertilizers or chemicals due to increases in subsidies (Glauber and Collins 2002, Goodwin 2001). Just et al. (1999) go much further by claiming that the participation in crop insurance is mainly caused by the possibility to exploit the system of subsidies fraudulently and results in adverse selection. They provide empirical evidence to this statement by examining farm-level data for the US. The adverse selection problem is according to Goodwin (2001) due to the design as multiple peril insurance with an average risk measurement, which leads to over- or undercharging of individual risk. Furthermore, Glauber and Collins (2002) mention that farmers fear a lowering of crop prices as a result of crop insurance subsidies that are too high.

The problems within the US design of crop insurance show that the premium subsidies have severe shortcomings. Consequently, Glauber (2004) claims that “crop insurance subsidies are less efficient than lump sum transfers”. Nevertheless, an insurance concept including public–private partnerships may lead to higher insurance coverage, but implementing such a model would require a careful design and should take into account possible shortcomings. This means for example that governmental ad hoc help should be withdrawn. This strict course might in reality not work due to other reasons of governmental intervention like security of supply. Furthermore, there may be strong political incentives for governmental ad hoc aid (in particular before elections).

All-risks coverage

All-risks coverage should include all possible natural hazards. Especially in the agricultural sector such insurance solutions are discussed. The damages could range from storms and hail, which are the content of the most insurance packages, to drought, frost, continuous rain or high tides. Today in Germany there is no possibility to cover all risks with insurance. The insurance companies select risks and cultures. Hail insurance is common for the most cultures but for other natural disasters the culture is decisive and for special cultures only hail insurance is available. Similar circumstances of selection can be found in other European countries. Insurances covering more than a single risk are offered for example in Austria, Czech Republic and Slovakia and include a public–private partnership, but the insurance is only available for a choice of cultures.

The German Insurance Association made a proposal for crop insurance with all-risk coverage to overcome the problems with risk and culture selection (GDV 2008). The suggestion is for common cultures and excludes special cultures. The main aspect is that the risks are divided into two categories. The first one includes the risks of hail, storm, continuous rain as well as early and late frost. The GDV integrates these kinds of risks due to their local effects and their causality to short-term occurrence of extreme weather events. They suggest using the integral franchise method by 8%, as is common for insurances against hail. This means that the first 8% of the insured yield losses have to be taken by the producer and the further damages will be covered by the insurance.

The second risk group covers floods, droughts and damage due to frost, ice and snow. The damages of these risks are extensive and normally not of local or regional nature. The extension and severity of the damage depends also on non-insurable factors like soil quality. The GDV intends to use threshold values, which should be determined for the different kind of risks.

All-risk insurance systems could be combined with the public–private partnership solution and the index-based mechanism, but each of the mentioned methods are at a level where more research is needed to figure out the effects and their interactions.

State as insurer of last resort

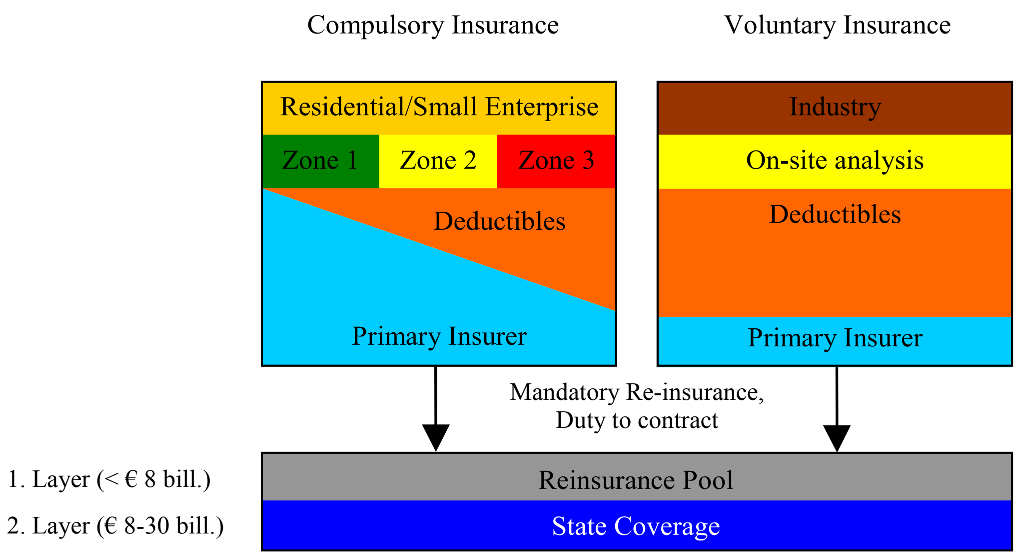
Finally, depending on the national circumstances there may be the responsibility of a government to act as insurer of last resort in case of extreme weather events. The fiscal effects will depend on the design of the implemented natural disaster insurance scheme and the role of the government in this scheme. Given the available information on damage estimates the necessary funds for the former may be considerable. The examples of natural disasters in Boxes 2.1 and 2.6 indicate how much damage costs could be expected after extreme weather events. These effects will presumably increase over time i) because temperature and therefore the frequency and severity of natural disasters increase and ii) because of increasing wealth, population changes, inflation, and changes in settlement behaviour. The design and organisation of the insurance scheme do also influence the fiscal consequences. If the insurance density is low the state has to be prepared to compensate victims for losses caused by natural forces. The financial aid may withdraw important public investments or increase the ‘fiscal gap’ that already exists in some countries owing to public debt and demographical change.

In contrast, if the insurance scheme is designed in a way that the density is high, many natural hazards can be compensated without governmental intervention. In this case public emergency relief would be necessary only if damage costs exceed the capacity of insurers and re-insures. That is state participation is strictly limited to cover the ‘mega-damages’. For example, Schwarze and Wagner (2006) propose a market-oriented mandatory insurance against natural disasters for Germany (see Box 2.8). They estimate the state coverage for the flood module to be between €8 and €30 billion. It is important to note that not only does this reduce the need of state intervention but also damage costs can be expected to be lower in case of high insurance density because appropriately designed insurance policies induce potential victims to take preventive measures.

Box 2.8: Mandatory insurance scheme against natural disasters in Germany

Schwarze and Wagner (2006) propose a market oriented mandatory insurance scheme against natural disasters for Germany. For the industry insurance is voluntary. For households and small enterprises insurance is compulsory. In highly exposed areas where floods occur frequently (Zone 3) only partial coverage is provided. With lower risk (Zone 2 and 1) deductibles decrease. Primary insurers must contract with re-insurers and the state steps in as insurer of the last resort. State intervention is strictly limited to ‘mega-damages’ above a threshold of €8 billion.

Scetch of the insurance scheme (Flood Module)



Source: Schwarze and Wagner (2006).

International pooling

The provision of risk coverage in very vulnerable areas is more feasible if risks are internationally pooled. Therefore a global market is necessary to diversify losses across the world. The three main practices to transfer single risks and pool them are reinsurance, catastrophe bonds and weather derivatives, which are discussed below.

Reinsurance

If risks are locally dependent, they might be globally independent and globally insurable (Cummins 2007). This is the case of reinsurance companies. A single insurance company can transfer its risks by reinsurance. The worldwide biggest reinsurance companies are Munich RE and Swiss RE. The reinsurance system is based on risk distribution by geographical and sectored diversification, including different business fields. Furthermore, reinsurance companies reinsure themselves, which is called 'retrocession' or transfer their risk to other instruments like catastrophe bonds and weather derivatives.

The two main types of reinsurance are proportional and non-proportional reinsurance. Proportional means that the losses are shared by a fixed ratio between insurer and reinsurer. The non-proportional reinsurance only takes losses, when they exceed a certain amount.

A study by Froot (2001) shows, that reinsurance by insurers against catastrophe large events is relatively small. This is verified by data of a large insurance company in the US. Furthermore, he found out that premiums are high comparing to the expected losses. According to Froot (2001) this is mostly caused by supply restrictions associated with capital market imperfections and the market power of reinsurers. Despite these critic aspects reinsurance is still an important instrument for natural catastrophes.

Catastrophe bonds

Catastrophe bonds, also called 'cat-bonds', are mainly used by reinsurers to transfer their risks to investors. Therefore special purpose companies offer bonds as over-the-counter deals to investors. Common are special bonds called 'principal at risk' with the whole nominal value at risk. The Munich RE suggests that bonds with different risks and probabilities of occurrence of damage might be useful to satisfy the potential investors (Munich RE 2007). Investors buy the bond and then two events are possible: the natural disaster happens or not. In the second case without any damages the investor will get interest rates and a premium paid by the reinsurer. If no damage happened after a fixed term then the investor gets his payments back. On the other side, when a natural disaster takes place the investor will not get the interest rates and the premium. Furthermore, the reinsurer will get payments for the damages. There are two main incentives for investors. On the one hand the high interest rates make investing in them attractive. On the other hand the catastrophic bonds should be designed in a way that there is no correlation with other bonds. Therefore they provide an option for risk differentiation.

Crucial for catastrophe bonds is the choice of a trigger, which is the basis of decision at which level of damage the payments will be made. The parametric trigger is similar to the index-based insurance method. The measurement of a natural parameter (e.g. wind speed) builds the basis for decision. If a certain threshold level is reached the bond is triggered. The indemnity trigger is based on the real losses of the sponsors due to an event of damage in comparison to the trigger indexed to industry loss, which is based on the claimed insured damages. Another method is to create a catastrophe model, where the parameters of a natural disaster are implemented into a reference portfolio. The simulation provides the extent of the losses. If they reach a specified level, the bond will be triggered. The indemnity and parametric triggers are prevalent for catastrophic bonds.

In 2006 catastrophic risk at a value of almost $5 billion were confirmed (Munich RE 2007). In the future the market of catastrophe bonds is expected to grow (Cummins and Weiss 2008).

Weather derivatives

In general derivatives are financial instruments that value is derived by other market values of goods or assets. Weather derivatives are comparable to other derivatives but are based on the index weather. The base values are temperature, wind speed, precipitation, humidity and other weather variables. There are two main differences of weather derivatives comparing to other derivatives. First, weather trends are independent of human factors. That means not that climate change is uninfluenced by human beings, but the weather is a physical phenomenon on the short run, which we cannot influence. Therefore weather is not correlated to the stock market. Second, weather has no price itself, because it is not tradable. Cao et al. (2003) classify three valuation methods for weather conditions, especially temperature: i) insurance or actuarial valuation, ii) historical burn analysis and iii) valuation based on dynamic models. The first one is based on statistical analysis of historical data, where the probability is connected to the insured event. In case of weather this method is useful for extreme and rare events, which can be a matter of subject for a contract. The reason is that normal weather conditions are recurring and predictable and therefore probabilistic assessment is not useful (Cao et al. 2003). The assumption of the second method is that the distribution of the past payoffs reflects the distribution of the future payoffs, so the past can be transferred in future payoffs on average (Cao et al., 2003). Especially with climate change weather variables like temperature will change and therefore using historical data is critical. Furthermore, Cao et al. (2003) claim that the insurance valuation and historical burn analysis are only useful for single dealers but not to create a unique market price. Contrary to use historical data, dynamic models simulate directly the future behaviour of temperature. Therefore a stochastic process for the temperature is needed, which can be constructed as continuous or discrete process. The proposal of a temperature process relies on studies about observed temperature behaviour with which the temperature derivatives are valued by simulation (Cao et al. 2003).

Contracts that arrange the conditions for buying, selling or compensatory payments are the basis for derivatives. The main types are options and swaps. Options are differentiated in call and put options. The call option gives the owner the right to buy an asset whereas a put option includes a right of selling. To become an owner of an option one has to arrange a contract with another player and pay a certain price for the option. Furthermore, the players specify the duration of the option and the strike price, which is a certain price at which the sale takes place. Another crucial subject in the contract is the tick size. This is in general the minimum allowed change of the value of an option.

For weather derivatives, degree-day options are common to hedge risks caused by temperature fluctuation. The decision basis for degree-day options is a comparison of the average temperature of a specified period with a reference temperature as an absolute difference, which is comparable to the strike price in other options. Here it is called ‘strike value’ because – as explained earlier – temperature has no price itself. If the difference reaches a special level, the option payment, determined in the contract, takes place. The tick size is the amount of the payout. Furthermore, contracts for weather derivatives include a cap for the payout, which is called a 'limit'.

Swaps are contracts between two parties for payments. Swaps for weather derivatives include fixed and variable interest payments. The variable interest payments can be designed in a way that they depend on specified weather conditions, whereas the fixed interest rates remain unchanged (Munich RE 2007).

At first weather derivatives were mainly used by energy companies to smooth the demand volatility by protecting against temperature fluctuation. However, weather derivatives are becoming ever more attractive for other sectors depending on the weather like agriculture and tourism. Munich RE also mentions that it is common practice that organisers of open-air events (e.g. sports or cultural events) try to cover their weather risk by options (Munich RE 2007). The Weather Risk Management Association (WRMA) claims that the total limit of weather transactions had an executed amount to $45.2 billion in the period 2005-2006, according to the Price Waterhouse Coopers survey on behalf of WRMA. Comparing to the period 2003-2004 it is almost ten times higher.[19]

Weather derivatives as a complementary tool to the common reinsurance system can provide positive welfare effects. Cao et al. (2003) mention that weather derivatives can improve the risk-return trade-off in asset allocation decisions. Dosi and Moretto (2001) claim that weather derivatives may provide coverage at a lower cost than 'standard' insurance coverage schemes. There are also limitations, however: weather conditions differ not only among countries and regions but also among small local areas. It will not be practicable to measure the weather variables of every single vulnerable area. Furthermore, the measurement of the variables of interest should be taken by an independent institution. Therefore it will be the task of the government to provide credible data.

The innovative insurance methods may provide incentives for individuals to insure and in a next step the international pooling of risks with new systems like catastrophic bonds and weather derivatives can offer solutions to overcome the convergence of the capital markets and the insurance and reinsurance sector. On the other hand, Dosi and Moretto (2001) address the issue that not all risks can be covered and therefore differences in risk coverage among countries may occur.

Apart from providing general information on climate change risks and establishing rules for the introduction of innovative insurance schemes the role of the government in insurance markets is one of control and enforcement of contracts and in general the improvement of conditions for viable private insurance. In developed countries, for example, governments set building standards to prevent dangerous and faulty construction work. Such legislation can be in some conflict with the freedom of consumer choice, but basic standards in construction work are a prerequisite for contracts between a building company and its client, defining quality standards of construction work. Building standards are relevant for insurance markets, too: they create a level field for insurance by making more explicit likely risks associated with buildings. Therefore these standards can reduce the scope for moral hazard and adverse selection.

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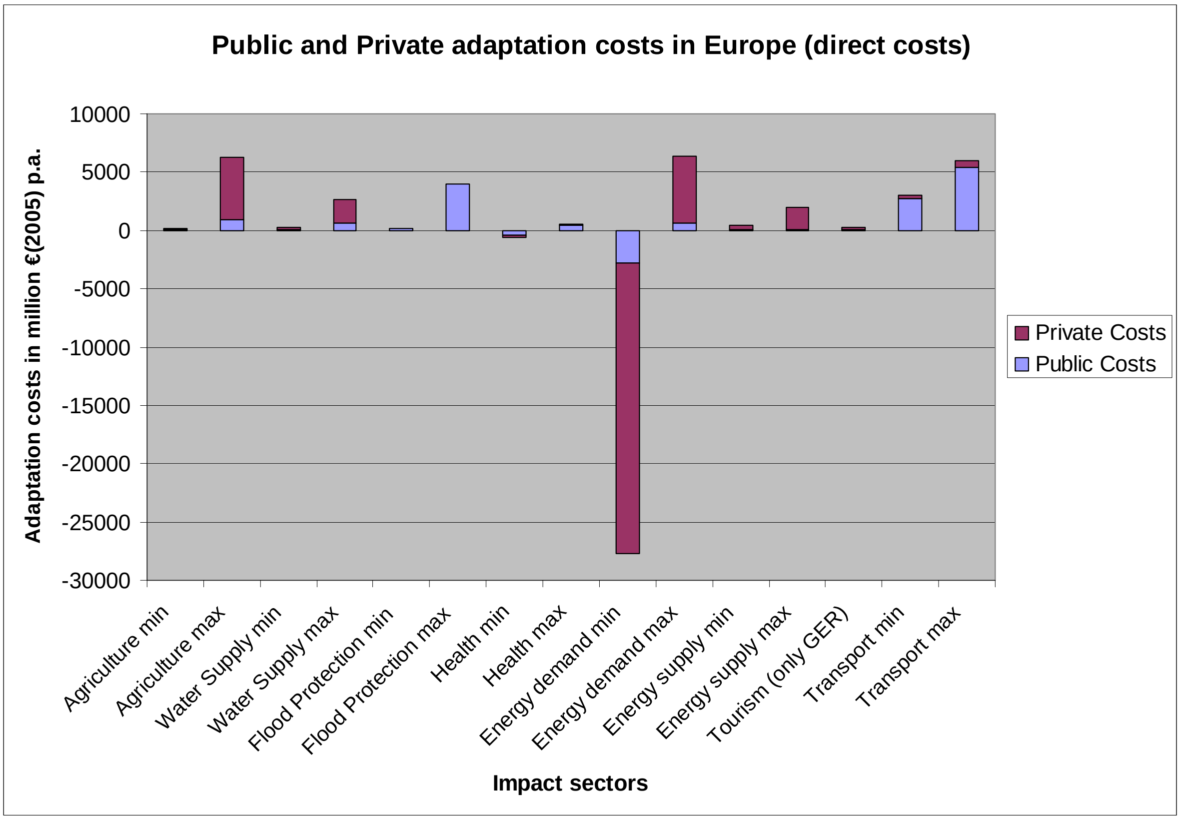
[19] See http://www.wrma.org/risk_trading.html (2010-03-02).

In summary, the regulation and monitoring of the insurance markets play an important role in the efficient adaptation to climate change. There are several problems that may hamper the effectiveness of the insurance market. Governments have different possibilities to improve the effectiveness including 'soft' measures, such as information campaigns, as well as 'strong' regulations, such as a mandatory insurance scheme. In a later section the fiscal implications of the regulation of the insurance market is explored.

3. Drivers of the fiscal implications of climate change

The fiscal implications of climate change have generally not been studied, with the exception of some studies on direct costs, notably related to government infrastructure investments. There is little if any literature on the overall fiscal impacts, which takes into account both the direct and indirect costs as well as the indirect impacts on fiscal revenues. A rare exception is a case study on Germany that is presented in PART II of this report. The summary analysis of adaptation measures in PART II is presented in a matrix in section 7.3 and an attempt to derive fiscal costs is made in chapter 5 of this PART, but these pertain to direct budgetary costs. In fact, the figures show public costs for the EU of around €15 billion a year maximum for adaptation (Figure 3.1), but with a minimum far below this figure. Still, these results do not indicate the highest threat from climate change for budgetary balances – extreme events and indirect effects.

Figure 3.1: Direct public and private costs of adaptation (annual average costs)



Source: Figure 5.2 in section 5.3.

The results plainly show that very little work has been done in this respect, with most estimates based on vague welfare implications or a few specific infrastructure costs. The lack of a unified methodology and assumptions also make the comparisons and a coherent description of the fiscal implications rather impossible. The results nonetheless give clear indications of the areas in which the fiscal implications are of special concern.

It can be expected that climate change will affect (almost) all economic activities and thereby growth, which in turn has implications for the level and composition of tax revenues. At the same time, climate change may also affect the expenditure side through spending on social benefits such as unemployment or health. Climate change will create a multitude of impacts, comparable to the complexity of the effects of population ageing. A rare study incorporating such effects exists for Germany. Bräuer et al. (2009) estimated that the indirect effects of climate change on public costs will amount to 87% of the total effect. Direct costs are thus not the main fiscal repercussion, and would mean that the total cost of adaptation for the state could be more than triple the direct costs, implying an average, annual fiscal impact ranging from €10 to 60 billion a year.

Therefore further study of the fiscal implications and interactions is needed. Such research is especially needed in countries where the negative impacts caused by climate change are expected to be the strongest. In addition, another important theme is the handling of extreme events in fiscal terms. Lis and Nickel (2009) have studied the budgeting for extreme weather events by governments. They found that developed countries in and beyond the EU tend to ignore and treat climatic extremes as something that has no strong fiscal relevance and as easy to absorb over time, based on a simple inter-temporal spread of costs. No differentiation among different kinds of catastrophic events is made and estimates are based on an econometric analysis of trends and average costs of state intervention.

What we do know, however, is that climate change will gradually impact the sectors of the economy that are sensitive to climatic conditions, such as tourism, fishing and agriculture. A simple amalgamation of relief costs and trends based on past expenditures is likely to be insufficient to prepare for the changes. The projections of the European Commission's working group on ageing (EC and EPC, 2009) show one case where past expenditure shares are not an appropriate guide for longer-term budgetary expenditure projections. The economic crises have also put into question the economic growth trends and thus the fiscal capacity of the states to afford the costs of population ageing. Climate change just adds another layer of complexity with a very significant margin of uncertainty, notably surrounding the costs and recurrence of extreme events.

The fiscal implications of climate change can be altered, however, by introducing planned, anticipatory adaptation measures to avoid the negative impacts of climate change and even foster potentially positive, new opportunities. To do so, states need to understand the drivers leading to negative or positive fiscal implications, similar to the way changes in pension, unemployment, education and health costs are analysed in the projections of the budgetary costs of population ageing. The objective of this chapter is to present the drivers identified in the reviews of the literature and the case studies.

Six drivers have been identified that will determine the size and importance of the fiscal implications:

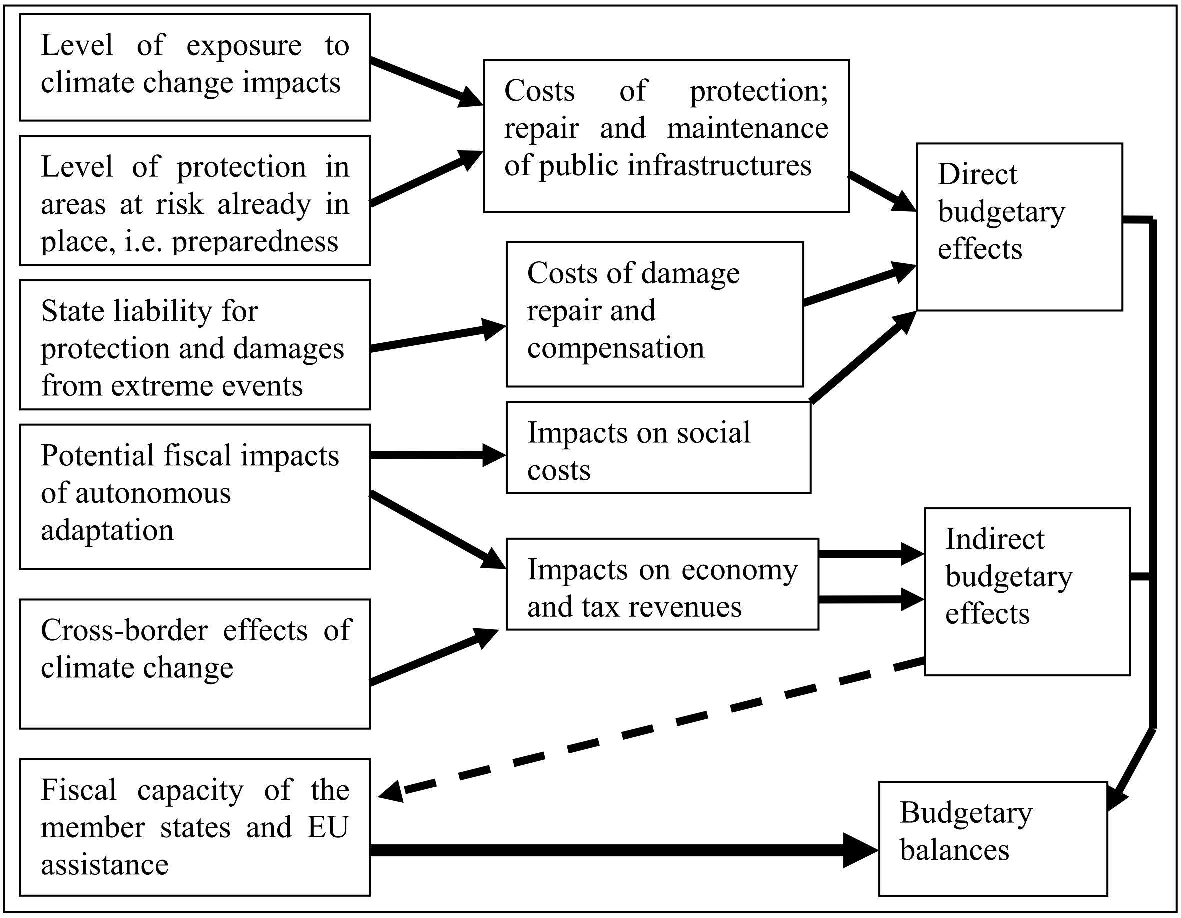
1) the degree of exposure to gradual and extreme climate events;
2) the level of protection already in place in areas at risk, i.e. preparedness;
3) the state's liability for damages;

4) the potential and impacts of autonomous adaptation and remedial actions;
5) the cross-border effects of climate change; and
6) the fiscal capacity of the member states and the role of the EU.

Figure 3.2 presents in a simple diagram the changes that lead to fiscal implications. These are classified according to the kind of primary impact they may have, either as direct budgetary costs or indirect ones.

Direct costs to the budget come from the construction and maintenance of protective infrastructures, as well as from the additional maintenance of public infrastructures affected by climate change (i.e. climate proofing). Other direct effects on the budget are changes in social expenditures, mainly from potential repercussions on employment or alterations in health expenditures. Fiscal balances are also likely to be affected by fiscal revenue changes, brought by changes in the national economy as well as in the economy of trading partners. They may likewise be affected by negative spillovers from residual damages originating from adaptation actions in neighbouring countries. The indirect effects on the state budget will in turn affect the fiscal capacity of the state to deal with the impacts as well as the eventual level of support by the EU. Of course, some climatic changes may reduce costs in some areas, for example damages from extreme winter events if the weather becomes milder.

