Climate Change

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CLIMATE CHANGE IN GERMANY

VULNERABILITY AND ADAPTATION OF CLIMATE SENSITIVE SECTORS

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Climate Change in Germany

Vulnerability and Adaptation of climate sensitive Sectors

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1 Introduction

1.1 Objectives and Structure of the Report

1.1.1 Objectives

This report is the result of a study conducted by the Potsdam Institute for Climate Impact Research (PIK), commissioned and financed by the Federal Environmental Agency, Germany (Umweltbundesamt, UBA), and carried out between March 1st, 2003 and June 30th, 2005.

The objectives of this study were

1. to document existing knowledge on global change (and particularly climate change) in Germany and analyse its current and potential future impacts on seven climate-sensitive sectors (water management, agriculture, forestry, nature conservation, health, tourism and transport),
2. to evaluate the present degree of adaptation and the adaptive capacity of these climate-sensitive sectors to global change,
3. to draw conclusions on the vulnerability to global change of sectors and regions in Germany by considering potential global change impacts, degrees of adaptation and adaptive capacity,
4. to discuss the results of the study with decision-makers from government, administration, economy, and society, in order to develop a basis for the development of strategies of adaptation to global change in Germany.

In order to reach the objectives stated above we made use of the results of a European research project (ATEAM[1]; Schröter et al., 2005), which was coordinated by PIK. These results are based on a set of consistent, spatially explicit scenarios of global change, a range of ecosystem models and indicators for ecosystem services, as well as a continuous dialogue with stakeholders. The bulk of scientific information on global change and its potential impacts in this report is drawn from analyses of the results of the ATEAM project. Moreover, we conducted surveys for the seven climate-sensitive sectors in various regions of Germany, in order to assess the regional and sectoral significance of potential impacts of climate change, and to develop suitable adaptation strategies to these potential impacts.

To assess vulnerability we integrated results from scenarios on potential impacts of global change that were developed in ATEAM with findings from other studies, as well as with results from our surveys. The results were discussed during several "Expert Talks on Climate" (Klimafachgespräche), which were organised by the Federal Environment Agency and during a stakeholder workshop with representatives from government, administrative bodies, the economy, and the wider public.

1.1.2 Structure of the Report

Chapter 1 is an introduction into the causes, the character and the general impacts of global change. The interrelations between ecosystems, ecosystem services and society are elaborated. Terms and concepts in the context of adaptation to climate change, adaptive capacity and vulnerability are introduced and the state-of-knowledge regarding these topics is summarised.

The concepts and methods this particular study is based on are introduced in chapter 2. Those are mainly the analyses of scientific studies, in particular the project ATEAM, as well as the experts' survey on adaptation to climate change.

Chapter 3 describes the characteristics of global change in Germany. On the one hand, we analyse and evaluate observed climatic changes and various scenarios of future

[1] ATEAM – Advanced Terrestrial Ecosystem Analysis and Modelling (EU Project No. EVK2-2000-00075), www.pik-potsdam.de/ATEAM.

climate changes until the year 2080. For this we elaborate on particular climatic variables (temperature, precipitation), extreme events, as well as spatial and temporal variations of these phenomena. On the other hand, we discuss two other important elements of global change, i.e. land use changes and changes in atmospheric concentration of carbon dioxide.

Chapter 4 is the central chapter of the report. Here we analyse impacts of global change (particularly climate change) and the state of adaptation to global change in seven selected sectors (forestry, agriculture, water management, tourism, nature conservation, health, and transport), and draw conclusions on the vulnerability of these sectors. For this we analyse results from the project ATEAM and other studies, as well as findings from the experts' survey on adaptation.

Chapter 5 summarises the results of the stakeholder-workshop with representatives from policy, administrative bodies and the economy that was conducted on adaptation to climate change as part of this study.

Chapter 6 contains conclusions and recommendation. Conclusions regarding Germany's vulnerability to climate change are drawn from the results presented in chapter 4. Highly vulnerable regions and sectors are identified. Recommendations on the communication of results on climate impacts, on how to deal with uncertainty in climate scenarios, and on the societal adaptation to climate change are given.

Chapter 7 contains an English and German executive summary of the report.

1.2 Global Change

1.2.1 Global Climate Change – Historical Development

Rate and degree of climate change in the 20th century are extraordinary – e.g. present temperatures in the Northern Hemisphere are probably the warmest since 2000 years (Moberg et al., 2005). In the Northern Hemisphere the 1990s were the warmest decade, and the years 1998, 2002 and 2003 were the warmest years in the last thousand years (IPCC, 2001; WMO, 2003) (Fig. 1-1). Since 1900, global mean temperature has risen by 0.7 ± 0.2 ºC. Precipitation in the middle and higher latitudes of the Northern Hemisphere has risen by 0.5 to 1% per decade during the 20th century, while it declined in the subtropical latitudes. Furthermore, climate extremes were observed more frequently, such as for example an accumulation of temperature anomalies in the Pacific Ocean since 1970 (so called "El Niño events") (IPCC, 2001). Since 1950, a profound increase of the damages due to natural hazards and flooding has been recorded (Munich Re, 2002).