Figure 3.2: Drivers of fiscal impacts



This chapter discusses in more detail the origins of fiscal impacts based on the findings from the theoretical framework in chapter 2 and the case studies presented in PART II. It discusses how to translate – mainly qualitatively – specific climate impacts into fiscal effects based on the six drivers/parameters mentioned above. The chapter concludes with policy options to mitigate the negative effects of the drivers. It is not the role of the chapter, however, to go into detail on policy actions.

3.1. Degree of exposure to climate events

The impacts and costs of climate change will depend greatly on the exposure of the individual countries to climate change. The case studies show important differences among the member states, which are in line with the broader findings of other studies, such as the PESETA study published by the JRC in 2009.

The case studies identify the climatic impacts that will have consequences for the economy, more specifically, changes in

- average temperature in the seasons, along with an expected rise in temperature extremes;
- precipitation patterns;
- snow cover;
- water systems – particularly river flows (flood and drought risks) and groundwater levels; and
- coastal regions – with sea level rise and flood risks.

Some regions are especially vulnerable to one or several such changes, which can lead to very costly state intervention to mitigate the direct impacts, as well as affect social transfers, changes in state revenues, etc. In areas where exposure to negative impacts is high, appropriate measures to reduce the negative impacts of climate change can considerably reduce the economic and fiscal effects of the events. Ensuring an ‘adequate’ level of autonomous and public anticipatory adaptation becomes a key determinant.

Sea level rise is expected to threaten important economic centres on the Atlantic coast, the North Sea and the Mediterranean. Studies have shown very different levels of protection in equally exposed regions. For example, most of the Atlantic and North Sea coast is highly exposed but at the same time generally also highly protected by existing infrastructures. In Germany, the existing infrastructure greatly cuts the costs of further protection. In the Mediterranean, protection from sea level rise has never been a central issue. While not exposed to the same level of extreme sea surges as on the Atlantic coasts, peninsulas like Italy with a very large coastline and a significant share of the population and economic assets concentrated along the coastline are highly exposed to the gradual rise of the sea level. Only Venice is developing a defensive strategy, but it pre-dates a climate-induced change in the sea level, instead originating from the land subsidence under the city.

Costa et al. (2009) have estimated the costs of protecting EU coastal areas and have pinpointed countries with high exposure that would also find the costs too high to bear. While the benefits of proper protection at the EU level are considered high in studies like PESETA, studies by Costa et al. (2009) and the IMF (2008) estimate that for smaller and poorer EU member states such as Cyprus, Malta or Estonia, the costs may be too high. In Estonia, the protection of the coastline highly exceeds the benefits in terms of GDP costs at the level of 2007. Following a purely ‘economic’ logic, it would therefore be rational to abandon large stretches of Estonia to the sea.

The Mediterranean countries are in general highly exposed not only to sea level rise, but even more so to drought, leaving aside the effects a reduction in snow in the mountain ranges of Spain and Italy on winter tourism. Considerable exposure to drought will entail large direct impacts on the agricultural sector and water infrastructures. Infrastructure costs and rises in extreme summer temperatures can increase social costs, such as those associated with health, and reduce productivity.

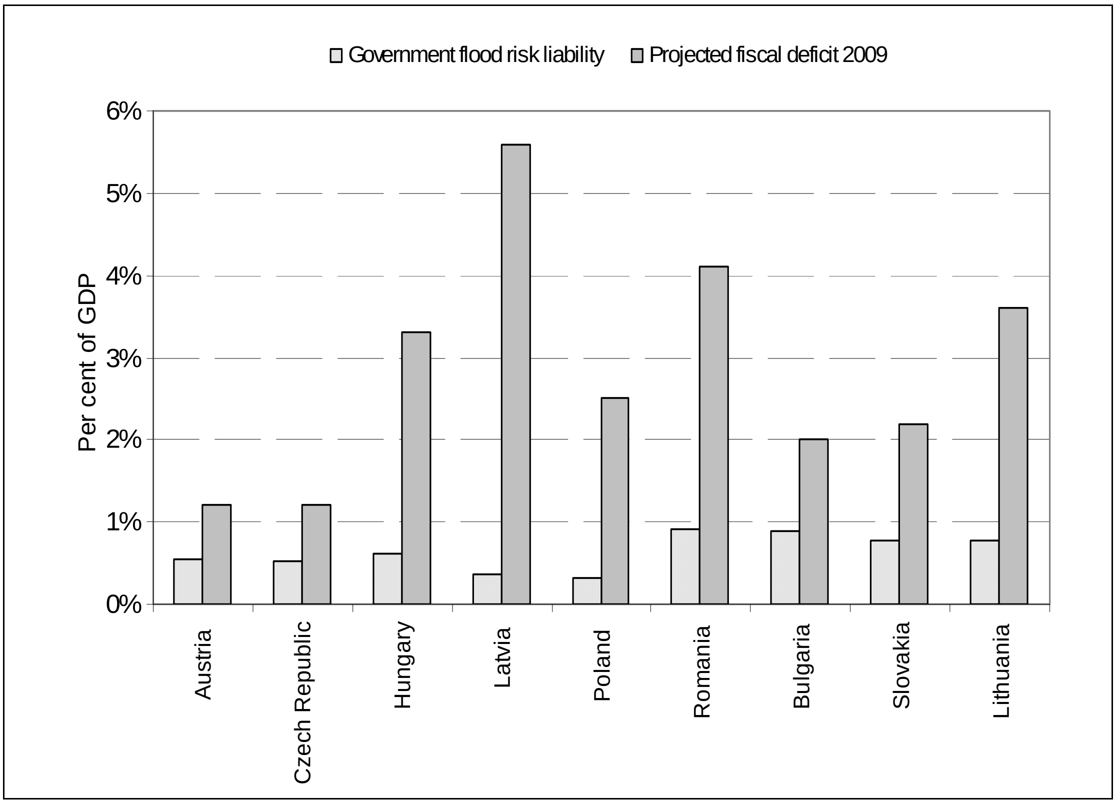
One of the only areas where the fiscal implications have been directly researched has been for sea level and river flood protection. This is due to the public nature of the infrastructures, which are mostly built and maintained by the state, and to the high level of state liability in responding to the damages caused by extreme events. However, most studies do not look beyond the direct costs towards the longer-term implications of changes and catastrophic events that may damage the growth rate of the economy for long periods of time.

Many parts of Europe are highly vulnerable to changes in river flows, affecting large areas, including many economic centres, and bringing a real risk of unsustainable fiscal impacts from repeated extreme events. Several countries are highlighted as being at major risk ('hot spots') with potentially significant budgetary costs from river flow changes, in particular floods. Poorer Central and Eastern European countries are facing potentially unsustainable costs, and even richer member states such as Austria are identified as hot spots of extreme flood events with the associated large costs to be incurred by the government. The example of Austria's political and fiscal crisis after a flooding in 2002 reveals that extreme events can put the public finances of even economically more advanced European countries under strain. Figure 3.3 gives an indication of the average, annual expected damages already with today's conditions in relation to the annual budget deficit. Some projections by Mechler et al. (2009) for the end of the century show that almost all of the EU member states with below average per capita GDP have a potential flood damage risk higher than 1% of GDP annually (Figure 3.4).

The impact of Hurricane Katrina in the US has also been a clear signal of the risks of underestimating the costs of extreme events. In New Orleans the potential damage costs were estimated at $16 billion before the event, while just the direct damage alone to dwellings, government buildings and public infrastructure reached $27 billion. An aid package of over €100 billion had to be unlocked to assist the city.

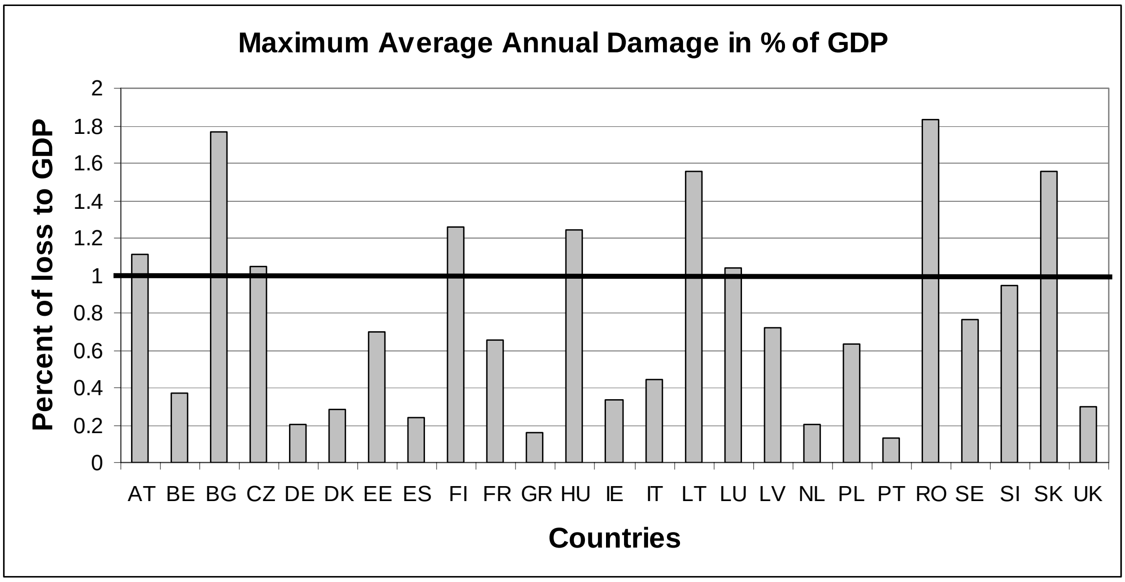
Other impacts that can have serious local repercussions are changes affecting the snow cover in Europe's mountains, which will affect the tourism sector, at times positively, but in some regions it can badly damage the local economy. Similar situations may arise for droughts affecting the agricultural sector in several Mediterranean areas. These localised impacts may have budgetary implications, notably for transfers related to increases in unemployment.

Figure 3.3: Annualised disaster risks and fiscal deficits in selected flood-prone European countries (today's conditions)



Source: Adapted from Hulme et al. (2009, p. 13).

Figure 3.4: Maximum average annual flood risks across EU countries (% GDP)



Note: This is not loss of GDP, but loss measured in terms of GDP. Losses relate to assets, while GDP relates to income generated from those assets.

Source: Adapted from Mechler et al. (2009, p. 9).

Also important is the exposure of critical infrastructure to climatic impacts, in particular in the energy sector, which causes concern and has been the focus of studies, like that by Jochem and Schade (2009) for the ADAM project. Changes in river flows can affect hydroelectric power supply as well as the cooling systems of many thermal and nuclear power stations. Combined with atmospheric temperature changes and weather extremes, this may require substantial adaptation investments to weatherproof power plants as well as the energy transportation and transmission infrastructure, while decreases in efficiency and hours of operation may be unavoidable. Some countries and regions can be at particular risk or their cost structure may make them uncompetitive. The result may well be the closure of plants with the associated effects on the local economy. Exposure to one or a combination of several of the impacts could hit local economies and affect the state budget.

Finally, governments may see the costs of maintaining infrastructures affected because of damages caused by climate impacts. At the same time, some regions will benefit from the increased temperatures, with a reduction of snow and ice-related damages.

3.2. Level of protection already in place in areas, i.e. preparedness

The levels of existing protection and awareness influence the costs of climatic impacts considerably. An already high level of protection and enhanced awareness on the part of the population and governments can reduce the future costs of adaptation to sea level rise significantly. This has been documented in the case study for Germany. But for other European countries, this may not be the case, at least as far as we know. A sea level rise is expected to imply either a costly development of coastal protection in many member states or a difficult retreat from the sea, shifting settlements and infrastructures away from the coastline. In Italy, existing laws restricting construction close to the sea front will reduce some of the costs.

Nevertheless, the projected increases in the sea level are at times too high to avoid considerable costs of protection even in well-equipped areas. In the Netherlands the sea level rise over this century might go beyond the technically possible protection offered by the present dykes system. The Dutch state therefore asked a special commission to undertake a study, which in 2008 presented a plan to create new defences – mainly through an extensive beach nourishment programme that would expand the territory into the sea (Deltacommissie, 2008). Given the uncertainty surrounding the future sea level rise, the commission recommends building protections based on the upper limits expected, in light of the major consequences of any shortcomings in the protection level. To give the order of magnitude, the Delta programme was planned to start from 2010 onwards at an annual cost of €1.2 to 1.9 billion a year until 2050 and of €0.9 to 1.8 billion after 2050. The constant maintenance of the infrastructure means that these costs do not decrease over time.[20] It is interesting that the annual expenditure estimated by the Deltacommissie for the reinforcement of their protection alone exceeds by far most estimations of the studies undertaken for the EU as a whole, which puts into question existing methods of estimation in the top-down EU-wide analyses.

[20] The Deltacommissie performed a cost-benefit analysis to take a decision on the construction. According to the Commission, 65% of the Netherlands is an area at risk from sea surges. This means that about €1,800 billion of the nation's wealth is at risk (national wealth is estimated to be five times the GNP of the country). The estimated damages from flooding with the present protection until 2040 are expected to reach between €400 and €800 billion in direct and indirect damages and a cumulated €3,700 billion by 2100. The study was aware of the mistakes done in New Orleans in estimating the costs of exposure.

3.3. Extent of state liability

The theoretical framework and the case studies identify as a major fiscal cost the liability of the state in compensating victims from extreme events. The state is in many countries expected to cover the costs of natural catastrophes, be it by floods or droughts. Yet, private insurance schemes, combined with an appropriate regulatory environment and a limited liability of the state for damages beyond the insurable threshold, would reduce the fiscal consequences of extreme events considerably and needs to be explored extensively. The lack of private insurance against natural events is highlighted as a problem in the cases of damages from a sea level rise, river flooding and droughts, especially for the agricultural sector. There have been attempts to impose a certain level of compulsory insurance for natural extreme events in Germany, but they have failed for political reasons and a lack of understanding by policy-makers (see section 2.8).

For most countries the state bears responsibility for the totality of coastal protection, but there are exceptions. For instance in Finland, responsibility is shared with landowners. Even so, the state liability is still estimated at 90%. Other interesting cases are those of Denmark and Malta, where the state liability for coastal protection falls to 50%. There the liability of the state for building coastal protection is limited. This encourages private owners to seek insurance and invest in protection, at the same time reducing the level of moral hazard caused by an expectation of state intervention.

As highlighted earlier in section 3.1, a specifically problematic situation arises when state liability for extreme events is too high in relation to the national budget. This is a problem in smaller and poorer countries. In those countries, the economy is not large enough to cover the risks of extreme events through private insurance often because the law of large numbers cannot be applied and too great a share of the population is at risk of the same event to balance out gains and losses. A solution at the EU level will need to be sought.

3.4. Potential fiscal impacts of autonomous adaptation

The fiscal impacts will strongly depend on the adaptive capacity (anticipative or reactive) of individuals and on the kinds of adaptation actions they undertake. Autonomous adaptation, as identified in the theoretical framework, will be driven by their private utility-maximisation objectives and their assessment of risks. Individual adaptive behaviour will often not be in line with the required behaviour to maximise social welfare because of the differing social and individual objectives. This is not the only aspect that will lead to a socially suboptimal adaptation by individual actors; market (and policy) failures and moral hazard will also play a significant role.

Some of the adaptation actions by individuals may in the future result in negative fiscal implications. A fairly obvious case is the expansion of residential areas in zones at risk of flooding. This may happen because of the absence of laws, a lack of awareness among those moving to the zone, an underestimation of the risks by individuals and a component of moral hazard when it is expected that damages or remedial actions will be covered by the state. If an extreme event occurs, the costs to the state of direct damages and social transfers may be considerable, yet could be avoided.

Another case with fiscal implications is the increasing use of air conditioners in areas suffering from a rise in summer temperatures. The power-hungry cooling systems may strain the energy grid, which can cause disruptions in the power sector. Water shortages may also affect the turbines of the power stations. In Greece, during a heat wave, the country experienced a serious blackout.

Serious issues emerge from the indirect impacts of climate change if individuals are unable to adapt to them. Unemployment stemming from economic impacts, deteriorating health owing to new diseases, and inward or outward migration can all affect a state's budgetary expenditures considerably. For example, when regional economies are hit seriously, some important activities become impossible (e.g. winter sports tourism and farming). While there may be a tendency to subsidise the region, the state should be proactively assisting the diversification of economic activities, through awareness training and programmes to facilitate job change and even planned migration to avoid rises in socio-economic costs.

3.5. Cross-border effects of climate change

There are two cross-border effects of climate change to be considered. One is caused by residual costs from actions in another country. In the EU, adaptation measures in rivers upstream may affect another country downstream. Another evident fiscal impact is aid transfers to developing countries to adapt to climate change, but technology transfer from donor countries partially mitigates the impact.

These are not the only impacts that may provoke fiscal effects, however. In the case study for Germany and Finland a reference is made to trade impacts, i.e. reductions in the demand for exported products due to climatic impacts abroad. Negative effects on the economies of importers may reduce a state's exports. The revenue implications for the state can potentially be large. Finally, climatic impacts abroad may lead to immigration pressures in some EU countries, with the associated costs.

3.6. Fiscal capacity of the state and the role of the EU

The fiscal implications will clearly be greater for member states with less fiscal strength, highlighting the predicament of poorer member states. The financial impact of either building the necessary infrastructure or reacting to counter the impacts of an extreme event can be very high in relation to the state budget of poorer member states. As mentioned earlier, in the river flood hotspot of Central and Eastern Europe, the costs of repairing the damage of floods and protecting the riverbanks can be a considerable burden for the state. But fiscal strength is not just a problem for the poorer member states – wealthier countries may be threatened by extreme events as well. Strong fiscal pressures and downgrades in projected growth rates are reducing states' future room for manoeuvre to support adaptation to climate change.

Fiscal capacity is not only affected by direct costs, but also by the costs of social and economic repercussions. Climatic impacts may impair important economic activities, generate an increase in unemployment and thus social costs, and reduce tax revenues. In combination, the fiscal pressures can be extremely damaging. Larger countries can usually counterbalance the negative effects with the benefits of climate change in other areas. This is the case of a large country like Germany, where losses from winter tourism may be recovered by improvements in other areas of Germany benefitting from warmer weather, creating changes in the pattern of social transfers but not necessarily costs for the state. The smaller the country, the smaller is the capacity to counterbalance the effects of climate change.

The study has identified cases (e.g. Estonia, Cyprus and Malta) where there may be a need for assistance from supranational funds (i.e. the EU) to help such countries develop the appropriate protection and response capacities.

Another aspect relevant to fiscal stability is the increase in the temperature variability and thus of extreme events. It is generally expected that the various economic sectors will see a higher degree of income variability. In areas where the state intervenes to assist in extreme events, it may find itself incurring considerable costs with a more frequent occurrence than planned, creating budgetary problems.

3.7. Policy measures for minimising the impacts of fiscal cost drivers

Based on the theoretical framework and the case studies, there are a number of general recommendations that follow from the identification of the drivers of fiscal implications. There are different policy actions available to address climate impacts, but there are clearly some effective solutions that in turn reduce the negative fiscal implications or increase the positive ones. This subsection addresses the options for each driver identified.

3.7.1. Measures to reduce the negative fiscal implications of exposure

Appropriate balance between hard and soft protective measures. The fiscal implications from exposure to severe climatic impacts can be reduced by the appropriate combination of hard and soft public adaptation measures. Hard measures are those directed at blocking the threats, while soft measures are based on a strategic retreat from areas at risk and the creation of buffer zones using existing natural features. There are a number of examples in Europe of both types of adaptation. Land-use management and regulation can go a long way too in reducing unnecessary exposure to risk by individual actors.

Decisions on what measures to use should be taken based on appropriate cost-benefit analyses taking into account the value of the area to protect, using traditional cost-benefit tools such as contingent valuation methods.

Investment in research and development. Research and development can contribute to reducing the costs of future protection for a modest investment. New technologies can significantly affect the final cost of adaptation.

Help for individual actors in the economy to adapt. Governments should be careful to avoid using public policy solely to preserve present structures and activities; they should also strive to understand how to take advantage of opportunities created by the changed conditions and accept that there will be a shift in economic activities and infrastructures. Governments should additionally avoid protecting and subsidising declining activities, and instead concentrate on fostering new, alternative employment opportunities as part of an adaptation strategy and manage the transition.

Supranational provisions for catastrophic events that single countries cannot handle alone. There are areas in the study that call for collective action in the EU. The main point of concern is the existence of risks against which some small countries cannot ensure themselves (see point 3.6). Small countries may be unable to respond to a catastrophic event or may not have the financial means needed to develop optimal protection. This raises the issues of EU solidarity measures, such as an emergency fund for extreme events. Such a fund should be restrictive enough to avoid an absence of incentives and situations whereby local authorities and member states, counting on EU support, do not take their own necessary precautionary measures.

3.7.2. Measures to reduce the negative fiscal implications of state liability

Expansion of the insurance markets. As mentioned above, there is a case for expanding insurance markets, with the state intervening only in the event of damages beyond an insurable threshold. Compulsory natural hazard insurance would allow private insurance to sufficiently spread the risk and attract enough customers to cover the risks more efficiently. In very small countries the spread of risk may not be sufficient, thus an international mechanism with reinsurance or schemes covering more than one country could offer a solution.

Land and water use regulation. Land-use management is central to making certain that areas at risk are not used inappropriately. The study reveals that individuals tend to underestimate risks, and asymmetric information and moral hazard can lead to behaviour that puts people and capital at risk. Construction standards can also assist in reducing future damage costs. Water markets require some control, ensuring that prices reflect water scarcity and that infrastructures are appropriate to limiting waste and leakage, and efficiently managing water use and distribution.

Provision of appropriate information. There is a clear indication that lack of awareness and imperfect information does adversely affect autonomous adaptation, such as an underestimation of risks in the decisions of individuals. Information is a very cost-effective way of reducing risky behaviours.

A review of state liability. The case study of Finland highlights that there is a limit even in the provision of protective infrastructure for extreme sea-level surge events. It is important for the state to discourage risk-taking behaviour by ensuring, where possible, that individuals do not take risky actions in the expectation that the state will then intervene.

3.7.3. Measures to reduce the negative fiscal implications of suboptimal autonomous adaptation

The main problem with autonomous adaptation is the difference between the private objectives of maximising one's own utility and the needs for a social optimum. The role of the government is to understand the reasons for suboptimal adaptation and induce individuals to change their behaviour such that private adaptation is directed towards a social optimum.

Provision of adequate information. The first and most cost-effective action is the provision of information. Reducing imperfect information and the associated impacts is of paramount importance. This will ensure that private adaptation is optimised, leaving other interventions exclusively geared towards those residual effects of autonomous adaptation that do not reflect a social optimum.

Use of regulations. The regulatory arm of the state is crucial to steering autonomous adaptation. As noted earlier, land use and the use of other resources can be regulated to avoid damaging behaviour and even to open up new opportunities. It is also possible for climate change to free up land for agricultural production or other activities.

Use of fiscal incentives. Fiscal instruments, such as taxes and subsidies, can be highly influential in the choices of individuals. Taxes on damaging behaviour or subsidies to adopt positive actions are important.

Awareness of the net fiscal effects of incentives. It is clear that subsidies will entail direct costs for the state, but the impacts of changes in the tax composition and regulations can have a number of repercussions. It is recommendable to shift taxes in such a manner as to foster positive adaptive behaviour and reduce negative behaviour, for example by taxing water consumption in areas affected by drought, but reducing the taxes on water saving technologies. There is also a need to make sure that on balance, the state does not suffer negative budgetary outcomes by miscalculating either the effects on tax revenues or the impacts on the economy (and thus on social costs).

3.7.4. Measures to reduce the negative fiscal implications of cross-border effects

Reinforced coordinated action. The EU is in an enviable position compared with other parts of the world in view of its ability to reach agreements on common standards and compensation across EU member states, as well as with neighbouring countries. Coordinated action to ensure minimal cross-border residual costs and a system of financial assistance can help the EU reduce the EU aggregate and the separate national costs of climate change.

Coordination of standards. The case studies have pointed out that different countries and even regions within countries are using different assumptions about the impacts of climate change, dictating diverse levels of adaptation and thus putting neighbouring regions at risk of larger residual costs. Such divergences can be avoided by using similar standards and assumptions. In addition, residual damages that fall on neighbouring countries and regions will normally not be taken into account in cost-benefit analyses by local decision-makers, thereby potentially leading to inefficient responses from an EU perspective. Mechanisms at the EU level that make certain all costs are accounted for and that the EU (and even beyond its borders) is considered one territory can overcome this situation. The EU might need to coordinate cross-border financial transfer mechanisms that reflect a correct burden-sharing of costs.

Integrated use of resources. The expansion of interconnectivity, especially in the energy sector can help make sure that risks in the energy grids of one member state are spread across the EU, thus reducing the probability of blackouts. More will have to be done to address the efficient use of other resources (like water) at the supranational level.

3.7.5. Measures to ease the limitations on the fiscal capacity of some member states

Development of sufficiently robust EU assistance. As we have shown, there are several member states in the EU that face excessive fiscal pressures in relation to the size of the national budget, for either putting in place the necessary protection or dealing with catastrophic effects. While the EU may want to reinforce its cohesion policy to assist in the development of the necessary defences, this raises the question of providing rapid support at the EU level for extreme events in hotspots. Obviously, such assistance would need to be combined with governance rules that among other things avoid moral hazard, i.e. suboptimal adaptation at the national level in the expectation of a supranational bailout. Still, a functioning mechanism of financial support seems of central importance.

Integration of EU rapid response mechanisms. To cope with major impacts in specific hotspots, the EU should consider further integrating its response capacity in order to provide rapid, coordinated and effective action in the case of a catastrophic event. Hurricane Katrina in the US has shown how even in a unitary nation an appropriate response is time-consuming and difficult to set up; in Europe a similar magnitude of damages would probably entail a much deeper coordination problem, with economic, social and also political costs piling up in the process.

Higher multiannual budgetary provisions for extreme events. The study has highlighted that climate change will increase the variability in the incomes of economic sectors. Boom and bust cycles in weather-dependent activities such as agriculture and tourism will be more extreme and recurrent. Even in the case of Finland, which is expected to benefit from climate change, income fluctuations in the different sectors will become much more extreme as climate change progresses. The state will need to ensure that it has the provisions to react more flexibly and more often, smoothing the fiscal implications with multiannual budgetary strategies. Flexible labour markets, along with appropriate and flexible social systems, will be necessary to respond to this variability, with a higher provision of fiscal resources.

4. Cross-country summary tables of adaptation measures

This chapter provides a cross-country summary referred to the case studies in PART II, where various possible and realised adaptation measures in Germany, Finland and Italy are presented. As some impacts of climate change are the same throughout Europe, whereas some others have very different effects and therefore involve alternative coping strategies, it may be beneficial to compare the adaptation measures found in the case studies across the three countries. We therefore use the same sectoral order as in the case studies themselves. Tables 4.1 to 4.7 present the areas where adaptation efforts are required, either autonomous or public, in the three countries. This gives an overview of all areas that need to be analysed to understand the impacts on the economy and the government budget. These tables do not indicate that the adaptation measures should necessarily result in a fiscal impact.

Note that all the adaptation measures we outline below are conceivable in the particular country considered, albeit their implementation may not yet be realised, discussed or researched. Only a few measures are not considered feasible for a given country. One example is the use of air conditioning, which is pertinent in Italy but is not yet debated much in Germany or Finland.

4.1. Agriculture and forestry

The impacts of climate change on agriculture and forestry is mainly driven by projected temperature increase. Especially in Italy this may lead to conditions where the crop types are limited and forests face higher risks of fire. In contrast to Italy, Finland may gain from positive influences of climate change as increases in temperature may lead to expanding growing seasons or conditions for cultivating new crop types.

Table 4.1: Autonomous and planned adaptation measures in agriculture

Impact	Adaptation measure	Germany	Finland	Italy
Agriculture				
Increase in temperature	Change in cultivation to more thermophile plants (e.g. wine)	X		
Increase in extreme weather events	Use of insurance	X	X	X
	Floods: evaluating water protection guidelines	X	X	X
	Droughts: cultivation of more drought resistant breeds	X		X
	Droughts: Irrigation systems	X	X	X
	Redesigning drainage systems	X	X	X
	Rethinking short land tenancy period		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	
	Developing of new crop types	X	X	X
General impacts	Rearing more resistant crop types	X		X
	Increased use of fertilisation and plant protection (neg. externalities)	X	X	X
	Water-saving cultivation	X		X
	Research on regional climate change	X	X	X
	Development of plant and animal disease and pest monitoring	X	X	
	Considering new insurance regulation	X	X	

Source: authors' compilation

Table 4.2: Autonomous and planned adaptation measures in forestry

Impact	Adaptation measure	Germany	Finland	Italy
Forestry				
Pests	Control of pests and diseases	X	X	
	Earlier evacuation of trees after damage	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	X
	Reconsidering normative framework for fire breaks	X	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	
Less frost – difficulty of harvesting in muddy conditions	Expansion of road networks		X	
General impacts	Rapid harvesting after wind damages		X	
	Developing of higher resolution climate change models suitable for regional projection	X	X	X
	Research and development of new harvesting techniques and tree improvement	X	X	X
	Forest transformation to higher diversification of tree types	X	X	
	Financial support for private owners	X		
	Field mapping and regional cultivation recommendation	X	X	X
	Knowledge transfer of experts	X	X	
	Evaluation of current water management concepts	X	X	X

Source: authors' compilation

4.2. Water supply, inland floods and sea level rise

The water sector includes water supply as well as flooding dangers like river or coastal floods. Adaptation options to the two latter ones mainly include early warning systems and protection measures. Water supply includes the quantity as well as the quality of water.

Table 4.3: Specific impacts and adaptation responses concerning water

Impact	Adaptation measure	Germany	Finland	Italy
Inland floods & heavy rains	Expansion of water supply and sewage networks	X	X	X
	Use of insurance	X	X	X
	Flood-adapted building	X	X	X
	Property construction out of risk area	X	X	X
	Rethinking of land use in endangered areas, Evacuation of flood endangered areas	X	X	X
	Urban and land use planning, preparation of general plans for flood risk sites	X	X	X
	Research on regional flood occurrence and impacts, SLR monitoring	X	X	X
	Early warning systems	X	X	X
	Coordination and cooperation with neighbouring authorities	X	X	X
	Improvement of flood protection construction	X	X	X
	Emergency Management	X	X	X
	Evaluating dam safety	X	X	X
	Evaluating drainage systems	X	X	X
	Recreation of retention areas	X		
	Awareness building in the population	X		
Sea level rise/ Coastal floods	Spatial planning, prohibition of building, near the coastline	X		X
	Land protection barriers	X	X	X
	Monitoring of SLR, coastal climate and the erosion of the coastal zone	X	X	X
	Awareness building of the population	X		X
	Evacuation of flood endangered areas	X		X
Droughts / Impairment of water balance (groundwater level)	Restrictions on water use	X	X	X
	Water quality protection	X	X	X
	Responsible water use	X	X	X
	Reconsidering land use management	X	X	X
	Infrastructural measures (e.g. sufficient storage of water in impounding reservoirs)	X	X	X
Moving on ice becomes risky	Information of the public		X	
Nutrient leach into water reservoirs	Monitoring measures and reconsidering fertilisation legislations	X	X	X

Source: authors' compilation

4.3. Human health

The adaptation measures in the human health sectors are strongly connected to rising temperature and possible heat stresses. Concerning this impact, autonomous as well as planned adaptation measures are necessary. Changes in individual behaviour and technical adaptations in homes are the former ones. The latter ones involve providing information, early warning systems, urban planning regulation, health care infrastructure and adequate housing conditions of publicly owned buildings. Although Table 4.4 shows the same adaptation measures in nearly every country of the case study, in reality the efforts of the single countries differ. This is also attributed to the different location of the countries and the current climate circumstances. In an already warmer climate, a further temperature increase may lead to important changes in the well-being of the inhabitants.

Table 4.4: Autonomous and planned adaptation measures concerning human health

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

Source: authors' compilation

4.4. Tourism

The tourism sector is small in Finland. Therefore the focus is on Italy and Germany. Especially in Italy the tourist sector is economically important (see PART II section 6.3.3) as a winter and summer destination. The cross-country table shows similar impacts and adaptation measures in winter destinations. Winter tourism mainly takes place in the Alps, where Italy's area is larger than Germany's. This advantage in size could offer more alternative opportunities in the winter tourism sector (e.g. switch to higher altitudes). For summer tourism, Germany has better adaptive capacities. If the already warm summers in Italy grow even hotter due to climate change, this could act as a deterrent for summer tourism.

At the same time, warmer summers in Germany may attract more tourists, especially domestic travellers. Therefore the difference is that in Germany new tourist destinations may arise whereas in Italy the existing tourist infrastructure has to adapt to the changing temperature conditions.

Table 4.5: Autonomous and planned adaptation measures in the tourism sector

Impact	Adaptation measure	Germany	Italy
Winter sport tourism			
Less snow reliability (particularly in low altitudes)	Artificial snowmaking	X*)	X
	Reconsidering of legislation	X	X
	Concentration of slopes in higher altitudes (constrained)	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 tourist sites	See PART II, section 4.5.1	X	X
Increased potential for summer tourism (particularly beach holidays)	Enlargement of tourism opportunities	X	
Hot summers (IT)	Increased use of air conditioning		X
	Innovative house design		X
	Normative framework for construction design		X
Total tourism sector			
General impacts	Changing in recreation and travel behaviour	X	X
	Increase of weather independent offers	X	
	Provision of information about regional features	X	
	Diversification of tourism industry (e.g. alpine tourism)	X	X
	Expansion of current research	X	X

*) Also public subsidies for artificial snowmaking are possible.

Source: authors' compilation

4.5. Energy sector

The data provision limits the comparison of all three case-study countries. It is only for Germany and Finland that the available data can be assessed and put into a cross-country matrix for a better overview. Nevertheless, Italy's possible impacts and adaptation measures were also included in the table as a best guess of common understandings in the energy sector as a whole. Higher temperatures in winter might cause a decrease in energy consumption, whereas rising temperatures in the summer will lead an increase in demand for cooling. The net effect is unclear, but the empirical literature suggests positive net effects in Italy (i.e. higher total demand) and by tendency negative net effects in Finland (lower energy demand). Along with the consumption side of the energy sector, the producer's side will also be affected by climate change. Under changed weather conditions the cultivation of biomass material might be possible and economically profitable. On the other hand, the grids and networks might be threatened by extreme weather events. Furthermore, the restrained availability of cooling water may possibly affect the power production adversely.

Table 4.6: Autonomous and planned adaptation measures in the energy sector

Impact	Adaptation measure	Germany	Finland	Italy
Higher temperatures in winter	Decreased use of electricity for heating	X	X	X
	Increased use of wind energy as less ice disturbs propeller blades		X	
Higher temperatures in summer	Increased use of electricity for cooling	X		X
Inland water transport unreliable	Risk diversification, less dependence on waterways.	X		
Limited water cooling capacity in summer	Research for alternative cooling-systems	X		X
Improved temperature conditions for biomass	Increased use of bio energy	X	X	
	Expansion of bio energy infrastructure	X	X	
Increase in precipitation	Investment in additional hydro power		X	
Extreme weather events	Extension of underground power cable	X	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	X

Source: authors' compilation

4.6. Transport sector

The transport sector differs from one country to another. Especially the location of a country plays an important role (e.g. access to the sea, neighbouring countries). In addition, the aspect of the direction of the trade route (e.g. transit country) has to be taken into consideration.

Quality and quantity as well as the composition of the current transport infrastructure have to be considered. Germany, as a Central European country, faces transit traffic from north to south as well as east to west and vice versa. In comparisons with Finland as a northern European country, mainly transactions from north to south have to be considered. Italy as a peninsula and a large north–south extension faces different circumstances. As in the energy sector, data availability limits the analysis, in particular for Italy.

Table 4.7: Autonomous and planned adaptation measures in the transport sector

Impact	Adaptation measure	Germany	Finland	Italy
Extreme weather events	Upgrading of drainage systems and increases in pumping capacity of tunnels	X	X	X
	Protective constructions, more resistant materials for roads, airport runways, and railways	X	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 or due to intense precipitation	Elevation of roads and rail lines	X	X	X
	Early warning systems	X	X	X
	Building, heightening and strengthening of levees and dykes	X	X	X
	Monitoring and maintaining road and rail infrastructure	X	X	X
	Relocation of roads and railways	X	X	X
Shortening of ice and snow cover period	Less winter maintenance for road and rail networks	X	X*)	X
	Increase of winter traffic on maritime transport ways		X	
Increased snow intensity, more days around 0°C	More winter maintenance for road and rail networks		X	
Disturbance of inland navigation due to low and high water	Diversification of transport means	X		
	Upgrade of canals	X		
	Reconsideration of river regulation measures and other adaptation measures	X		
	Rethinking of alternative ship construction	X		
General impacts	Research and development	X	X	X
	New planning norms and guidelines for road and railway construction	X	X	X

*) Southern Finland

Source: authors' compilation

5. Fiscal adaptation costs

5.1. Outline of methodology

This chapter combines the numerical adaptation costs extracted from the literature (see chapters 3 to 6 in PART II, and as a summary chapter 4 of this PART I) with the theoretical considerations (chapter 2). The objective is to provide a reasonable, theory-grounded best guess of public adaptation costs. Adaptation costs are a central component of any cost-benefit analysis, which serves as the relevant economic tool for adaptation decisions (section 2.1). According to the developed theoretical framework for adaptation in a non-global context, mitigation is given as exogenous here.

Impacts on the government's budget from adaptation consist of direct and indirect effects (or first- and second-round effects). Direct effects mainly affect the government's expenditure, and result from, for instance, public investments in adaptive infrastructure or subsidies for private adaptation measures. These expenditures are surely the most obvious and visible budgetary effects, although they do not need to be the highest. Many will think of rising expenditures, like additional investment in dyke construction or in transport infrastructure. At the same time, one can also think of declining expenditures, for example in the field of heating energy for public buildings or winter road maintenance. The direct net effect of adaptation is therefore difficult to predict theoretically, but the results of the literature review and the case studies suggest negative impacts on public budgets in Europe.

Indirect effects, in contrast, become relevant when adaptation (whether private or public) as a side effect changes the tax revenue. To highlight the potential importance of indirect budgetary effects, we take a brief look at the results of Bräuer et al. (2009), who analyse the budgetary repercussions of climate change in Germany. The authors conclude that the indirect effects on public budgets may amount to approximately 87% of the total effect. For the case of adaptation, the net budgetary impact of these second-round effects is not obvious. We disentangle the indirect effects in a brief discussion (Box 5.1). Owing to data availability, however, we focus on the direct budgetary effects of adaptation in the rest of this chapter.

Box 5.1: Indirect budgetary effects of adaptation

In economic theory, it is assumed that firms would adapt if and only if adaptation increases their profitability (see e.g. Mendelsohn 2000, OECD 2008). Compared with a scenario involving climate change but without adaptation, the simplifying assumption of efficient adaptation suggests a clearly positive impact on tax revenue. Yet taking timing, uncertainty and other sources of inefficiency into account, the net effects on the public budgets may also be negative. Short-term negative impacts may arise from adaptation measures that incur costs (and thereby reduce the taxable income) today, while the benefits may only be realised in the long run (Fankhauser et al. 1999). The uncertainty of future climate impacts and consequently of the effectiveness of adaptation yields a further risk that the costs exceed the benefits, even in the long run (Mendelsohn 2000, OECD 2008). Moreover, myopic behaviour on the part of firms and individuals, as well as financial constraints may hamper efficient adaptation processes. If these drawbacks reduce the firm's overall productivity, the tax revenue also tends to decline.

The supra-industry perspective may also become relevant. As firm resources are limited, funds that have been spent for any non-adaptive activity x must now be spent on adaptation (activity a). Effectively, demand shifts from the sector providing activity x to the sector providing a. Given different effective tax rates for different sectors, the tax revenue may change owing to a shift in production towards adaptation-oriented sectors (e.g. construction or manufacture). In other words, the sign of the indirect budgetary effects of autonomous adaptation hinges on the question of whether production in the adaptation-oriented sector a yields relatively higher or lower tax revenues than the sector x where demand declines.

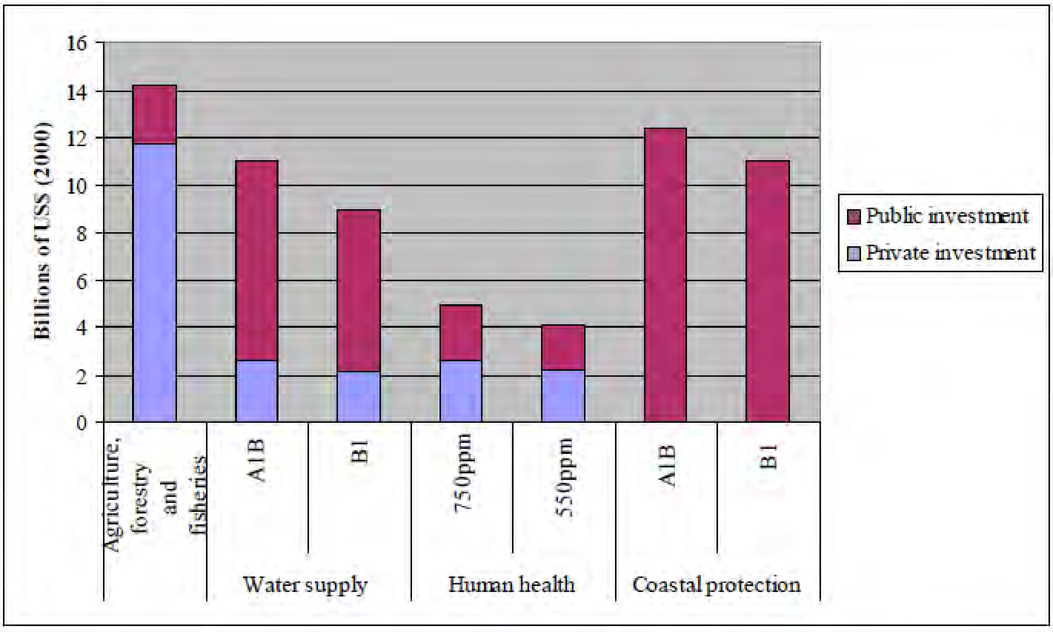
Eventually an adaptation-induced shift in production can also lead to changes in sectoral employment, such that labour demand follows the demand shift. This in turn can have positive or negative impacts on the government's social expenditures, depending on the sector-specific labour market situation.

Further indirect effects may rise in the context of open economies. A country with a relatively high degree of competitiveness in adaptation technologies will possibly gain from a global increase of adaptation demand, and probably achieve higher public revenues. In contrast, countries that import most of the adaptation technology and where adaptation demand crowds out domestic demand would feel additional pressure on their productivity and consequently public budgets.

Another aspect is the international dimension: an essential part of any binding international climate agreement, whenever it is accomplished, will be the payments of highly developed countries to developing countries.[21] Estimates of the financial needs for adaptation in developing countries range from $27 billion p.a. around 2030 (UNFCCC 2007, aggregated by Parry et al. 2009) to more than $100 billion p.a. between 2010 and 2050 (World Bank 2009). The latter figure translates in almost a doubling of current development aid, revealing the tremendous magnitude of the task. The Copenhagen accord commits developed countries to offering this level of support by 2020, starting in 2010 with $30 billion. It mentions that those funds are an aggregate of public and private financing, thus hinting at the need for reinforced instruments such as the Clean Development Mechanism set up by the Kyoto protocol, which creates incentives for private businesses to finance investments in developing countries. But a large share will need to be provided by public budgets. This additional burden will strain public budgets, besides the effects from domestic adaptation. Note that the indirect effects of exported adaptation technology may mitigate the negative impacts on the donor economies (Mendelsohn 2000 mentions this phenomenon with a negative connotation). That being said, we do not include these effects in our analysis, as they are highly uncertain and depend mainly on the outcome of the climate negotiation process, which is essentially a political issue. Furthermore, as soon as binding agreements are adopted, the additional burden should be relatively easy to foresee.

The subsequent sections focus on direct adaptation investments, disregarding indirect effects and international aspects. We base our analysis on an approach first used by the IMF (2008). The authors project the public adaptation investments in some of the impact sectors using absolute adaptation cost estimates by the UNFCCC (2007) and applying rough sector-specific ratios of public costs (see Figure 5.1).

Figure 5.1: Private and public adaptation investments (global perspective)



Notes: The A1 scenario makes the assumption of rapid economic growth and convergence among regions. The A1B scenario is like A1 balanced across all energy sources. The B1 scenario depicts a convergent world with

[21] The reasons highly developed countries should finance adaptation in other countries partly lie in international equity rationales and partly arise from considerations of future international migration and trade developments. They are, however, not the topic of this report. The point here is simply that payments will add to the budgetary burden in EU countries.

rapid development towards service and information economies. Ppm refers to parts per million atmospheric carbon concentration.

Sources: IMF (2008); absolute adaptation costs come from UNFCCC 2007; ratios are proposed by IMF staff.

We develop this method further by including more impact sectors and introducing theoretically and empirically grounded determinants for public shares in each impact sector, with references to the theoretical framework in chapter 2. We choose a sectoral approach because governmental intervention can be best described and reasoned in a sectoral context. We furthermore apply the proposed determinants of public adaptation involvement to the top-down estimates for various European aggregates.[22] The same procedure can also be used for data from the three case studies.

5.2. Governmental intervention in different sectors

5.2.1. Agriculture

The estimates in literature have a wide range. Fischer et al. (2007) propose adaptation costs for irrigation alone amounting to €161 to 966 million p.a. in Western Europe in 2030, based on different scenarios, with rising costs post-2030. Bosello et al. (2009) estimate a much higher amount of €6,274 million p.a. for irrigation in Western Europe in the 2060s, just to name two extremes of the estimates. The case for governmental intervention, especially long-run structural changes, is underpinned by a variety of reasons. The first one to mention is the interaction between mitigation and adaptation. Certain adaptation measures may not be conducive to mitigation. Changing cultivation or livestock production techniques can lead to increasing GHG emissions. Economic efficiency would require a price being set on these emissions. A task of the government is to set frameworks and support adaptation strategies, in which the interactions are taken into account. The second reason for governmental intervention is to facilitate autonomous adaptation. The long-term adaptation measures show that the distribution of information and provision of a regulatory framework are the basis for private adaptation. This primarily includes knowledge about the effectiveness of adaptation measures and the expected impacts of climate change, as well as regulation of property rights and tenancy rules. Another reason for the government to intervene is equity. Adaptation has the potential to become very costly. Especially in countries where agricultural production is a large share of GDP, the adaptation costs could lead to negative effects on national or regional welfare. Also in the EU, where the economic importance of agricultural production is relatively low, there are differences among the member states. Countries with a lower per capita income, particularly new member states, show a higher dependency on agriculture than richer member states. Moreover, the impacts of climate change may benefit northern Europe while the southern member states are rather disadvantaged. Therefore intergovernmental transfers could help to balance the inequalities. Equity aspects also play a role within a country. The provision of emergency relief after extreme weather events by the government can be justified if farmers cannot afford proper insurance or the possible damages are not insurable at all.

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[22] Due to a lack of detailed data, we do not use the adaptation costs in the cross-sectoral impact field of ‘extreme weather events’. Admittedly, according to the adaptation cost matrix the highest adaptation costs may be expected there. But as there is no information available in the literature on which actors are affected by these costs and how exactly the costs arise, to date it has not been possible to determine the specific degree of effects on the government. Therefore the methodology used cannot be applied here.

The attempt to quantify the share of public expenditures on climate change adaptation in the agricultural sector is challenging. The majority of adaptation is autonomous. However, taking into account the planned adaptation, equity and security of supply aspects the expenditures are not entirely private. According to global estimations by the IMF (2008), the public share of adaptation expenditures within agriculture, forestry and fishery is around 15%, which can be justified by our theoretical considerations. This translates into absolute values of approximately €940 million p.a. solely for irrigation in Western Europe in the 2060s and €25 to 145 million p.a. in 2030 (again, solely for irrigation in Western Europe), based on different scenarios with rising costs post-2030.

5.2.2. Forestry

There are no specific data available about adaptation costs in the European forestry sector, so cost estimations and public expenditures cannot be numerically presented. Adaptation to the impacts of climate change in forestry mainly involves precautionary measures, such as the implementation of early warning systems, diversification of tree types and transition to other tree types. The central characteristic of adaptation measures in the forest sector is their long anticipatory time horizon. Long growing periods and the relative impossibility of retrofitting call for early action. The government acts as a social planner, providing knowledge transfers and research on issues as well as early warning systems. Furthermore, it takes the positive externalities of forests into account. These are for instance their CO_2 compensation capacities and their positive effects on regional microclimates, on biodiversity and on local recreation. Finally, the state itself is an owner of forests. The average share of total public ownership weighted by the production size is around 40% (own calculations based on Eurostat data). The shares in the different member states vary largely, such that a European mean value (even a weighted one) has to be interpreted with caution. This ownership approach can only serve as a first assessment of the public shares of adaptation expenditures. Together with states actions as a social planner, the actual share of total adaptation costs is somewhat higher than the ownership share. We propose a share applicable in Europe of around 45%.

5.2.3. Flood protection

Summarised, the cost estimates for flood protection measures in Europe amount to annual costs of €281 to 4,022 million for coastal protection in the EU, assuming different scenarios regarding sea level rise. Flood protection is a prime example of a public good. It resembles a form of joint adaptation, which has to be provided by collective action and in most cases will be organised and financed by a governmental entity. Translated into budgetary effects, that means most (if not all) of the adaptation costs will be borne by public budgets. Assuming a public share of 100% of flood protection costs may be slightly overestimated, however, because some EU member states (e.g. the UK and some Scandinavian countries) share the financial burden of flood protection with private actors.

The phenomenon that in some countries the local municipalities and even private landowners are responsible for financing coastal protection is interesting. It rests on the theory that besides global public goods so-called ‘local public goods’ exist. Local public goods only benefit some of the population. According to the theory of fiscal federalism (Oates 1999), it is efficient to assign the task of providing the local public good to the local authorities and taxpayers. For example, the costs and benefits from the construction of a dyke providing shelter to one city only accrue to municipal authorities and local taxpayers. This view of local public goods can be altered by negative externalities. In the case of local public goods, if their provision in one locality has a negative impact on other localities, uncoordinated actions by the localities will be socially inefficient.[23] In that case planning by a central government can ensure the socially efficient outcome.[24] The fact that even private landowners are made responsible for the financing of coastal protection may be reasoned by the low population density in most of the areas where this regulation can be found. If a specific dyke gives shelter to only one specific plot of land, the theory of local public goods would suggest putting the financing responsibility solely on the private landowner. Whether this regulation is also conceivable and feasible in other countries or areas with a higher coastal population density, is nonetheless very questionable. Under the circumstances of a higher population density (which means that there are several beneficiaries of a coastal protection measure), the collective action dilemma explained in PART I, section 2.2 remains.

After a review of the different funding regulations for coastal protection in the EU, we propose a public share of around 98%. That means the yearly public costs amount to €275 million in 2050 (for the EU) and €3,950 million in the 2060s (in Western Europe), depending on the underlying sea-level rise scenarios and assumptions. Given the substantial planned protection of the coast of the Netherlands the lower estimate for 2050 would be underestimated by approximately €2 billion.

5.2.4. Water supply

Adaptation costs in the impact field of water supply are expected to be €251 to 875 million in European OECD countries in 2030 (UNFCCC 2007) and €2,655 million p.a. in Western Europe in the 2060s (Bosello et al. 2009). Governmental intervention in the water supply sector is mainly based on two rationales: first, networks for sewage or water supply create increasing returns to scale and thereby cause market failure. The second is grounded in security-of-supply rationales. Obviously, water is an indispensible good for any economy of the world, which gives a strong case for governments to ensure the secure supply even under new conditions like climate change. For these reasons one can also expect direct governmental action to ensure drinking water supply in times of extreme droughts. Based on these considerations, we propose a public share of adaptation investment costs in the water supply field. Bräuer et al. (2009) assume a share of 25% for Germany, which seems reasonable since great parts of the investment costs are refinanced by usage fees, so ultimately by private actors. Still, public resources are still strained to some extent, for the abovementioned reasons of governmental intervention. Owing to a lack of detailed data for other EU member states, we assume the same portion to be realistic for the entire EU. The budgetary effects of adaptation in water supply and sewage systems will therefore add up to approximately €60 to 220 million p.a. in European OECD countries in 2030, and €665 million p.a. in Western Europe in the 2060s, based on different scenarios.

5.2.5. Health

In Western Europe, global warming could reduce total health expenditure by €563 million p.a. in 2060-2065, as the net result of adverse temperature effects and a decrease of

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[23] For instance, the building of dykes by a local authority in order to prevent river floods upstream may increase the risk of floods down-stream. In a non-cooperative environment, an upstream decision-maker will not take into account the negative externality for the downstream region generated by the dyke.

[24] For a further analysis of the theory of fiscal federalism, see Oates (1999), and with regard to adaptation to climate change, Dannenberg et al. (forthcoming).

expenditures for cold-related diseases (Bosello et al. 2009). In contrast, in Eastern Europe and the former Soviet Union adaptation of the health infrastructure could incur costs in the same order of magnitude in the first half of the century (World Bank 2009). A great part of the adaptation related to health is taken autonomously, for example in cooling homes and other behavioural changes. Collective adaptation tends to entail higher costs, being characterised by, for example, the provision of infrastructure, the dissemination of information, research and the monitoring of climate change-related diseases. The free market normally does not provide these goods, so these measures are mainly taken by the government and hence they involve public expenditures. Furthermore, when it comes to the provision of equal access to health care equity aspects play a role. On the one hand, the geographical distribution of medical care – which means the number and distribution of physicians across the country – is necessary to ensure equal access. On the other hand, guaranteeing that the services are affordable for everyone is essential under equity considerations. Because of the lack of data about specific adaptation expenditures in the health sector we use the current public share of total health care expenditures as a proxy. The EU-wide public share weighted by total expenditures was around 77% in 2005 and 2006. Taking into account an ageing society and growing requests for public infrastructure (e.g. heat-wave early warning systems), we propose a slightly higher public share of around 80%. This means that public budgets in Western Europe are estimated to fall by €450 million p.a. in the 2060s (Bosello et al. 2009), whereas other literature suggests additional public costs in Eastern Europe of the same amount in 2010-2050 (World Bank 2009).

5.2.6. Energy supply

The energy sector plays a central role in the climate change debate. But most of the discussion concerns mitigation in the energy sector. For adaptation, the literature suggests the following cost estimates: €563 million p.a. in the 2060s for undefined adaptation measures in Western Europe up to €1 billion in 2050 for cooling measures in thermal power plants in the EU27 plus Norway and Switzerland. Energy networks have always been regulated in some way because of network externalities. In the EU member states, the regulation itself is currently characterised by two slightly different strategies. In both alternatives the network is operated by a transmission system operator (TSO), which is separated from the generating companies (legally, by management or by ownership, see Sioshansi and Pfaffenberger 2006). TSOs may be private companies, regulated by a governmental authority (e.g. the Federal Network Agency in Germany), which sets price ceilings or return-on-investment ceilings. Moreover, TSOs are legally committed to secure an enduring energy supply. In the other alternative, TSOs are publicly owned companies, as is the case in most EU member states. In both cases TSOs should charge prices that ensure a cost-effective operation of the network, without any cross-subsidies. That means that if budgetary costs rise due to some adaptation of energy networks by state-owned TSOs, these costs should be reflected by higher transmission fees ultimately charged to the consumer. Thus, the end consumers should be affected and not the public purse, regardless of the ownership structure of the TSO.

Another situation arises in the context of security-of-supply considerations. No government would accept an enduring breakdown of power networks or even the danger of such an event. Budgetary effects may possibly arise if TSOs require very high price increases for consumers in order to invest in the necessary grid infrastructure, prompting the state to intervene. For ensuring the security of supply, power plants also have to tackle the problem of insufficient cooling water supply. If governments have a strong interest in the security of supply during large-scale heat waves, they might implement policies ensuring that power generators care for these events, which would possibly accrue expenses.

Equity-related issues may affect the fiscal adaptation costs in the energy sector as well. Vertical equity considerations may call for greater public support of citizens in need if the energy retail prices rise because of climate adaptation. To sum up these aspects of governmental intervention in energy supply, we recognise the significant regulatory interventions, but put the overall budgetary costs of adaptation on the energy supply side at not more than 5% of the total adaptation costs. Note that this guess incorporates the assumption of no cross-subsidising of the regular network operation. Combining this share with the available cost estimates, we conclude the following fiscal costs of adaptation in the energy supply sector: €28 million p.a. in the 2060s in Western Europe and around €50 million in 2050 in the EU27 plus Norway and Switzerland.

5.2.7. Energy demand

Adaptation to climate change (i.e. warming) is likely to result in more demand for cooling and less demand for heating energy. Although this behaviour seems trivial and it could be interpreted as a form of impact, it fulfils the criteria of a *reactive adaptation* measure, as defined by the IPCC (IPCC 2007). Therefore, it is included in this analysis. Tol (2002) estimates a net effect of additional energy costs adding up to over €6 billion p.a. in European OECD countries (Tol 2002). Another study suggests net savings from decreased heating needs of around €28 billion in 2050 in the total EU27 plus Norway and Switzerland (Jochem and Schade 2009). The wide range of these figures highlights the immense uncertainty of available adaptation cost estimates. The various results cannot solely be explained by differences in time horizons, spatial coverage and underlying scenarios; there remains a large amount of scientific and technological uncertainty. The effects are relatively high, compared with other adaptation costs, and vary strongly across regions and among different studies. Budgetary repercussions from this adaptation behaviour may occur to the extent that buildings are owned and maintained (heated and cooled) by governmental entities. Thus, the public share of the effect of demand adjustment hinges on the share of public buildings in the total building stock. Bräuer et al. (2009) use a ratio of public buildings over the stock of total buildings of 10% for Germany. An analysis of Eurostat statistics on fixed assets shows that the German value may serve as an approximation for the EU average (weighted by the total fixed assets), although the differences within Europe are high. For the aggregate of all EU member states, a ratio of 10-15% seems reasonable, which means that 10-15% of the demand adjustment effect will affect the public budgets. Expressed in figures, this means that in the total EU energy costs may rise by €600 million to 1 billion p.a. due to the cooling of public buildings (Tol 2002). In contrast, based on the study by Jochem and Schade (2009), there will be energy cost savings for the public purse amounting to €2.7 to 4.2 billion in 2050. These values, however, entail a high degree of uncertainty with regard to the technological development within the 21st century.

5.2.8. Tourism

For adaptation measures in the tourism sector, only rare information on adaptation costs is available (moreover, no estimates are available for costs in the total EU). The (direct) budgetary costs of adaptation by the tourism industry depend on the level of governmental intervention in the predominantly private economy. Most adaptation options practised at present constitute private goods. The benefits as well as costs of new tourism opportunities, of the prolongation of the main season and of the exploration of new tourist sites mainly accrue to the (private) decision-makers. Hence, there is no large-scale market failure in the sense of joint adaptation (see section 2.2).

Externalities may occur from private adaptation measures, such as artificial snow-making. The operation of snow-making facilities consumes water and electricity. Although the externalities from electricity production are at least partly internalised through the EU ETS (see section 2.1), externalities from unusually high water consumption may still exist. The use of natural water reservoirs in the vulnerable Alpine region is highly controversial, and the consequences and long-term total costs (including environmental damages) are not fully foreseen. So the economic theory of market failure may justify governmental intervention to restrict excessive use of artificial snow-making, if the total costs are not priced into the production costs. But the budgetary effects of these interventions seem to be low.

Although most of the adaptation options are characterised as private goods, there are also measures that have strong common-good properties and therefore call for collective action. The most evident is the promotion of regional tourism. Regional marketing may become important in relation to adaptation, as some regions may gain recreational attractiveness, but also need to be promoted properly. Other regions may wish to highlight specific features and offers that are attractive even if snowfall is not assured. There are private initiatives by regional tourism associations for regional marketing, but generally they face problems related to the voluntary participation in these projects. An individual provider of tourism services cannot be excluded from the benefits of a marketing campaign for a specific region, even if that provider does not participate in funding. Therefore there may be the case for the provision of regional marketing by the government (on the basis of governmental provision of joint adaptation, see section 2.2).

Alongside negative externalities and public goods there are further aspects that actually serve as arguments for governmental intervention. Tourist regions are frequently located in marginal locations (e.g. Upper Bavaria, north-eastern Germany, Alpine Italy, Wales, Islands in the Mediterranean Sea and coastal regions). The economies of these remote regions tend not to be broadly diversified and they largely depend on local tourist industries, not least in terms of local employment opportunities. If regional (or national) governments value the local economic importance of the tourism sector to a sufficient extent, they can decide to support it even if there are no market failures. A possible trigger for this could be different tax systems in neighbouring countries as is the case in the Alpine region. Recently, the German federal government has reduced the value added tax rates for hotel stays. One of the declared reasons was the threatened competitiveness of German hotels compared with Austrian ones. So at the bottom line of these measures are equity considerations (see section 2.3). First, the need for equal conditions among competitors can necessitate governmental intervention. Second, economically weaker regions need protection from hardships. These aspects also exist without climate change, but they may serve as justifications for supportive governmental intervention in the adaptation processes.

Whether these equity-motivated interventions are advisable or not for policy-makers is not evaluated in this document. We just point out that motivations for government intervention in the absence of market failure exist and that they have their own reasoning in equity considerations. These equity arguments notwithstanding, interventions in free markets may possibly hamper a necessary structural change in the economy and thereby cause inefficiencies. Consequently, the total costs of adaptation borne by society may increase. This is part of the classical trade-off between equity and efficiency, as is analysed in connection with adaptation in Dannenberg et al. (forthcoming). Economists can contribute to this debate mainly by illustrating the consequences of alternative policies (with regard to distributional and efficiency effects) and highlighting the possible inconsistencies of policy instruments. In the end, the actual decision is a political one, bringing together the particular interests of various groups in society.

Quantifying this support in financial terms is not easy. The example of snow-making facilities provides an insight into what can be expected as fiscal costs. The Bavarian state government has announced the co-financing of investment costs in regions that are not eligible for co-funding by the Federal Ministry of Economics and Technology, to provide the possibility of public co-funding to each tourist region in Bavaria. The share funded by the public purse will presumably be in the range of 10-20% of the cost.[25]

Aggregating all private and public adaptation measures, the proposal of a single share of public costs in the tourism industry cannot be more than a first attempt. Great portions of adaptation measures are private, without any direct budgetary effects. The provision of joint adaptation may incur public costs, albeit to a limited amount. Interventions for equity considerations may increase these expenditures to some extent. Summing up, we propose that in future analyses of adaptation costs in the tourism sector the share of public costs in the total adaptation costs be set at around 15%.

5.2.9. Transport

In the transport sector, cost estimates range from €3 to 6 billion for the adaptation of infrastructure in the EU27 plus Norway and Switzerland in 2050 (Jochem and Schade 2009). Besides the impacts on traffic safety, the infrastructure is the most critical issue in the transport sector. Governmental intervention in the transport sector is mainly justified by market failure issues. Road networks that are free of charge and open to the public constitute a public good. While there are roads and other transport infrastructure co-financed by user fees, the bulk of transport networks in Europe (in terms of km) are still free of charge and mostly financed by the public sector. Furthermore, privately owned roads and railways exist. Unfortunately, data on ownership structures are not available at the EU level. Knowledge about the private and public ownerships of the networks would provide a basis for an attempt to estimate the government share of adaptation expenditures. Nevertheless, the share is expected to be high (we assume more than 90%), owing to the high level of public engagement in the transport infrastructure.

Even if there are possibilities to exclude users from road services and thereby introduce user fees, governmental intervention may occur owing to security of supply and equity rationales (sections 2.3 and 2.4). If user fee-based road networks fail to provide an adequate quantity (e.g. the distribution of airports or railway stations across the country) and quality (e.g. paved roads) of infrastructure, the government may step in to ensure the access to transport services for each region and each needy member of society. Thereby the public share of total adaptation investments may rise beyond the actual share of the public network infrastructure. But with user fees and privately owned infrastructure, the upper limit is less than 100% for the public share. This results in a range of between 90% and less than 100% for the public

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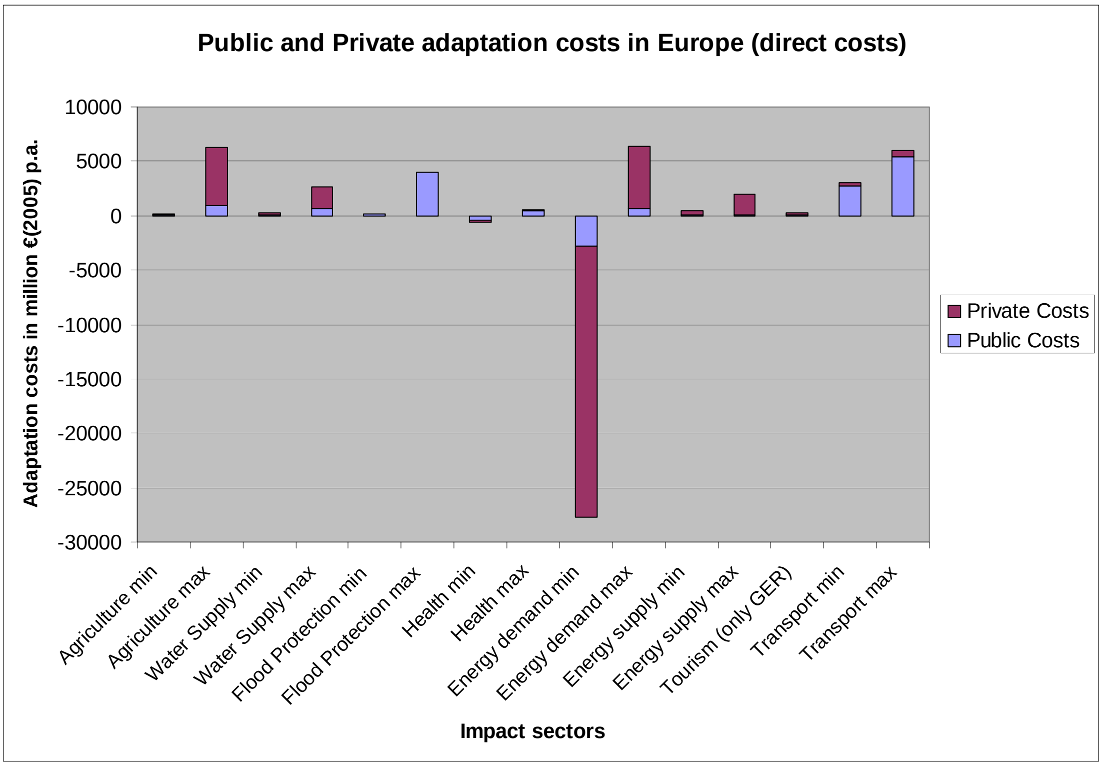
[25] Co-financing shares funded by the Federal Ministry of Economics and Technology for tourism investments in economically weak regions.

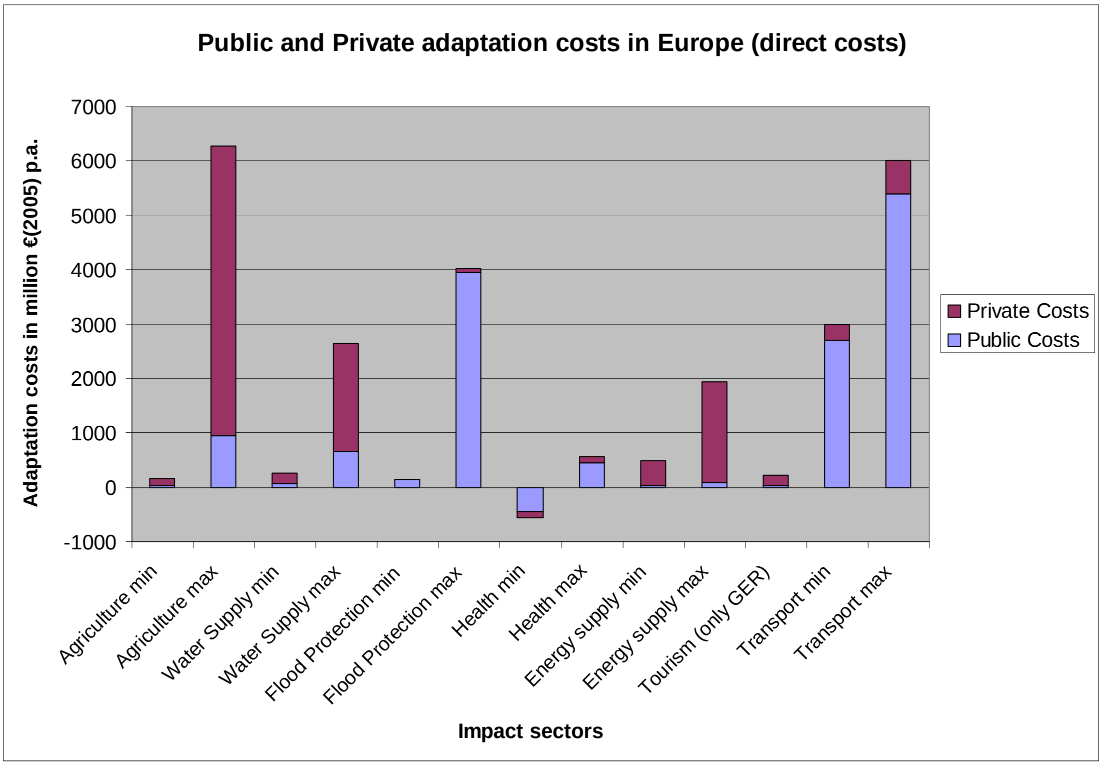
share in the transport sector. Admittedly this is a rough best guess, which can only serve as a first attempt to project the actual public burden. An assumption of a 95% public share (as the middle of the assumed range) would translate into absolute budgetary costs of approximately €2.9 to 5.7 billion for infrastructure in the EU27 plus Norway and Switzerland in 2050.

5.3. Conclusions: Direct fiscal adaptation costs in Europe

In the previous sections we provided theory- and data-based guesses of the direct fiscal costs of climate change adaptation in the most important impact sectors. The analysis of the fiscal ramifications of the direct adaptation costs provides initial insight into the fiscal implications of adaptation and combines the theoretical background and the results from the literature review and case studies (chapters 2 to 6 in PART II). As noted earlier, the cross-sectoral impacts of extreme weather events could not be integrated into this kind of analysis, due to the lack of data availability (for an explanation see footnote 22). This has to be kept in mind in the discussion of results. Still, the findings highlight certain fields in which the impacts are associated with relatively high public costs, compared with others where the total adaptation costs may be high, but the public burden is expectedly low. Figure 5.2 depicts the public burden in the different impact sectors graphically. The comparability of the bars is limited, as the values are derived from various studies (incorporating different methodologies, models, assumptions, time horizons and climate scenarios). Therefore we have included the lowest and the highest expected costs for each sector, such that a wide range of possible outcomes is illustrated. Detailed information on the underlying scenarios, time horizons and assumptions can be found in the adaptation cost matrix in chapter 7 of PART II. The upper part of the figure shows the projected adaptation costs, divided into public and private costs, as they appear in the matrix. Owing to very high negative costs in energy demand, the other bars are hardly visible. That is why we have included the lower part of the figure, where energy demand is dropped to improve the visibility of the other sectors.

Figure 5.2: Direct public and private adaptation costs (upper part including energy demand, lower part without energy demand)





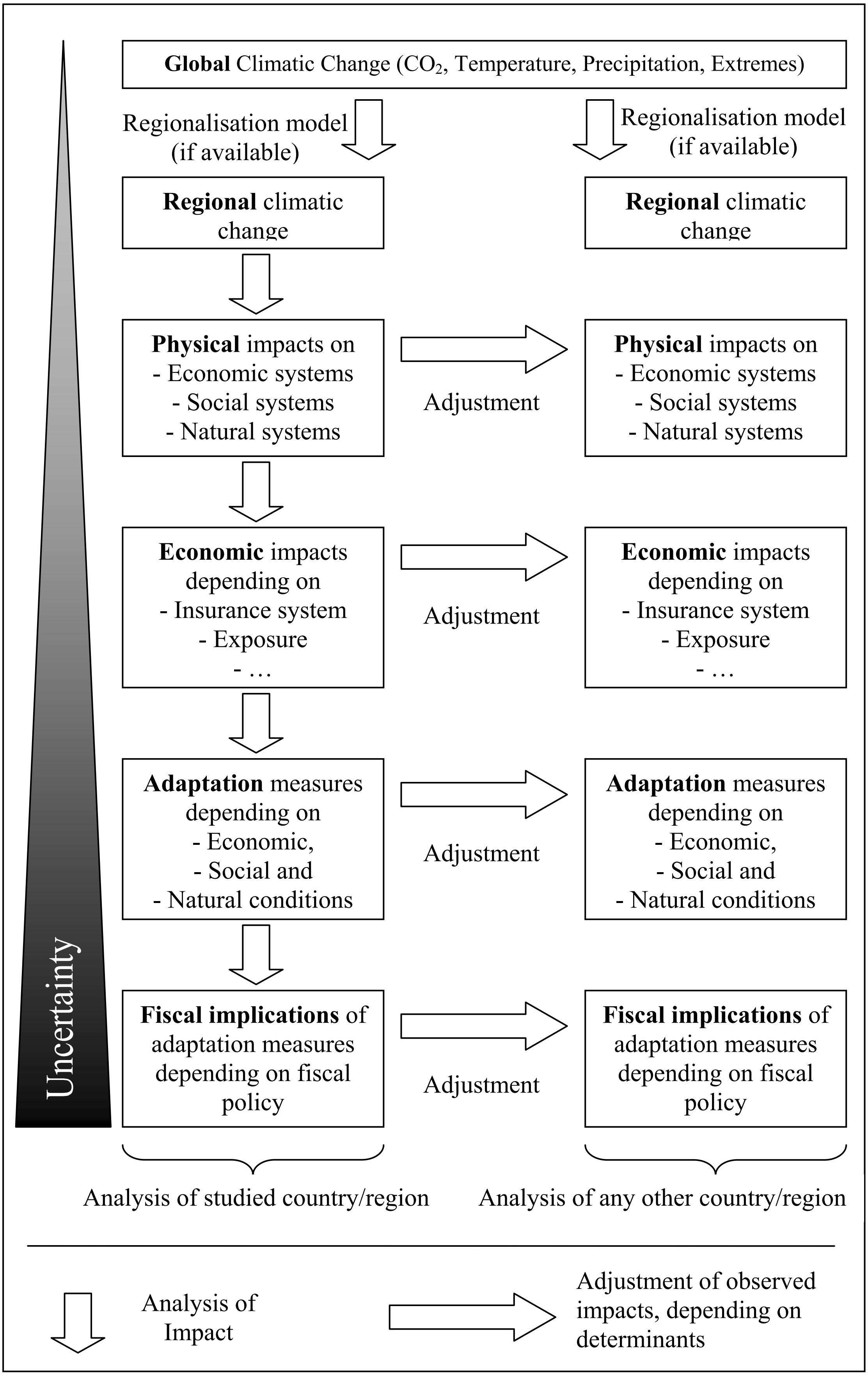
The direct budgetary costs of adaptation are comparably high for transport infrastructure and flood protection. In other impact sectors (e.g. agriculture) adaptation gives rise to higher costs, but these are mainly financed by private actors. Direct effects due to energy demand are highly variable over regions (Jochem and Schade 2009, Eskeland and Mideksa 2009), so the figure for the total EU (savings of up to €28 billion p.a.) has to be interpreted with caution. While northern European countries may significantly gain from saved heating costs, there is a possibility of net public costs owing to cooling needs in Mediterranean countries. All cost projections (including energy demand, transport and flood protection) are subject to a high degree of uncertainty with regard to climatic change scenarios and future socio-economic development. For instance, the budgetary effect of flood adaptation is estimated to be in the range of €137 million p.a. (EC12 without East Germany, by 2100) to €3,950 million p.a. (Western Europe, 2060s), depending on the underlying assumptions and scenarios. Given the Dutch proposals by the Delta Commission (Deltacommissie 2008), the lower estimates are most likely unrealistic. The Delta Commission's recommendations estimate a yearly investment from 2010 of €1.5 to 2 billion to defend the Netherlands from sea surges. Regarding the budgetary effects of adaptation of the health sector, even the sign is not sure. Yet, although the uncertainty ranges are still very high, this analysis can serve as a first, theory-grounded and reasonable insight into what magnitudes of budgetary effects will be triggered by which sectors.

5.4. Transferring case study results to other member states

The methodology outlined can be used to derive a best guess of the direct budgetary effects of adaptation not only for Europe overall, but also for the three countries examined in the case studies, albeit with an even lower degree of literature availability, reliability and certainty. Still, after gaining initial insight into the direct fiscal costs of adaptation investments in Germany, Finland and Italy, the next step could be to transfer the results to other EU member states. This procedure is highly desirable since it would allow a reasonable estimation of the total EU fiscal implications of adaptation, without actually relying on the extensive work of 27 in-depth country case studies. Moreover, the multitude of empty cells of the matrix in chapter 7 of PART II highlights the potential benefits of applying research results to different contexts.

To perform this transfer reasonably and effectively, a number of aspects have to be considered. Figure 5.3 illustrates the discussion in the next section, which explores the different stages of an adaptation cost assessment by transferring case study results. The figure clarifies which steps are necessary to come to well-grounded estimates of fiscal adaptation costs. On the left-hand side the impact sequence is illustrated for a given country analysed in a case study (comparable to the case studies in PART II); on the right-hand side the same sequence is illustrated for any other country to which the results shall be transferred. Then each of the single steps is explained in more detail.

Figure 5.3: Schematic illustration of multiple stages of a transfer of fiscal adaptation costs



The estimates and results from the literature review and case studies summarised in chapter 4 based on the analysis in PART II are influenced by a multitude of determinants at different levels. The first impact stage is global climate change, quantified for instance in global CO_2 emissions, radiative forcing and average temperature increases. This stage yields uncertainty, which is not negligible, but by nature does not cause any differences within countries or regions.

The next stage looks at changes in the regional climate. Regionalised climate models, like WETTREG or REMO for Germany and FINSKEN for Finland respectively, use dynamic or statistical methods to translate global climate models into regional climate impacts. These models partly provide a very high resolution of expected temperature and precipitation; however, thereby they are also an additional source of uncertainty. For transferring economic climate impacts, the first step therefore would be to apply a regionalised climate model for the target country, in order to determine the regional characteristics of climate change. In cases where a regional climate model is not available one has to revert to global climate projections, which can provide only a fraction of detail. A transfer of regionalisation results is not feasible as regionalisation models by nature depend strongly on site-specific conditions.

Subsequently, a transfer of the physical impacts on the economic, social and natural systems can be attempted. Obviously, these systems differ substantially from country to country. For example, an increase of the mean temperature by 2°C can have significantly different outcomes in the agricultural sector, depending on many physical features, such as current mean temperature, topography and hydrologic parameters. While transferring physical impacts, one has to keep these differences in mind and – if possible – adjust the expected impact to the parameters of the new location. This procedure is more practical and less error-prone if two countries are chosen that are comparable in terms of their climatic parameters, topographies and human activities. In reality, it is very likely that no country is the perfect image of another, even when the analysis is restricted to the physical conditions.

The transfer becomes even more problematic at the stage of economic impacts. The translation of physical into economic impacts hinges on various parameters of the social and economic systems. For example, a river flood may incur huge direct public costs in one country, as the government may feel the need to support many uninsured flood-affected people. In a neighbouring country where the private insurance sector has a higher market penetration, the same flood may strain insurance budgets instead of public budgets. The division of the flood costs would be totally different – in the first case they would have to be borne by all taxpayers, whereas in the second case by private insurance companies and consequently by the collectivity of their customers. Another point is even more relevant – the exposure of economic systems to climate risks differs within countries. A further example illustrates this: while the physical impacts of a 1 m rise in sea level may be the same in two regions with comparable orographical characteristics (i.e. the flooded land area would be the same, in the situation of identical protection levels), the economic impacts are highly dependent on the capital accumulation and population density in the flooded area. Transferring economic impacts thus requires particularly careful consideration of the respective levels of exposure. The complexity of that task is at least as high as in benefit transfer studies.

To analyse the fiscal burden of adaptation to climate change, the next stage would be the transfer of adaptation measures. The nature and intensity of optimal adaptation depends on its expected effectiveness and the expected climate impacts (see section 2.1). That is, the main economic indicators of adaptation requirements are expected climate impacts and adaptation costs (and their marginal values). A simple transfer on the basis of comparable economic impacts can be misleading, however, since differences in natural, social and economic systems may make other adaptation techniques more efficient. For instance, in one country the relocation of residential or industrial areas may be an accepted governmental intervention, while in others it would give rise to massive public protests and would not find any acceptance in public opinion.

Furthermore, countries differ in terms of their values and norms with regard to governmental interference. Whereas in some countries governmental intervention through laws and regulations may be widespread and commonly acknowledged as an appropriate means of policy, in other countries the government is much more prone to use market-based instruments. In those countries strong governmental regulation may be more difficult to implement and enforce. Although the validity of the economic theory of market failure and governmental intervention is not affected by these differences in government perception, it may be put in practice in various ways and with different accentuations.

Another difference can arise from divergent political systems. Even assuming that both countries in the comparison are democratic regimes, the concrete system can differ considerably. The degree of federalism is an important variable in this respect. As an example, in Germany a compulsory insurance scheme for flood damages could not be realised, partly because of unresolved federalism issues (Schwarze and Wagner 2006). Adaptation solutions will most likely look different in federal and centralistic political systems.

In addition to the cultural and political differences that may render some adaptation techniques unfeasible in certain countries, differences in adaptive capacities also have to be tackled. It may be the case that all the physical and economic impacts are comparable, but the efficient adaptation techniques are simply not affordable for one country while they are employed in another.

Finally, even if concrete adaptation costs can be evaluated by transferring case study results, the question remains open about how much of the total adaptation costs have to be borne by the public budgets. The share of public involvement in investment funding is by no means identical. Coastal protection may serve as a first example. Whereas in most EU member countries the public sector is in charge of planning, organising and financing the complete coastal protection measures, in Scandinavian countries and the UK private actors (landowners or other beneficiaries) also have to bear some of the financial burden (Policy Research Corporation 2009). Another illustration is given by the expenditures made in the adaptation of the health sector. Given that additional health expenditures caused by climate change are allocated to private and public budgets in the same ratio as current health expenditures, one can expect great differences in the fiscal burden of health adaptation. (The ratio ranges from 90.6% of total health expenditure in Luxembourg to 42.5% in Greece, with 2006 data, according to the WHO.) These differences, which are actually differences in fiscal policy, have to be studied carefully and taken into account when a transfer of fiscal adaptation costs is attempted.

In all these stages, from global climate change to the fiscal implications of adaptation, the uncertainty of the analysis increases. Of course this does not mean that the uncertainty in the first stage, i.e. global climate change, can be interpreted as low. Indeed, the global climate projections with all their scenarios involve a large degree of uncertainty. Any other analysis based on these projections increases the uncertainty of the outcomes. This is illustrated by the triangle on the left-hand side of Figure 5.3. Consequently, one has to trade the knowledge gain of transferring case study results for the growing uncertainty of the results. The efforts needed for a reasonable and comprehensive transfer study should not be underestimated either, considering all the aspects mentioned above.

Finally, we want to mention an interesting alternative to single country case studies. The case of Italy shows clearly that countries can comprise very different climatic zones and thus climate impacts, which makes it difficult to come to country-wide conclusions or specify policy measures. Instead, studies focusing on coherent vulnerable regions (e.g. the Alps, the North Sea or the Mediterranean) have the potential to yield detailed and reasonable impact estimates, and possibly to result in well-grounded policy advice. Of course, the abovementioned cross-country problems will arise here, too. The socio-economic conditions of Upper Bavaria in Germany and Tyrol in Alpine Italy are very different indeed, which will challenge this kind of study as well. In the case of the Mediterranean, as a vulnerable region the complexity increases because many of the countries bordering the Mediterranean Sea are not even EU member states. So at the stage of socio-economic impacts (and all the following stages of a fiscal effects analysis), cross-country studies face particular problems. Eventually, a stronger combination of vulnerable-site studies for the evaluation of physical impacts and national studies for estimating the resulting socio-economic impacts and policy measures is a promising strategy for the future.

6. Knowledge gaps

This chapter provides a description of the main knowledge gaps derived from the literature review, the case studies and the matrix in PART II. For this purpose, the coverage of the five aspects – time horizon, scenarios, methods, sectors and regions/countries – have been taken into account.

The *time horizon* of the different studies refers to past data or a future perspective. Furthermore, just a point in time or a period of time can be covered. There are also studies where no time horizon is mentioned (e.g. Liebermann and Zimmermann 2000). The majority of the literature concentrates on ‘point in time’ predictions, where a single study can deal with several points in time in the future. The focus of the existing literature is on a medium-term perspective, which means future predictions for the 2030s to the 2080s. Estimations for the near future are lacking. The maximum time frame is the year 2100. There is only one exception with a longer time perspective, up to the year 2155 (de Bruin et al. 2009). As also stressed in the literature review (PART II, section 2), the long-term effects should not be neglected in future research.

Regarding *scenarios*, the core of the studies is based on the IPCC scenarios, where mainly the A2[26] scenario is used. In addition to the IPCC socio-economic scenarios, explicit temperature and sea-level rise scenarios are used. Estimates for the best as well as worst case scenarios are currently neglected. For example, a melting of the Greenland ice sheet (improbable, but

[26] The A2 scenario depicts a heterogeneous world, in which increases in global population, economic growth and technological change are fragmented and slower than in other scenarios.

possible) would result in a sea level rise of several meters – a scenario not looked at in terms of adaptation costs.

There are several completely different *methods* for estimating the fiscal implications of climate change adaptation. The most frequently used approaches are estimates or simulations based on a literature review. Case studies are also commonly used and consulted as part of the methodology. Besides these approaches, computable general equilibrium models are often used. They are based on different models such as the DIVA model (Costa et al. 2009) or the WIAGEM model (Kemfert 2007). Econometric analysis (Lis and Nickel 2009) based on past data and surveys are rare. Especially with progress in the collection of data, more econometric analysis might be provided in the future. In the literature review in PART II (section 2.1), the difference between top-down and bottom-up approaches and their advantages and disadvantages are explained. Accordingly, mainly top-down analyses are performed.

The case studies and the matrix concentrate on nine different topics or *sectors*: agriculture, water supply, inland floods, coastal floods, health, tourism, energy, transport and weather extremes. These are not covered equally. The topic of 'coastal floods' is the one examined the most, followed by the agricultural sector. Some literature can also be found on the health and energy sectors. Yet transport and water supply are only scarcely covered, while for the tourism sector almost no literature seems to be available. The reason might be that this sector is hardly aggregated as one economic sector, but is mostly treated as a cross-sectional industry and therefore specific data are rare. In addition, the topic of weather extremes, which overlaps with other issues and affects various sectors, lacks specific data. Not only is the coverage of the various subjects insufficient but also the coverage of the different time perspectives and alternate scenarios for each one is unsatisfactory.

The *regional/country* perspective shows significant differences. Among the case studies (PART II) Germany is the most studied country followed by Finland, with the least coverage given to Italy. One reason for this sparse literature backing of the Italian case study is that data are sometimes only available in native languages. In the literature review (PART II) it is pointed out that the estimates for the European level are not as extensive as for the global level. In addition, for Europe different regional separations were found in the literature: Europe, EU27 (plus Norway and Switzerland), Western Europe, Eastern Europe (plus the former Soviet Union) and the European OECD. The most thoroughly covered and therefore most often discussed region is Western Europe. Especially for Eastern Europe estimates are missing. Moreover, cross-country analyses are scarce and are limited to specific regions (e.g. the Mediterranean).

The main knowledge gaps that need addressing and research according to our analysis are the following ones:

- There is still a lack of data with regard to regional differences in climate change impacts, not only *between* countries but also *within* countries.
- The existing literature has focused mainly on autonomous and reactive adaptation. Future research should therefore aim at including planned and anticipative adaptation.
- There is a lack of short-term (up to 2050) and long-term perspectives (from 2100 onwards). Research on the near future might help the planning and design of appropriate policy responses.

- There is a need to integrate more thorough sensitivity analyses into studies. There is also a need to show a range of possibilities with the best and worst case scenarios and their probability of occurrence.
- More econometric analyses should be performed as data availability improves.
- Comprehensive overviews of climate change impacts and adaptation options exist only for a few sectors. Other sectors, for example ecosystems and landscapes, demand more attention.
- Some impacts – such as non-market ones, those from extreme weather events or low-probability events – are often excluded and should be included in future research.
- Cross-sectional data (e.g. weather extremes) estimates are needed.
- Eastern European countries have been neglected so far and need to be studied more thoroughly. Many face serious economic and fiscal challenges.
- Cross-country analysis should be provided.
- The indirect effects on the wider economy need to be researched more thoroughly. In this regard, macroeconomic models dealing with direct and indirect effects should play an important role in future research.
- The costs of adaptation are rarely considered and estimated. There is a need to research further the indirect economic and fiscal effects of climate change.

7. Summary and conclusions

Climate change will have an effect on the European Union. The repercussions will be regionally varied, with impacts on several sectors of the economy. Yet current knowledge about their size, their timing and the precise form of the impacts is very limited. For policy-makers, this is a very problematic situation, in particular concerning decisions that may affect infrastructures and the behaviour of individuals in the long term. The member states' public finances are also strained, and thus the fiscal consequences are important to estimate and the worst case scenarios need to be avoided.

The fiscal consequences have until now rarely been studied rigorously, and there is a lack of understanding about the origin and magnitude of the fiscal effects. The literature review and the three case studies for Italy, Germany and Finland in PART II attempt to determine the causes and magnitude of the fiscal implications and present the knowledge gaps in this field. The lack of relevant research is clearly identified in the reviews performed and graphically presented in a matrix in PART II. The matrix plainly identifies the large gaps in our understanding of the potential economic implications of climate change.

It has been possible to estimate to a certain extent the direct costs to the state budget of gradual climate change (approximately €5 to 15 billion a year), but the far more serious impacts from extreme events and indirect effects through ramifications on the economy are missing. Based on just one estimation for Germany by Bräuer et al. (2009), the indirect effects of climate change on public costs will amount to 87% of all public costs. Thus there is a clear signal that yearly average costs can treble to around €60 billion a year, i.e. 1% of total public expenditure for the EU, and not be evenly distributed territorially. For extreme events, there are very few indications of the expected costs, but studies by Costa et al. (2009), the IMF (2008) and the Dutch Deltacommissie (2008) on the protection of the Dutch coast give some flavour of the serious costs of damages from flood events in the event of insufficient adaptation.

In the face of rising fiscal pressures caused by population ageing, the negative economic and fiscal costs need to be minimised. This study also reveals a number of areas where planned adaptation actions can intervene to reduce the fiscal implications and increase welfare. Many of these actions represent win-win situations and are beneficial without climate change, while increasing the resilience against negative climate impacts in the future.

To identify the areas of action, this study presents a list of the main fiscal drivers behind direct and indirect costs:

1) the degree of exposure to gradual and extreme climate events;
2) the level of protection already in place in areas at risk, i.e. preparedness;
3) the state's liability for damages;
4) the potential and impacts of autonomous adaptation and remedial actions;
5) the cross-border effects of climate change; and
6) the fiscal capacity of the member states and the role of the EU.

There has not yet been any study that satisfactorily addresses the way these factors affect the state budget and particularly its stability. This study offers a first attempt at classifying the fiscal risks. From the case studies and other literature reviews, it is evident that the fiscal consequences are not negligible. A number of predicted climate changes and extreme events could severely impair the fiscal stability of some member states.

In general, the gradual changes caused by climate change are considered manageable from the point of view of direct budgetary costs. But in relation to the costs of extreme events and related indirect effects on growth and thus government revenues, the impacts are not necessarily manageable. Furthermore, the indirect effects of gradual climate change and consequences in other countries can also threaten fiscal stability. A few impacts have been identified as having especially strong, negative fiscal implications. These are primarily related to the risks of floods due to rises in sea levels, increases in sea surges and changes in river flows. In the case of river floods alone, the annual costs of maintaining the necessary protective infrastructure and reacting to damages from extreme events has been calculated to exceed 1% of GDP in several member states. This being an average, the cost in any given specific year could be much higher.

To mitigate the economic as well as fiscal impacts, the study has in the following recommendations:

- Select the right level of protection using appropriate cost-benefit analysis tools.
- Invest in research and development.
- Provide a high level of public information.
- Limit the state's liability through innovative public–private partnerships with the insurance industry.
- Adopt appropriate regulations on land use and on the use of other natural resources.

- Use appropriate mixtures of legal and fiscal instruments to guide autonomous adaptation.
- Reinforce coordinated action across Europe.
- Ensure that appropriate assistance is provided to countries whose internal fiscal resources are insufficient to undertake the necessary adaptation measures or react to catastrophic events.

It is clear that to be able to address the issues presented here, there is a need to improve the level of knowledge on climate impacts using bottom-up studies, such as those performed in PART II, with the aim of devising cost-effective and efficient planned adaptation actions, while taking into account the findings from the theoretical framework. The knowledge gaps are very wide while the few studies undertaken use very different assumptions, which make it difficult to compare them and even more so to aggregate their results. One need that has been identified is for different regions – especially those that can influence each other through their adaptation actions – to coordinate their responses and to use the same working assumptions. At present, even regions within the same country use diverse impact assumptions.

Of course planned adaptation should not only be directed at averting the negative welfare effects and budgetary costs caused by climate change, but also policy adjustments may be needed to take advantage of new opportunities created by climate change. While some land may need to be taken out of use because of drought and flood risks, other regions can be opened to exploitation for the opposite reasons. It is thus important that research on climate impacts and varying conditions is deepened. This study shows that the knowledge gaps are large and while implementation of initial adaptation policies can start today, many require more detailed knowledge of regional impacts.

According to our analysis, research on the economic and fiscal impacts is very scarce and where it exists it is not sufficiently well developed. We list a large number of weaknesses and needs. Generally there is an absence of proper analysis with a unified methodology across regions and countries. Studies lack appropriate sensitivity analyses and econometric studies are scarce, with studies often concentrating on average impacts. Extreme events and increased weather variability are often ignored, while positive impacts and best-case scenarios are absent. The focus of studies is mainly on the direct costs, but the much higher indirect costs are often neglected. The timescales applied by the analyses tend to make the studies difficult to use for any policy design. Many countries have not undertaken any studies on climate impacts.

Thus, more bottom-up studies are required to understand the risks, opportunities, needs and potential at the national, regional or local levels and thus determine the appropriate actions with some level of confidence. With the increasing realisation that there is a need to develop adaptation strategies today, it is important that policy-relevant background research is properly undertaken. A methodological baseline allowing for cross-regional comparisons and coordinated action across the EU is also highly recommended. Guidelines could be developed by the JRC. Studies could then be financed by EU R&D funding.

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THE FISCAL IMPLICATIONS OF CLIMATE CHANGE ADAPTATION

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FINAL REPORT

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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

[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

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.

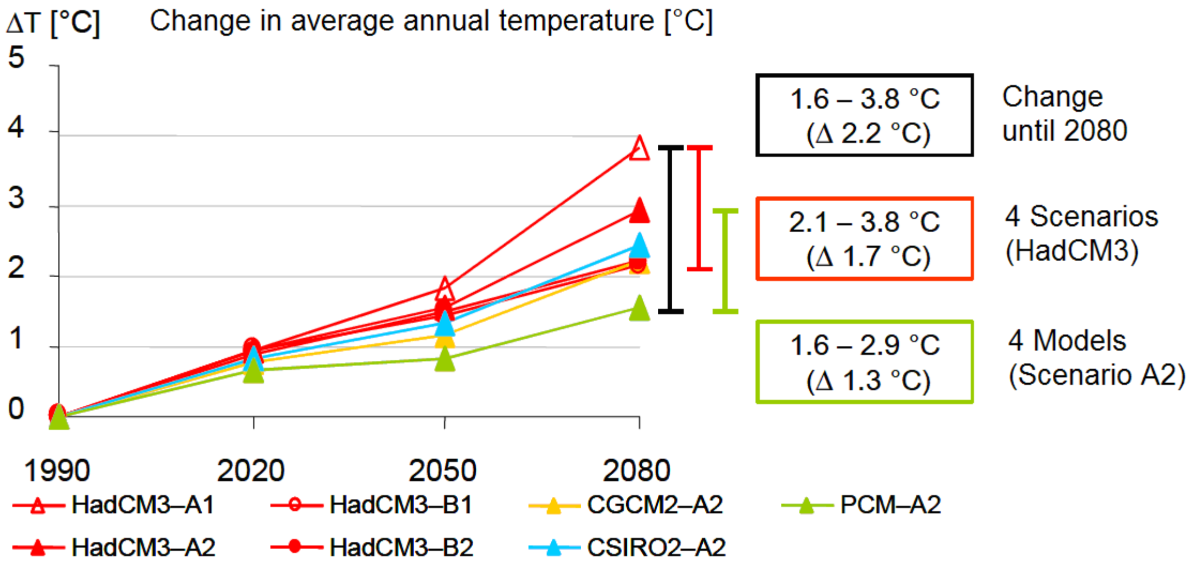
As a next step, Global Climate Models are regionalised in order to take a more differentiated look at climate development in Germany. This is necessary for Central Europe, in particular, since it is often placed in a transition zone in Global Climate Models, i.e. the consequences of a changing climate 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

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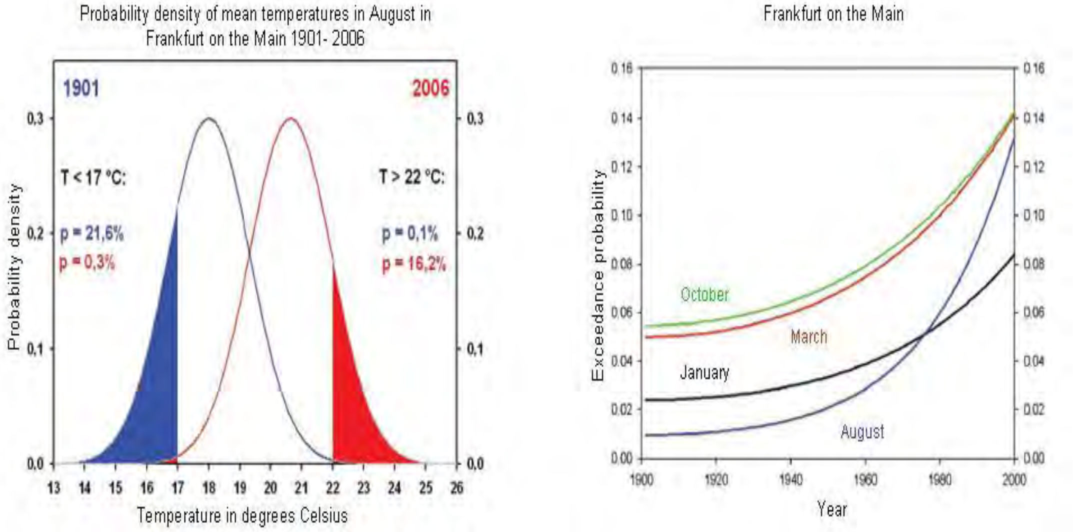
[3] Orography means the study of average relief and height structures of land.

[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.

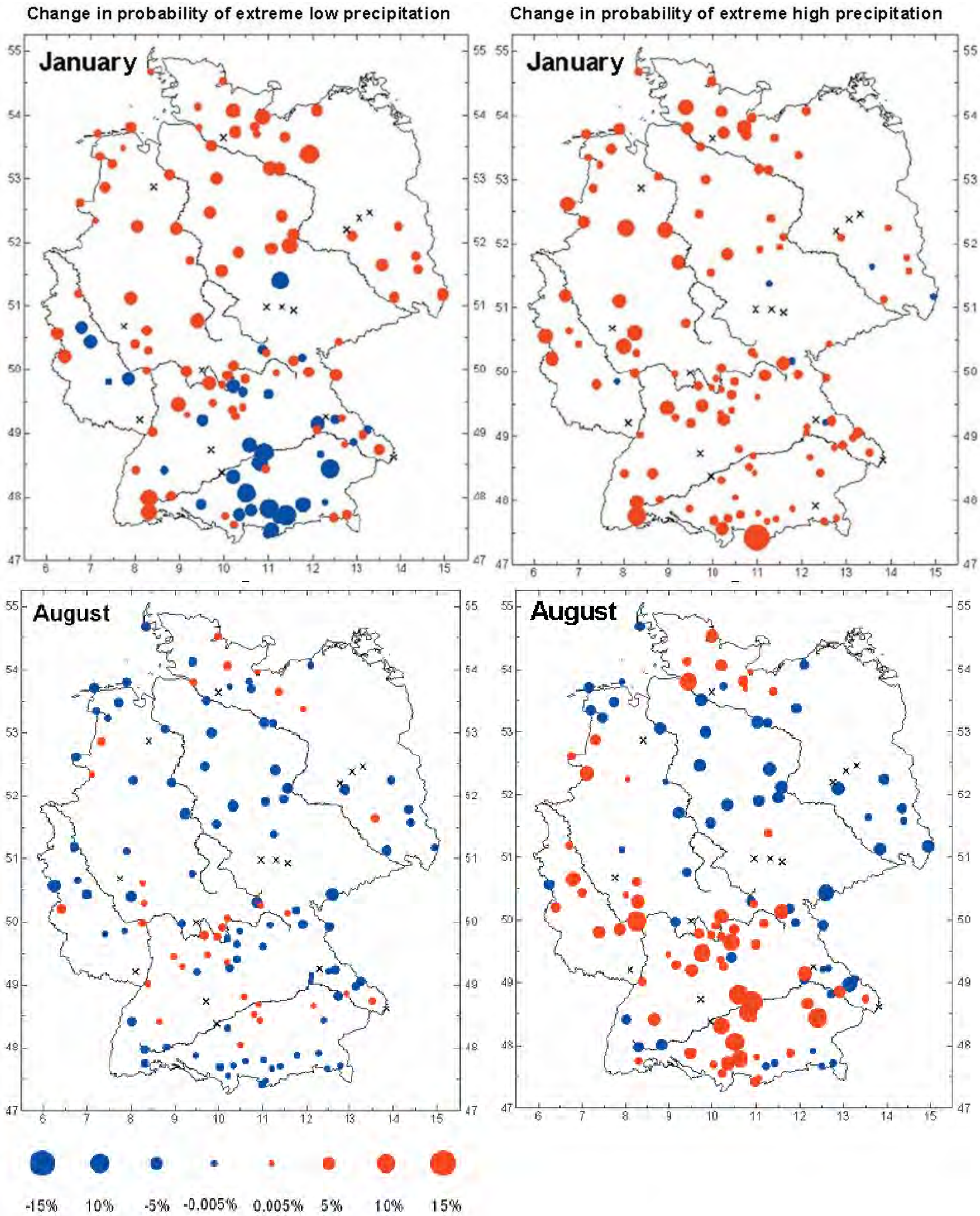
Despite the clear shift towards warmer temperatures with peak values in summer, no clear tendency to an increase in extreme temperature events (cold and heat waves) may be detected for the last century (UBA EWE).

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).

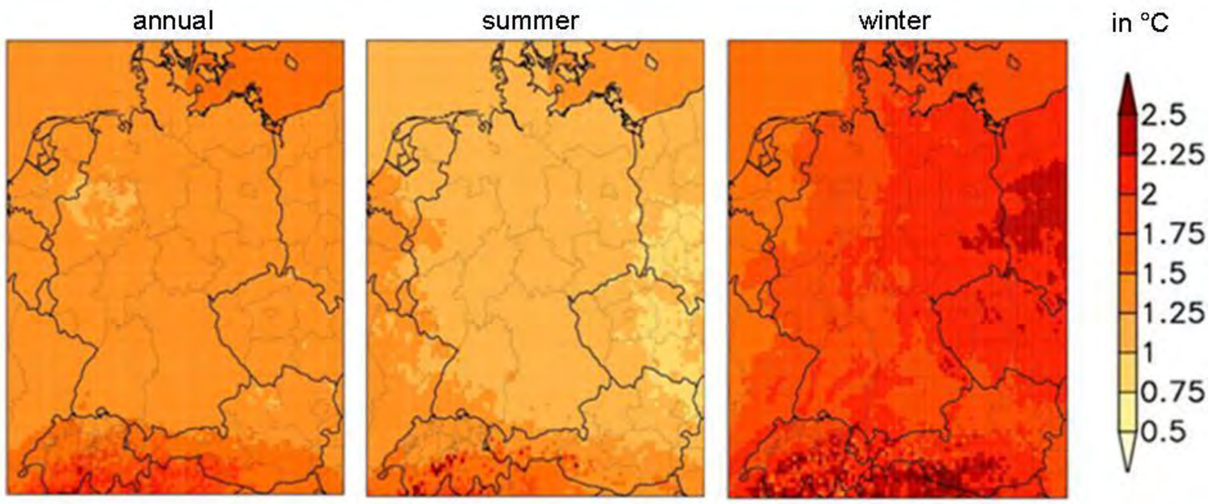
4.4.2. Climate change in the future

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

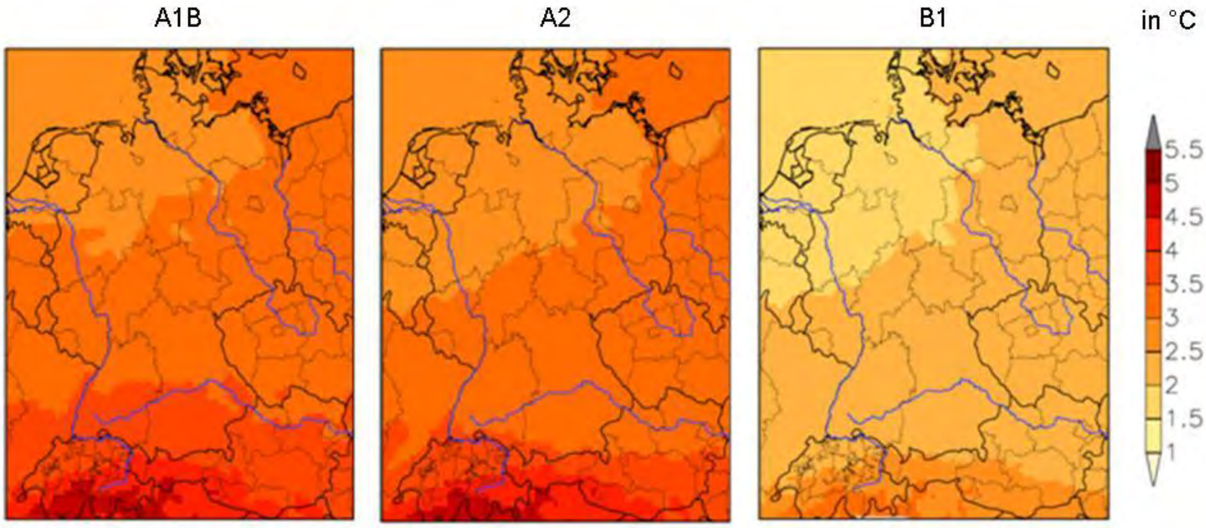
The climate scenarios are calculated with a resolution of 10km x 10km. Comparing the average of the period 2031-2060 with the average of the period 1971-2000 (scenario A1B), a relatively homogeneous annual temperature increase throughout Germany with approximately 1.25 to 1.5°C is expected (see Figure 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.

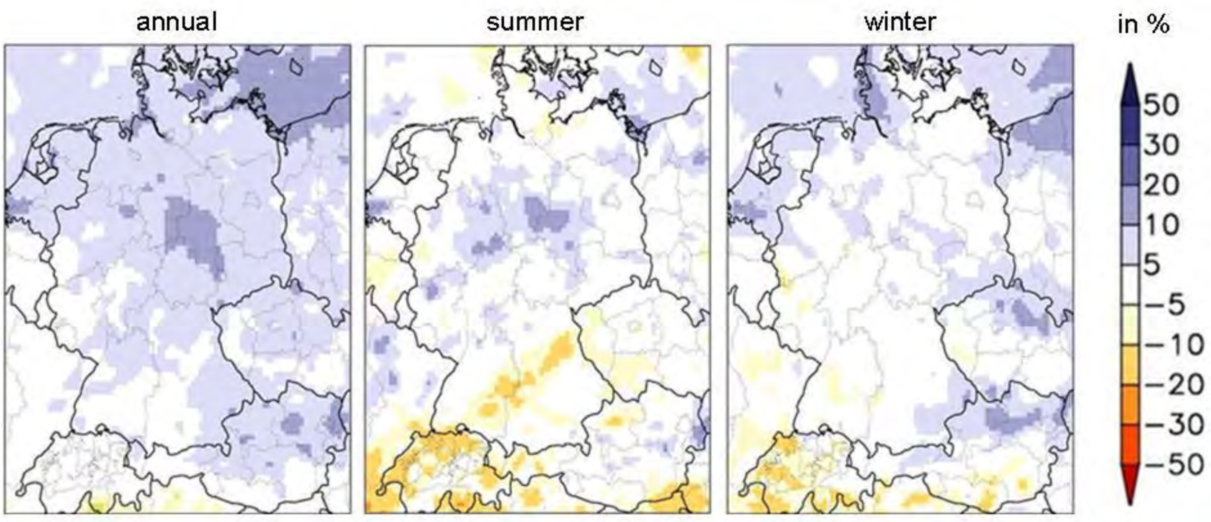


4.4.2.2. Precipitation change

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.

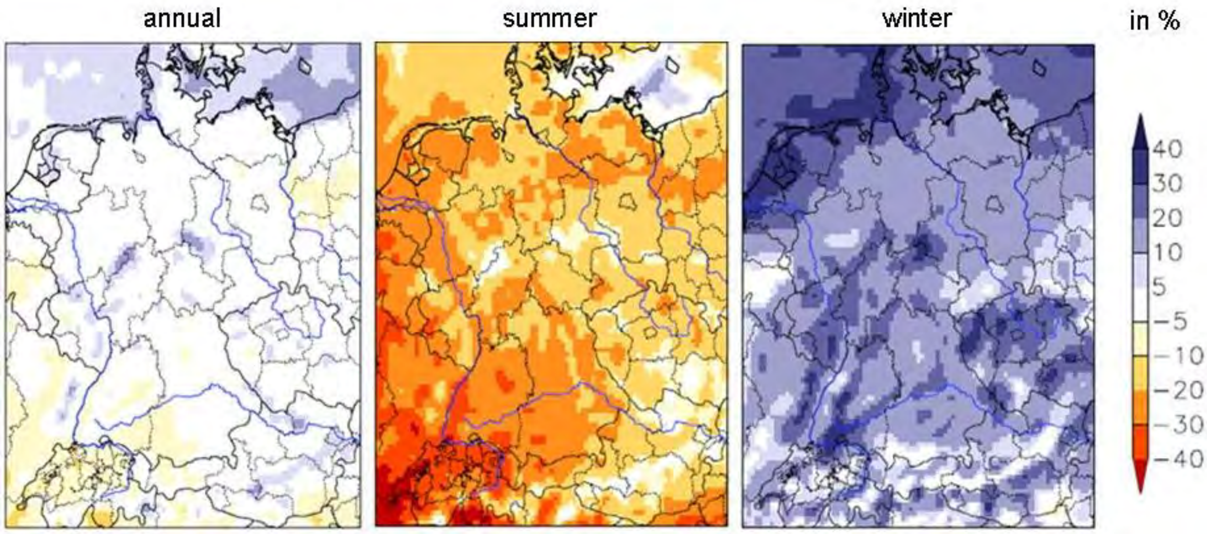
The picture changes significantly if seasonal patterns are considered. A shift of precipitation from summer to winter is estimated for all scenarios for the period after 2050. Besides, an increase in autumn and spring precipitation is projected until 2100. As shown in Figure 8, the highest decrease in 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).

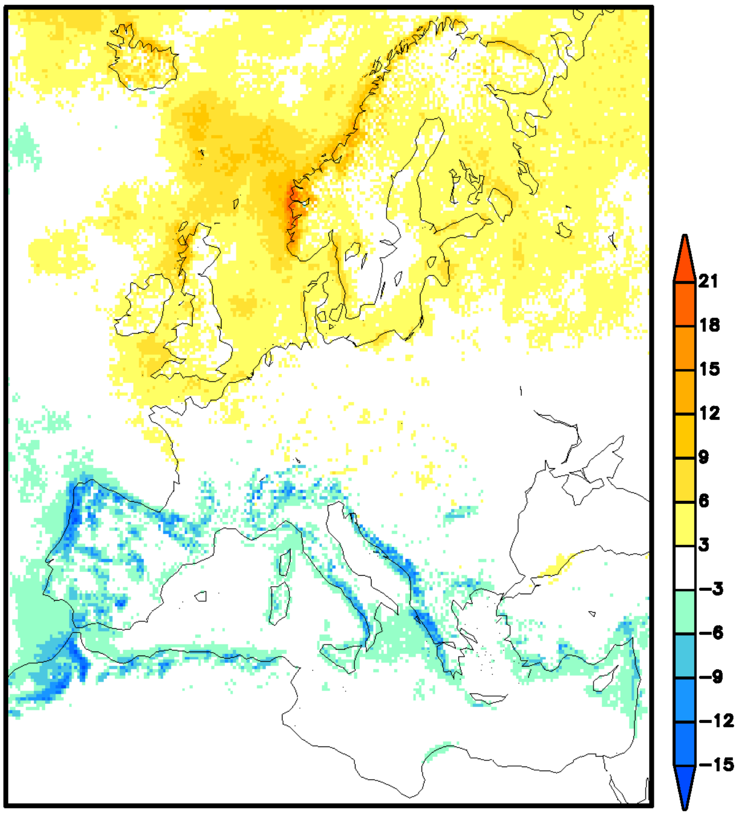
Since the studies are currently in process, further results concerning the probability of extreme weather events are likely to come. So far a significant change in windstorm and heavy rainfall events has not been simulated. Concerning droughts, a certain shortening of maximum drought periods in a year 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.

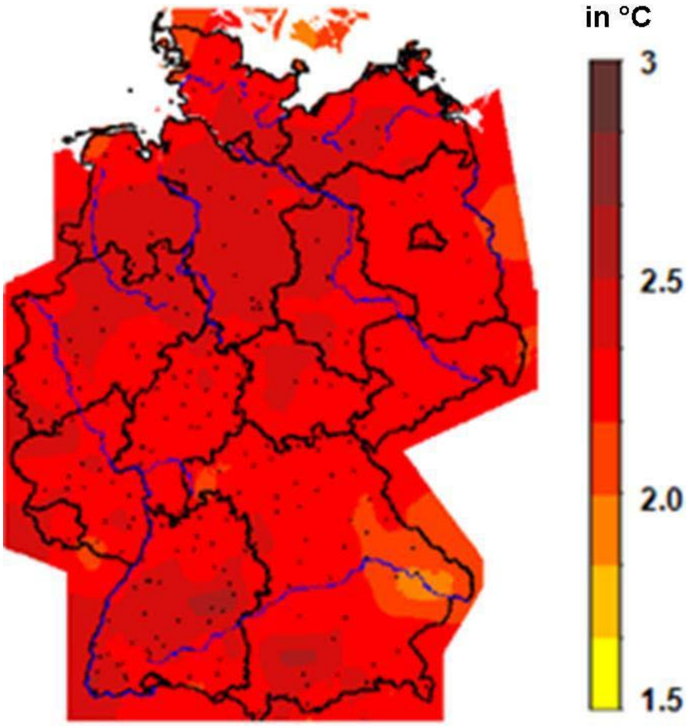
Figure 9: Changes in the number of days with heavy precipitation in Europe under IPCC scenario A1B, calculated using the regionalisation model CLM. Source: Böhm 2008.



4.4.2.4. A short presentation of WETTREG-results

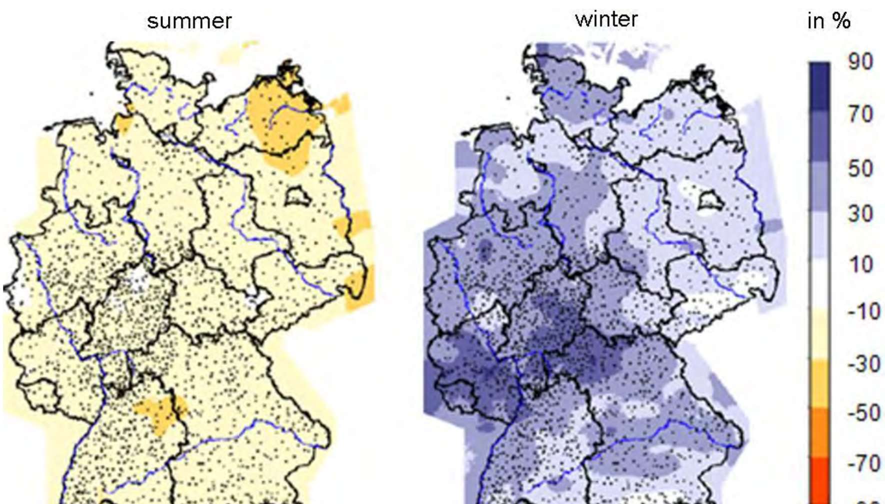
Like Remo, WETTREG also identifies a significant increase in air temperature. It calculates an increase of 2.3°C on average over the whole of Germany assuming the A1B scenario. Scenario B1 calculates an increase of 1.8°C. Compared to the REMO results, WETTREG shows different regional patterns until 2100, 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.

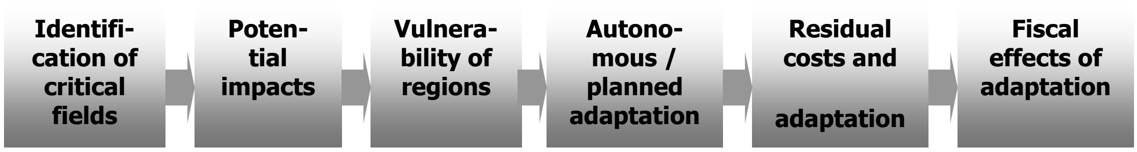
[6] Characteristic days are specified by the following criteria: Ice days are defined as days per year with maximum temperatures ≤0°C; frost days as days with minimal temperatures ≤0°C; summer days as days with maximal temperatures ≥25°C; heat days with maximal temperatures ≥30°C; tropical nights as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

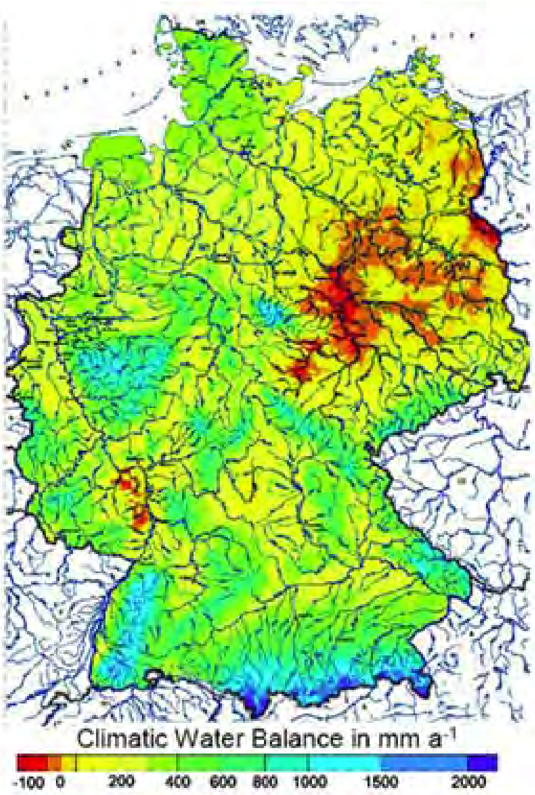
Water surfaces (rivers, natural lakes and water reservoirs) account for 2.2% of Germany's total surface. 11.7% of the surface is classified as drinking water protection area and is subject to restrictions of use in order to protect existing water resources. The water availability is closely connected 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

[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

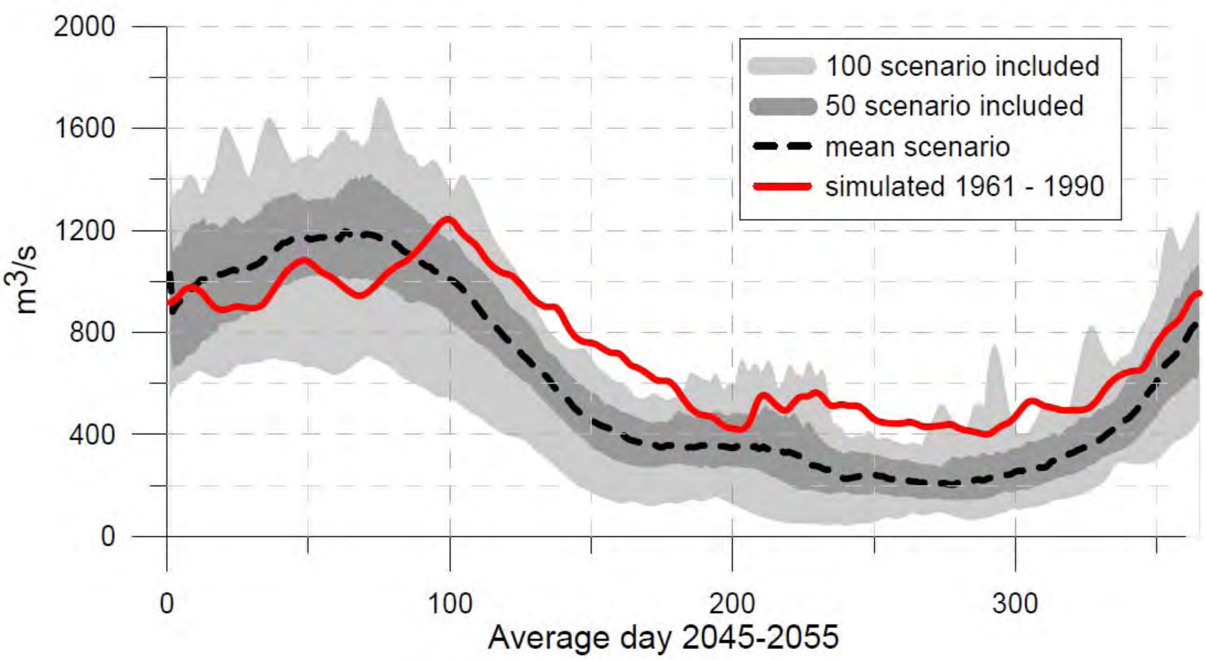
The changes of precipitation discussed in section 4.4.2 lead to a spatially and quantitatively redistributed pattern of water availability. Besides the changes of sub terrestrial water reservoirs which will not be considered here, this leads to changes in river drainage regimes and run-off rates. Models[9] 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

[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).

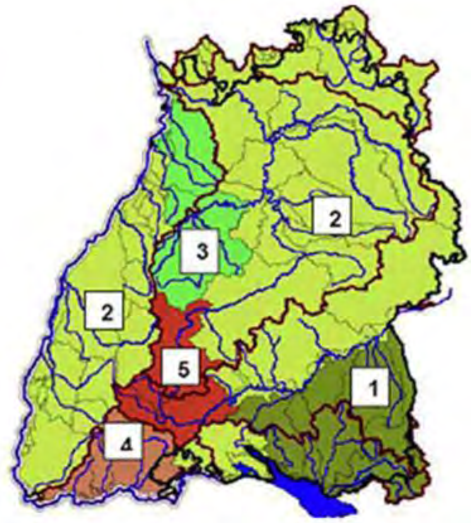
Public authorities which plan precautionary flood prevention measures will have to tackle one further problem mentioned in Part I in section 2.2 (part on "Joint adaptation"). Dikes, levees and other constructed inland flood protection in up-river communities will mostly interfere with the flood risk 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.

[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.

[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

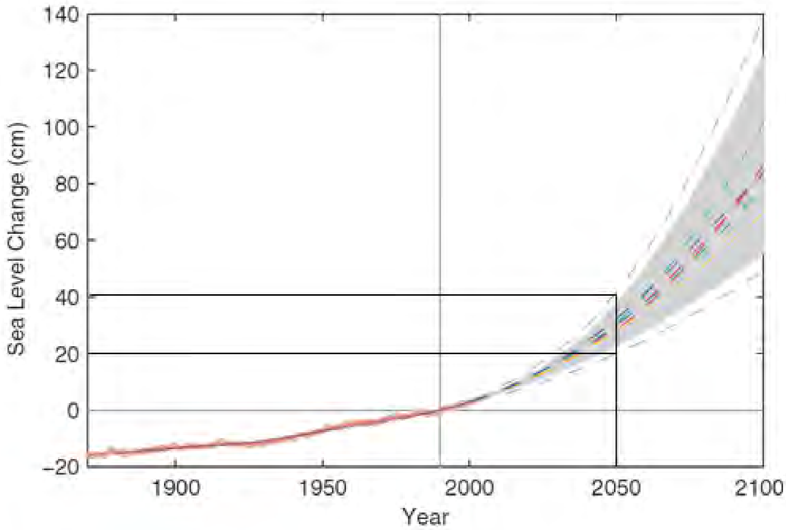
Germany coastlines extend along both the North Sea and the Baltic Sea. The North Sea coast has a length of approx. 1,590 km and the Baltic Sea coast a length of approx. 2,110 km, making a sum of 3,700 km. Since approx. 70% of the North Sea coast and 55% of the Baltic Sea coast are threatened by denudation 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).

[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.

[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.

[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

[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

[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.

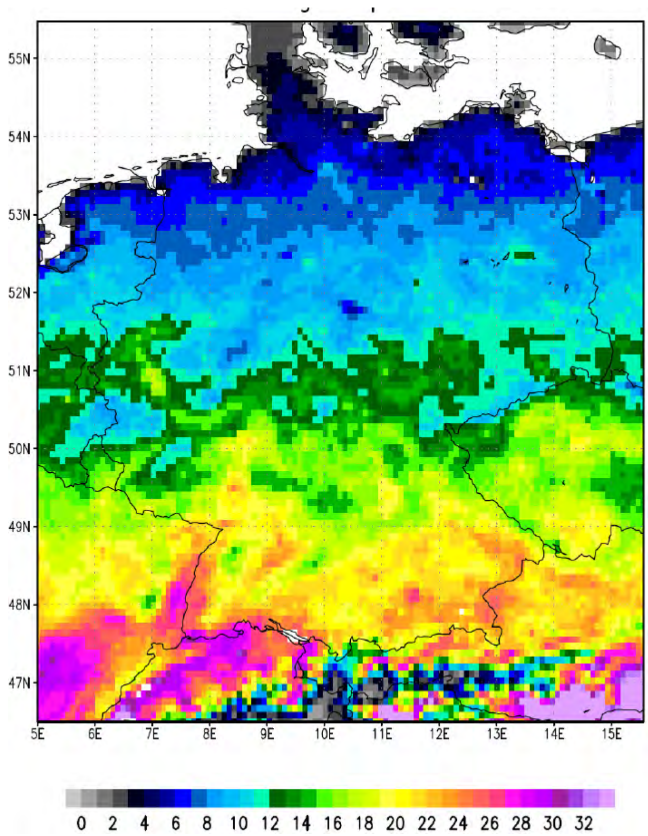
Vector-borne diseases are the most threatening indirect impact on human health in Germany. Studies undertaken in Sweden and the Czech Republic come to the conclusion that Lyme borreliosis and tickborne-encephalitis have already spread into higher latitudes and altitudes (UBA 2005). Therefore this development 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	

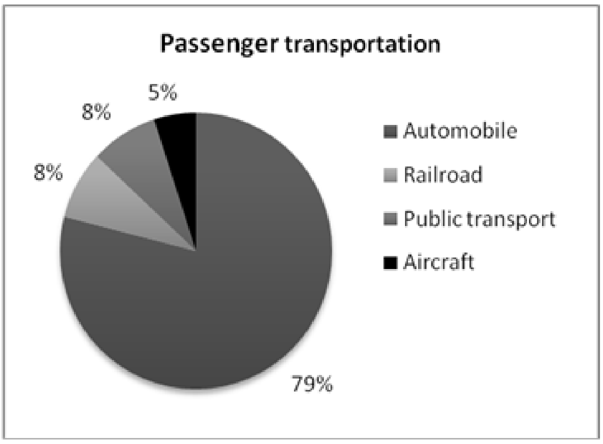
total effect is unclear; ** in case of subsidies for biomass energy.

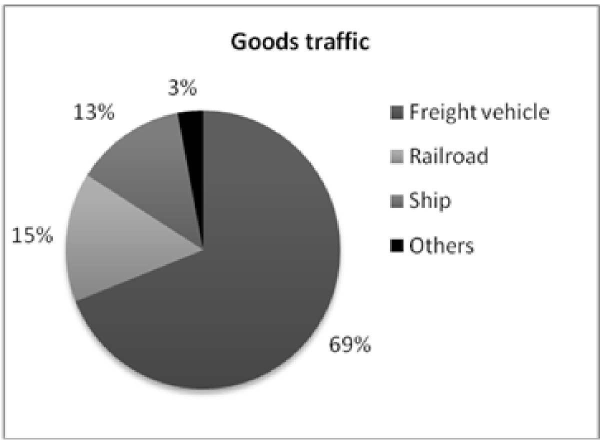
4.5.6. The transport sector

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).

[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

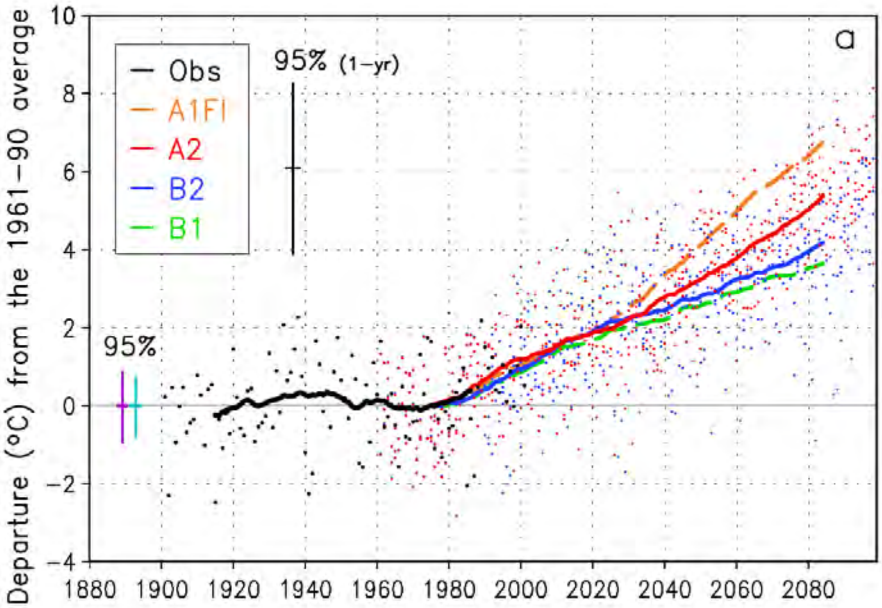
5.2.2.1. Temperature

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.

[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.

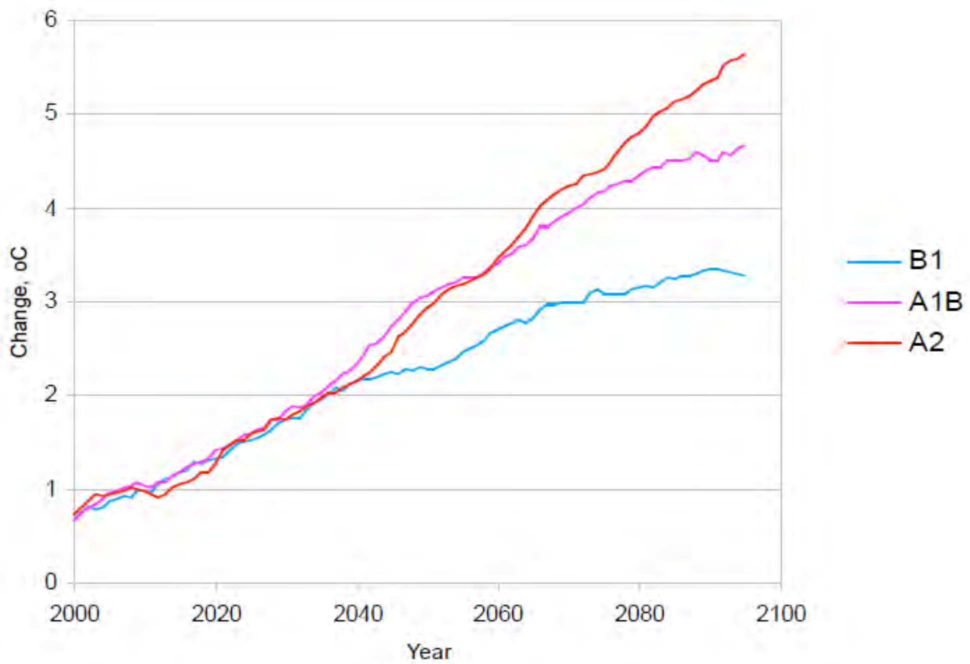
An overview of simulated changes in average temperature (and precipitation) for the FINADAPT A2 and B1 scenarios is provided in Table 11.

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 B1	1.1 (0.8)	2.6 (0.8) 2.5 (0.7)	4.7 (5.3)	9.7 (6.9) 7.3 (7.0)
March – May A2 B1	1.1 (0.6)	2.2 (0.9) 1.9 (0.9)	3.8 (4.2)	7.3 (7.3) 7.6 (6.6)
June – August A2 B1	0.6 (0.3)	1.5 (0.4) 1.3 (0.3)	1.9 (2.7)	4.1 (3.0) 2.8 (4.0)
September – November A2 B1	0.7 (0.5)	1.8 (0.5) 1.6 (0.3)	1.4 (2.8)	5.5 (3.4) 5.1 (1.5)
Annual A2 B1	0.9 (0.4)	2.0 (0.4) 1.8 (0.4)	2.7 (2.1)	6.4 (2.4) 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.

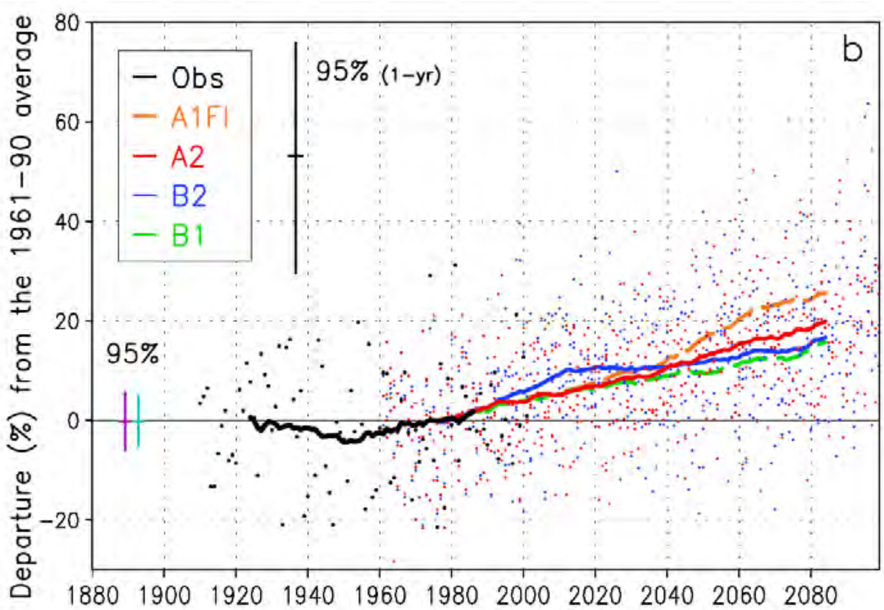
Figure 20: Annual temperature change, compared to the baseline period 1961-1990, depending on three IPCC-scenarios. Source: Jylhä et al. 2009 (in Finnish), cited by Ministry of Agriculture and Forestry 2009.



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.

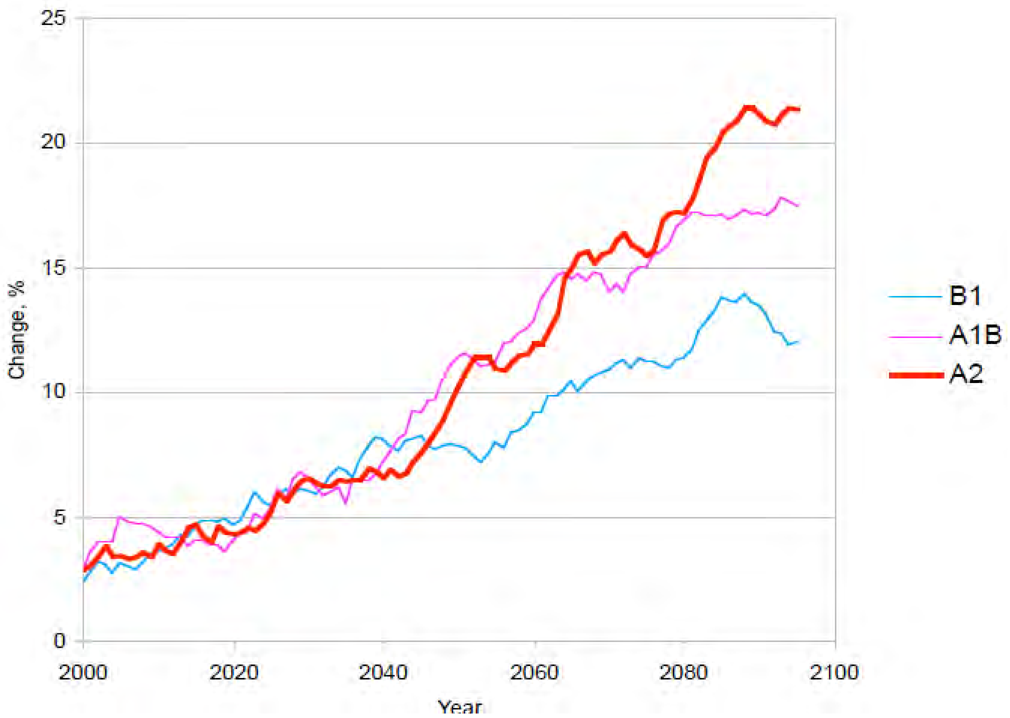


An overview of simulated changes in average precipitation (and temperature) for the FINADAPT A2 and B1 scenarios is provided in Table 11.

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.

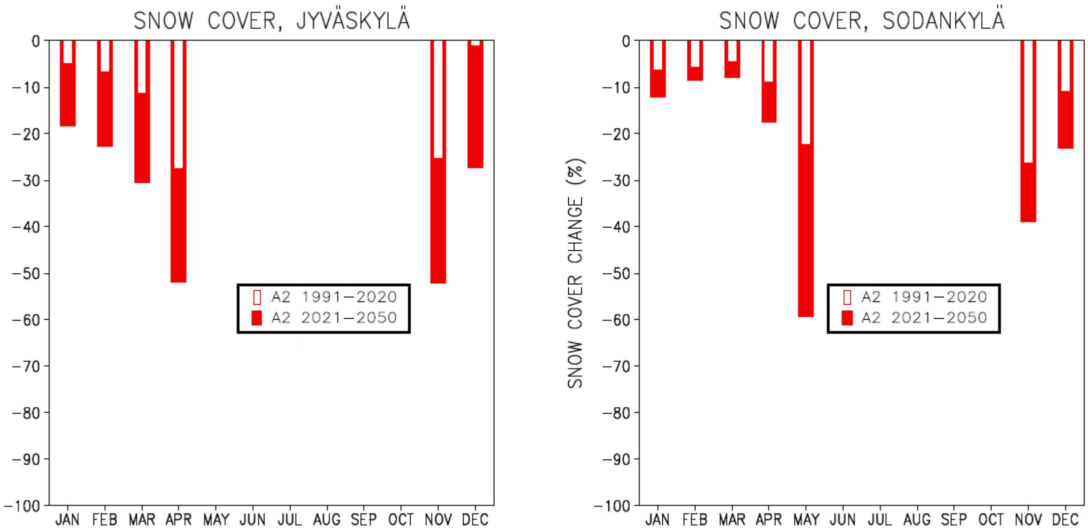


5.2.2.3. Snow Cover and ground frost

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

[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).

[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.

Type of Effect	Impact source	2000-2030	2030-2050	2050-2100	
				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)*

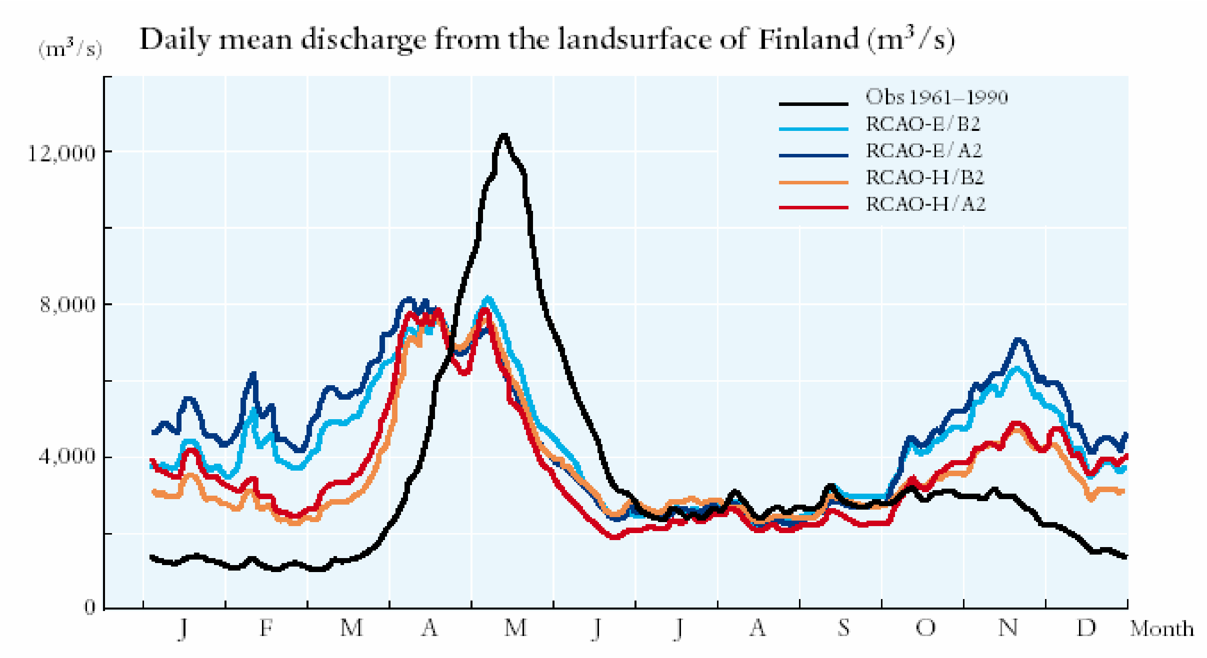
Compared internationally, water resources in Finland are abundant and of high quality. Naturally, the care for water resources is of high public interest. Therefore the cost of maintaining clean water can be associated with the fiscal side of governments.

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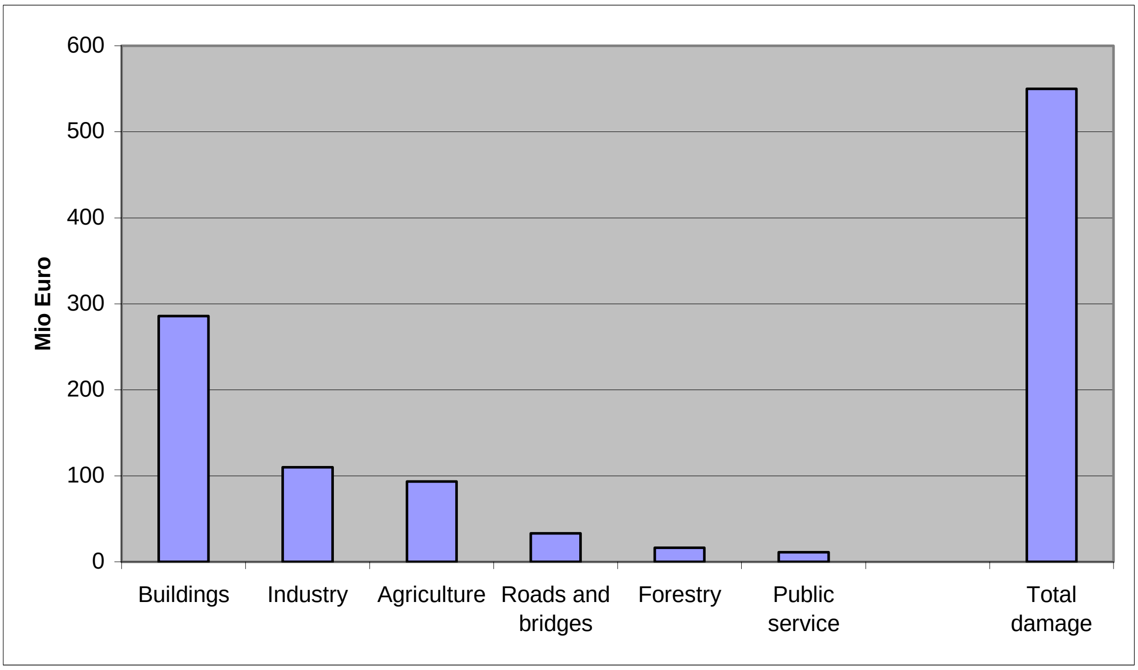
[27] Eutrophication is an increase in chemical nutrients in an ecosystem leading to excessive plant growth.

[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 €

[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

[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	

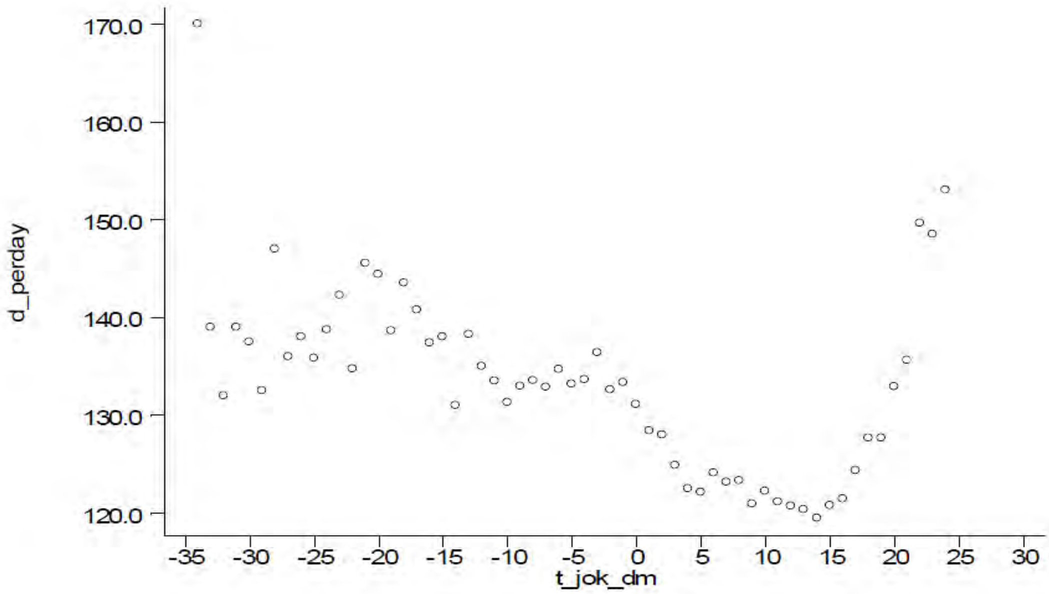
5.3.6. Health

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.

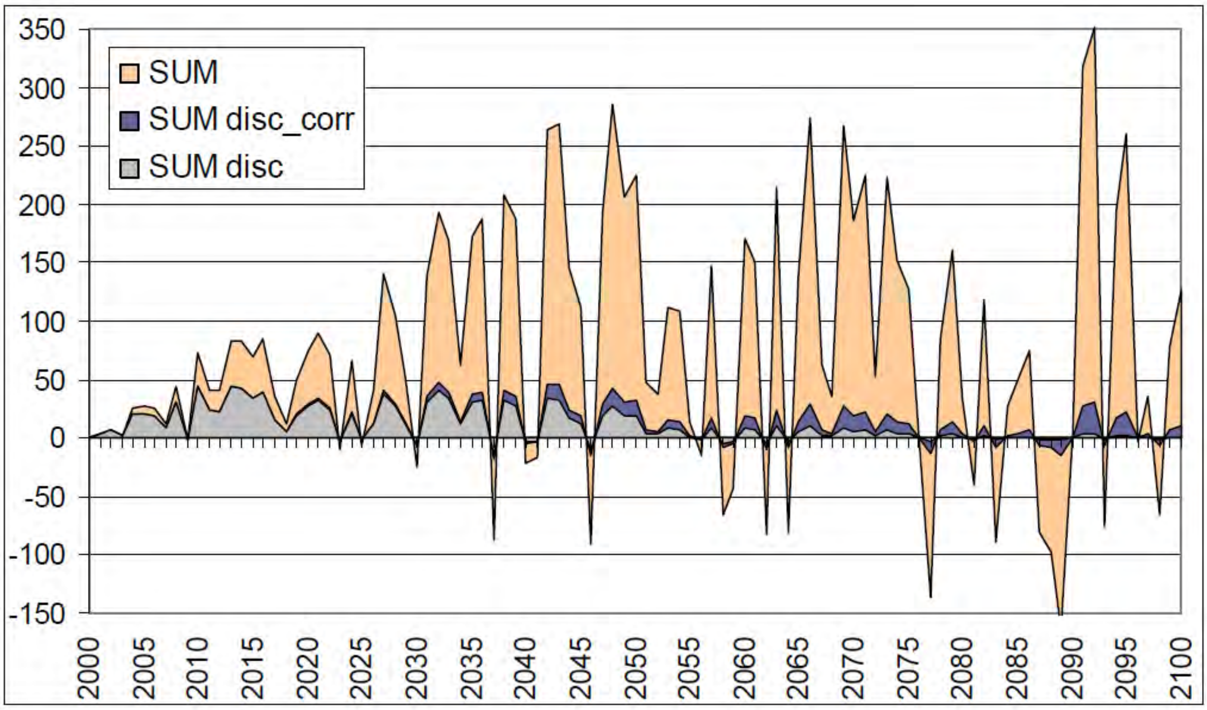
[32] First-order costs are explained as effects on production costs or damages to capital and sales stock. The (not-analysed) spill over effects to the rest of the economy depend on how these changes in first order costs are absorbed in product and factor prices.

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 €.

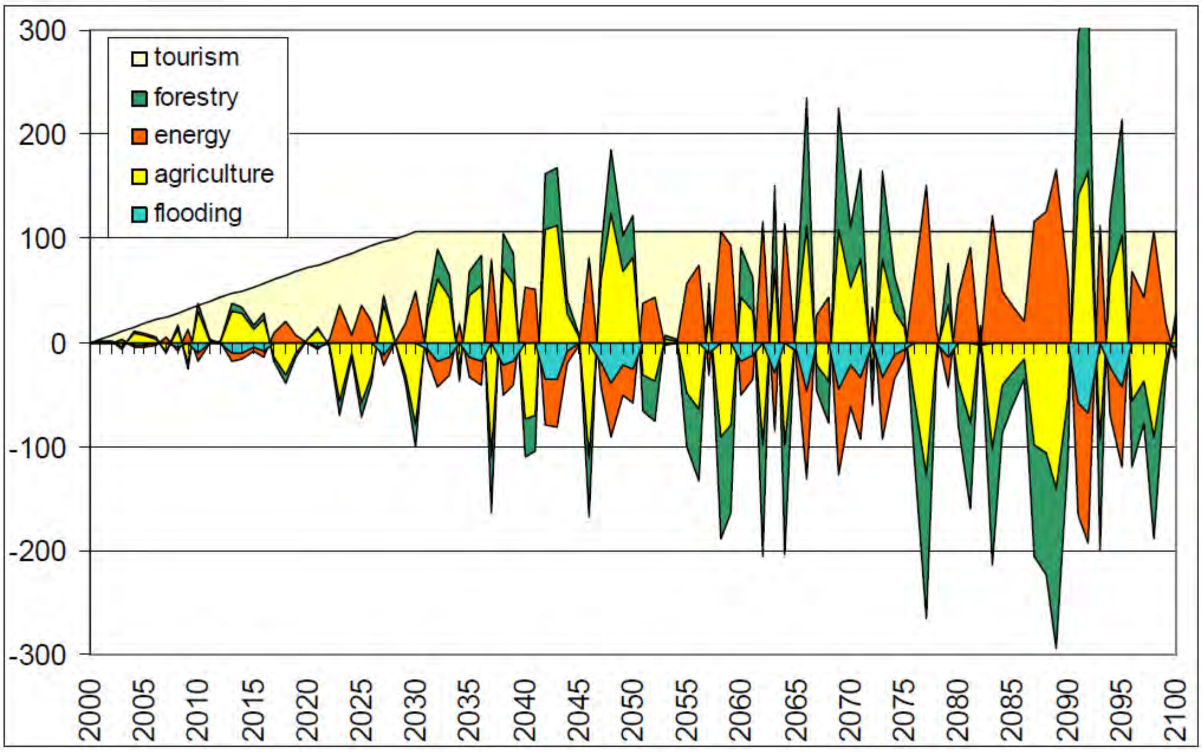


"SUM" depicts the simple value of the effects which occur in the respective year. "SUM disc" is calculated by a traditional discounting method and thereby accounts for the low importance of events in the far future. "SUM disc_corr" uses a crude correction method ensuring that the discount rate increases 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

[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

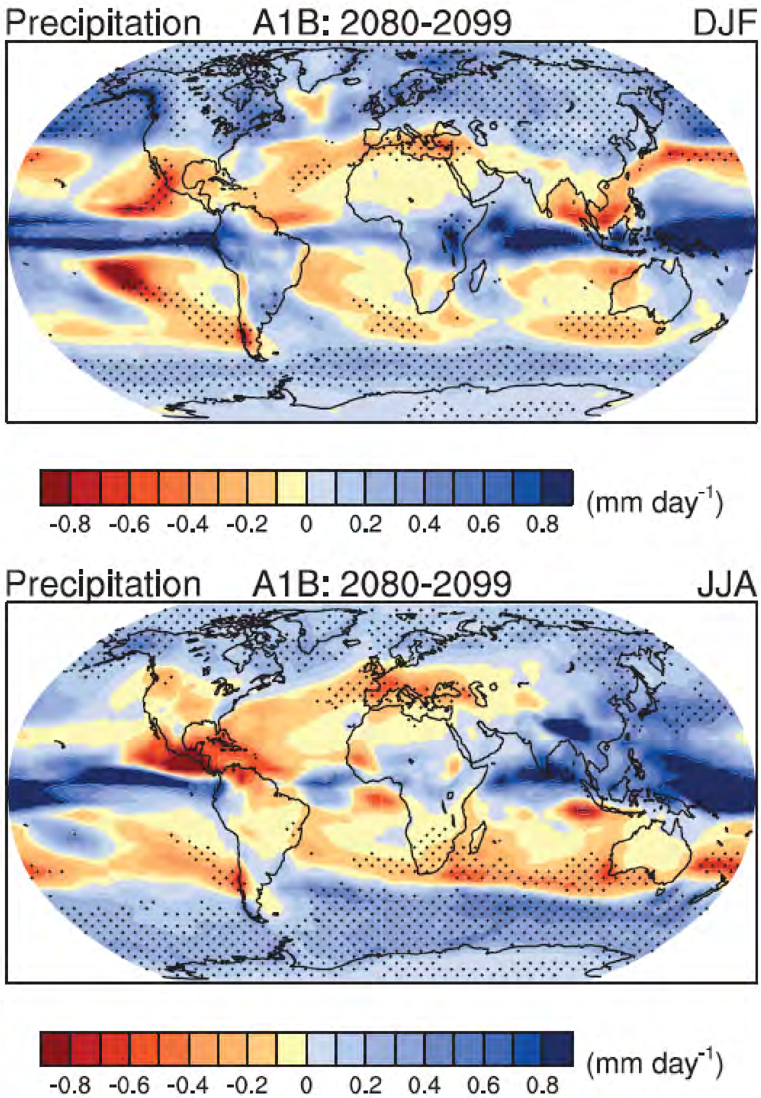
6.2.1. General overview

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).



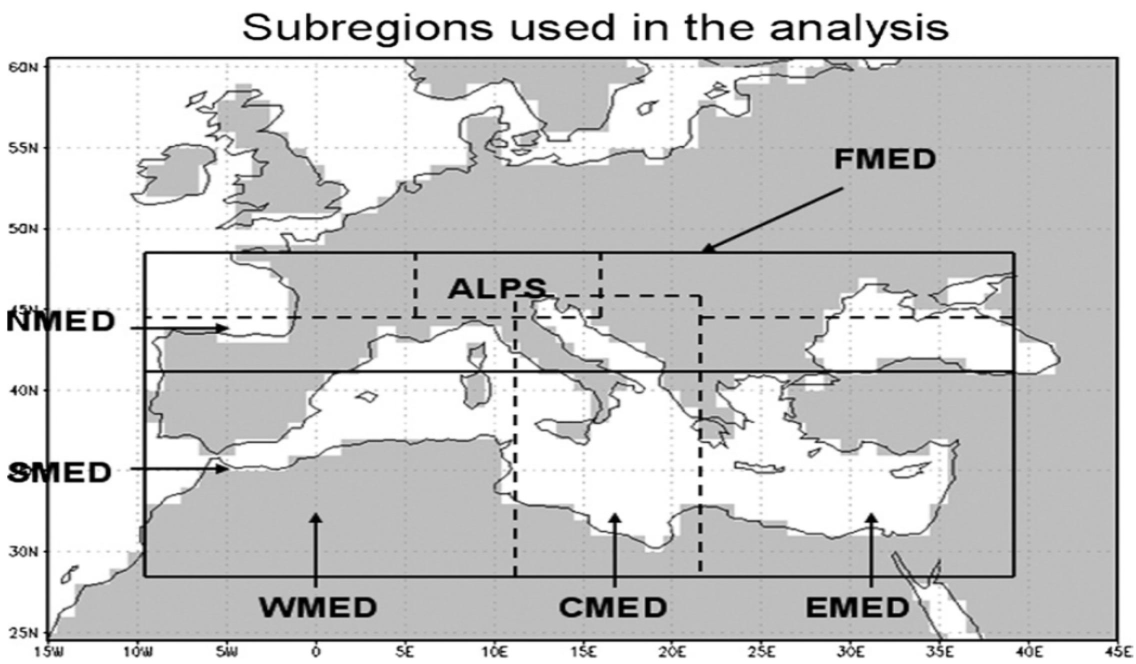
Changes are given for the IPCC A1B scenario, for the period 2080/2099 in comparison to 1980/1999. Stippling denotes areas where the magnitude of the multi-model ensemble mean exceeds the inter-model standard deviation, i.e. here the results of the multitude of models show a reasonable correlation. Source: 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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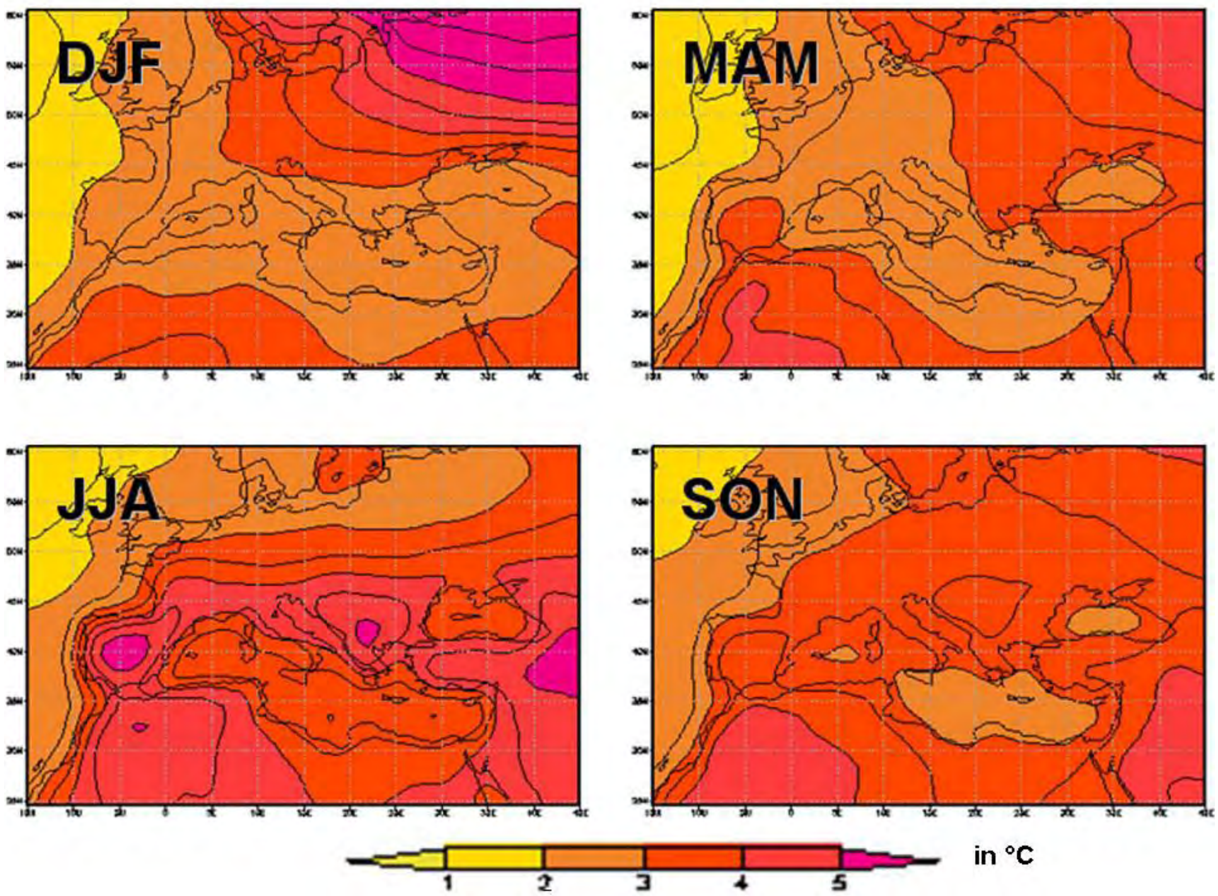
[34] CMED is geographically defined as 28–46 N and 10.5-20.5 E

[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.

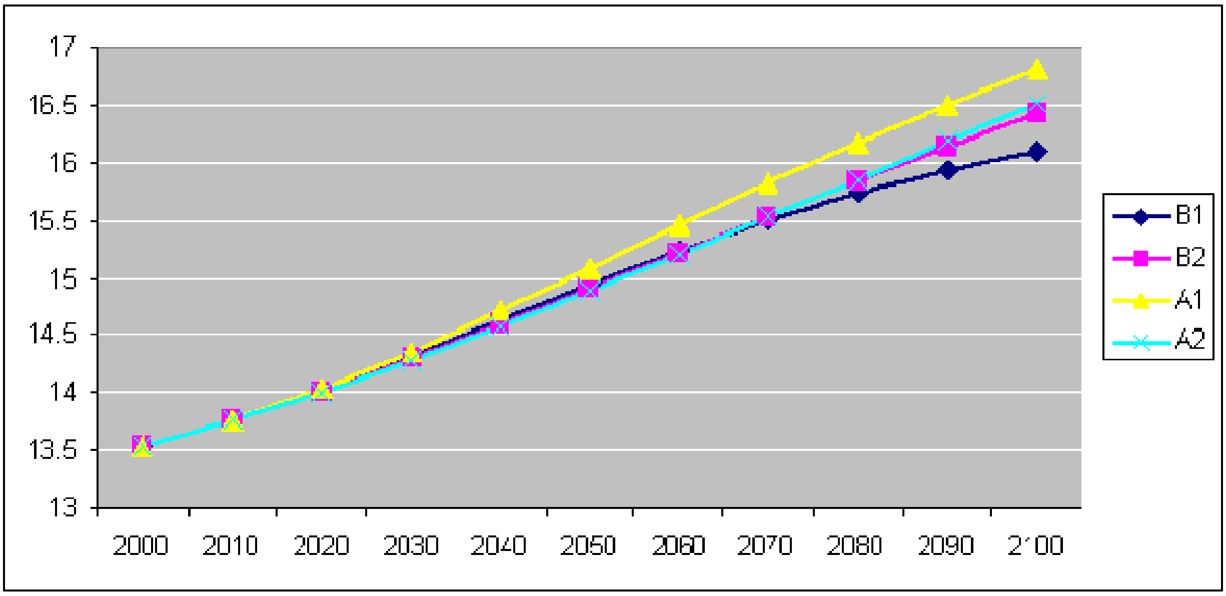
Figure 31: Average temperature change in the Mediterranean in °C; 2071/2100 to the baseline period 1961/1990.



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

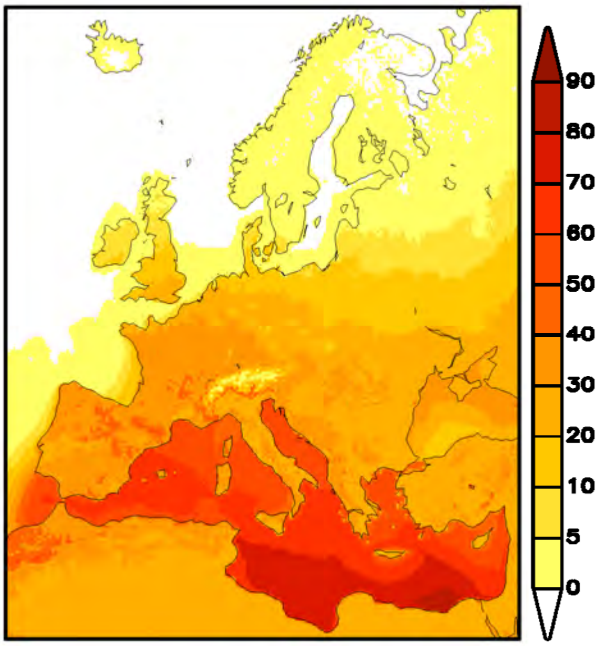
In a sub-regional projection for the period 2071-2100, the CMED region is expected to heat up between 3 and 4.5 degrees Celsius, with the temperature increase largest in summer. The ALPS region is projected to experience a comparable increase in mean temperatures. To give an impression of future climate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

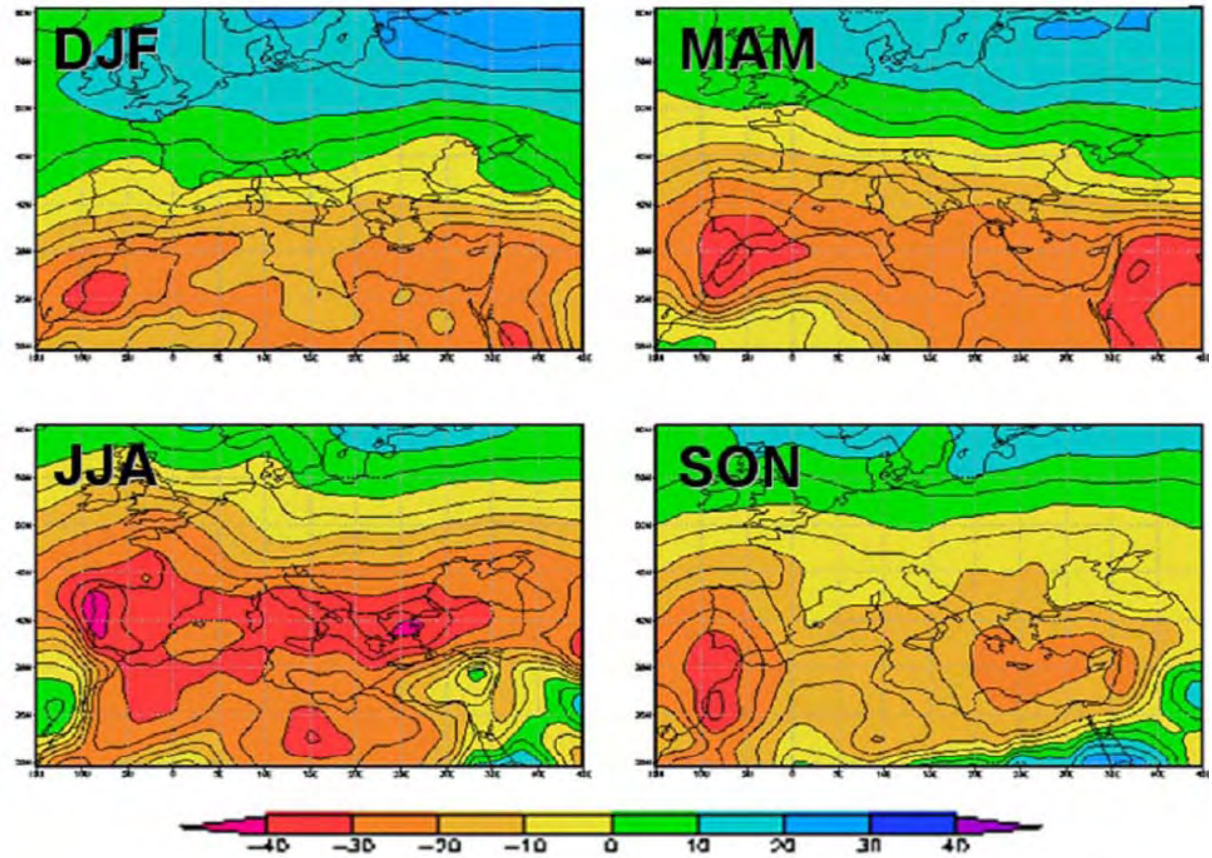
Following these data, all the models concur in forecasting warmer summers than the warmest summer of the period 1980-1999 for the end of the century, in South Europe and assuming scenario A1B.

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.

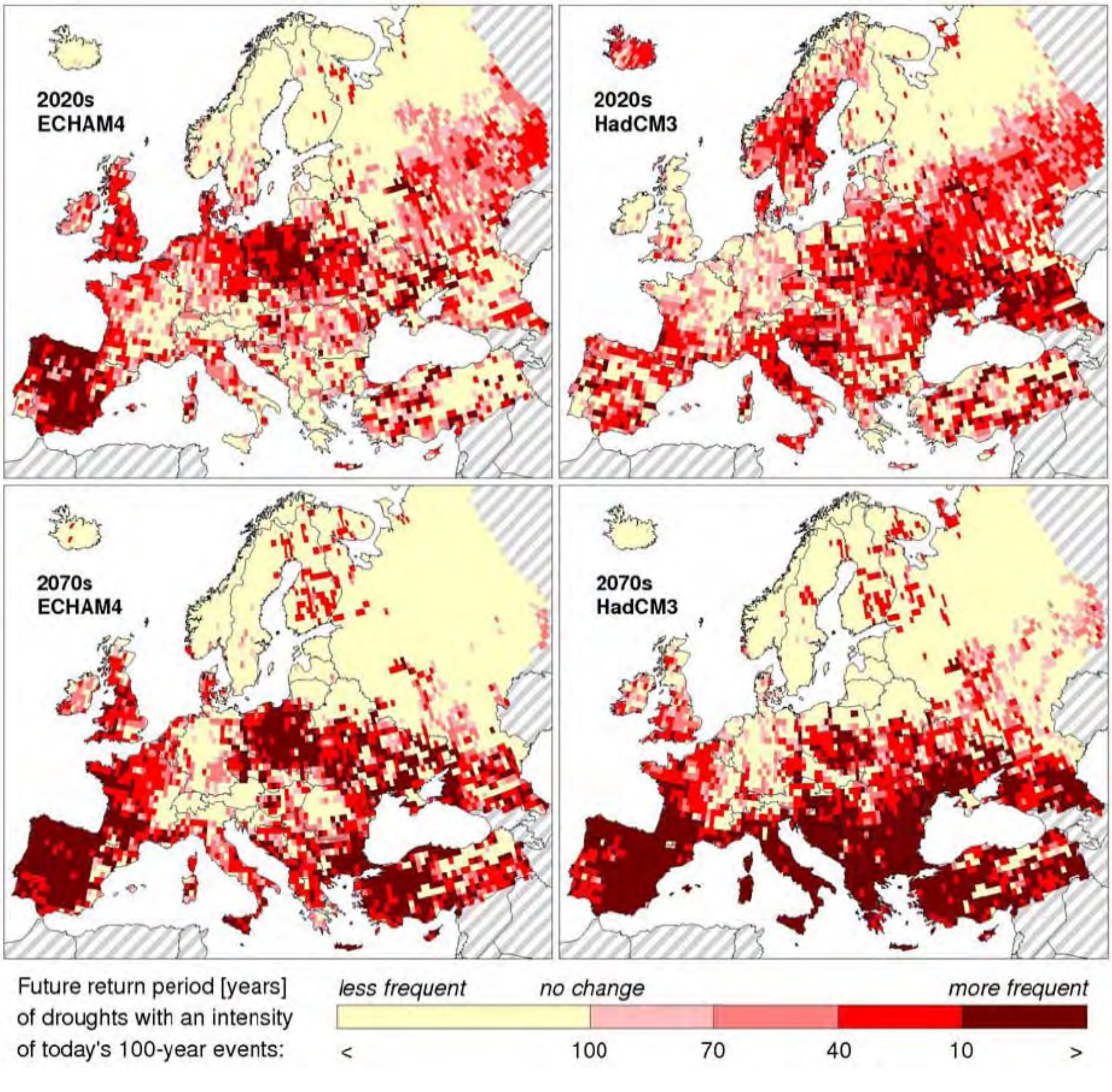
Table 22: Percent variation of cumulated rainfalls foreseen by 21 models from 1980-1999 to 2080-2099 and probability of "extremely rainy season" and "extremely dry season" in the period 2080-2099.

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,

[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.

[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 <u>technological development</u>. 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

[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 m^3 of water is needed to get 2.5 m^3 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).

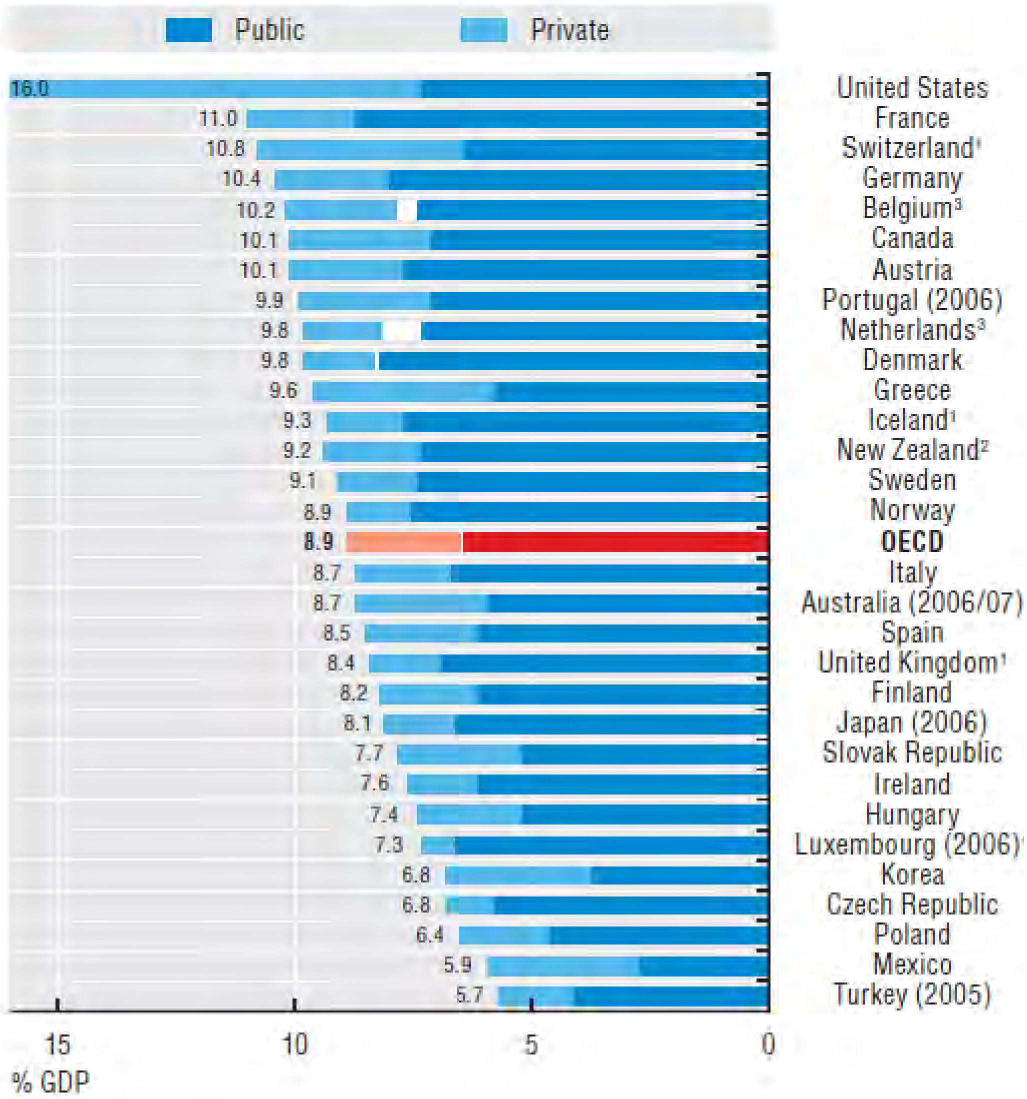
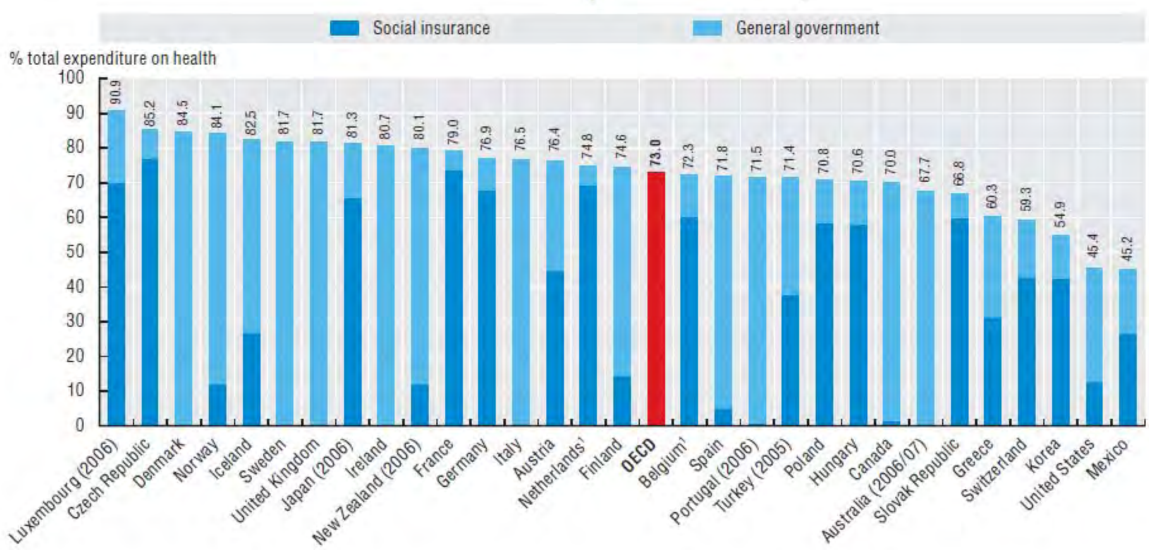


Figure 38: Share of public health expenditure in detail. Source: OECD (2009).



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.

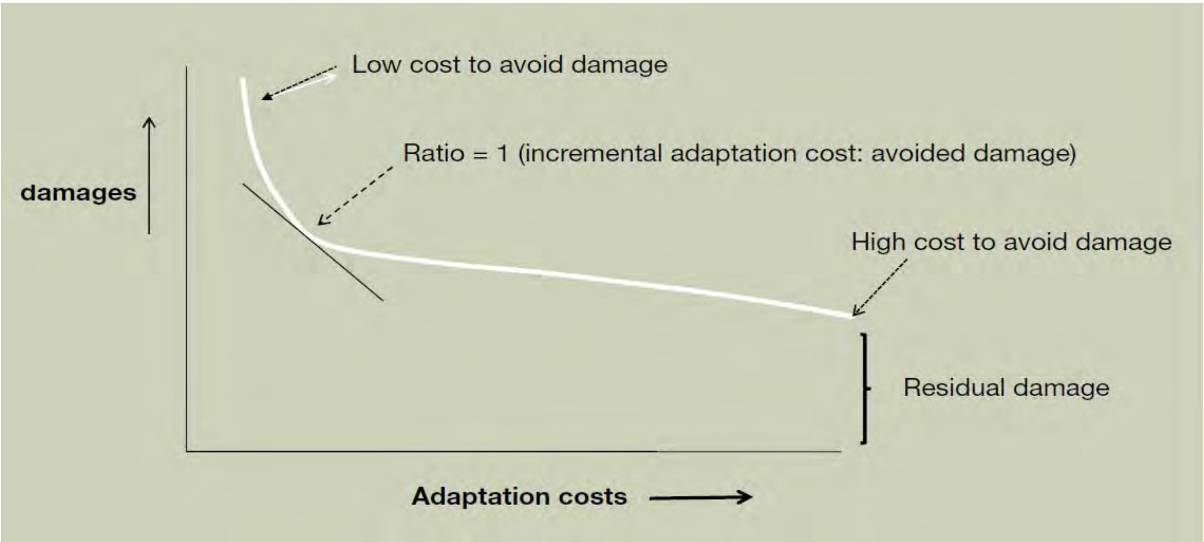
7.2.2. Scenarios

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	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
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)				
				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				1 2000€ = 1.093 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
	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						
				Source					Alberini and Chiabai 2005						
	VSL (Value of a statistical Life) mean WTP	survey	2005	Costs					1.533						No information about price level
				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							
			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							1013.4 1995€ = 1171.9 2005€

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