Only a small fraction of this climate change can be explained by natural factors such as volcanic eruptions, changes in solar activity or deviations in the Earth's orbit around the sun. Meanwhile, there is overwhelming consensus in the scientific community that the main cause of climate change is human activity, in particular the emission of greenhouse gases (IPCC, 2001; Oreskes, 2004). In order to meet our energy demands, in a few generations we are using up fossil fuels that took hundreds of millions of years to form. In doing so we produce greenhouse gases, such as for example carbon dioxide. Greenhouse gases such as water vapour, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) reflect part of Earth's heat radiation (infrared radiation) and thereby cause a "greenhouse effect" that is warming the atmosphere and the Earth's surface.

Since the beginning of industrialisation the atmospheric concentration of the most important greenhouse gas CO_2 has risen by 34% from 280 to 375 ppm (parts per million), due to burning of fossil fuels and land-use change, and has probably reached its highest level in 400'000 years (Petit et al., 1999). Over the same time the concentration of methane, the second most important greenhouse gas, has even risen by more than 150%. In the absence of drastic measures to reduce emissions, the atmospheric carbon dioxide concentration is expected to double even within the next few decades (to almost 600 ppm, relative to pre-industrial level; IPCC, 2001).

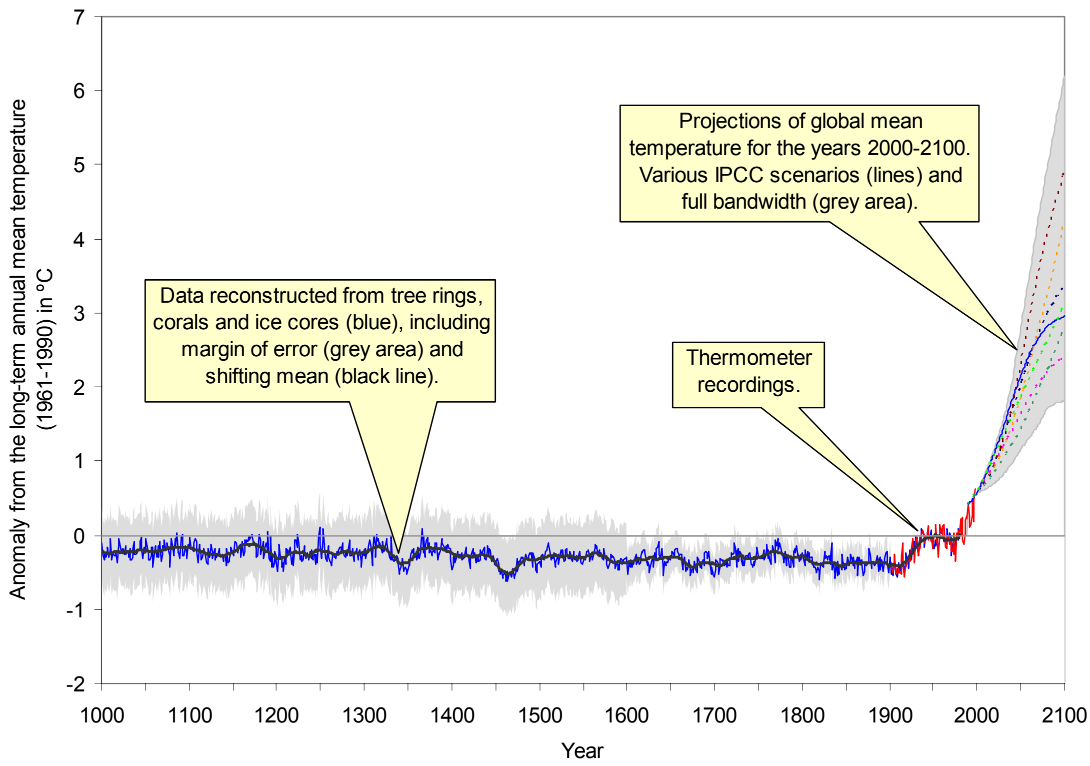

Figure 1-1: Development of the mean temperature of the Northern Hemisphere during the last 1000 years and projections for the next one hundred years (IPCC, 2001; Mann et al., 1999)

1.2.2 Global Climate Change – Projections of Future Development

The European Union is committed to keeping global warming below 2ºC, relative to pre-industrial temperatures, in order to prevent "dangerous clime change" (see Article 2 of the UNFCCC). Cimate sensitivity, that is the rise in temperature following a doubling of the CO_2 concentration, is assumed to lie between 1.5 and 4.5ºC globally. The probability of overshooting the 2-degree target in the long term rises rapidly under concentrations that lie much higher than today's values (Hare & Meinershausen, 2005). To reach the 2-degree target, today's global emissions need to be lowered from 7 Gt carbon per year to 2 Gt per year (Jaeger & Oppenheimer, 2005). This is a formidable challenge, in view of the emissions of the United States of America and of densely populated countries such as India and China that also exhibit rapid economic growth. The projection of emission trajectories is very uncertain. In this study we use the SRES scenarios published by the IPCC. They do not consider any explicit climate policy, but nevertheless embrace a range of emissions that are possible in the light of today's climate policy strategies.

The IPCC acts on the assumption of the continued increase of all greenhouse gas concentrations to values of between 650 and 1215 ppm CO_2-equivalents. The carbon dioxide concentration alone will therefore rise to values of between 607 and 958 ppm, ranging between a doubling and a tripling of pre-industrial levels (Nakicenovic & Swart, 2000). In consequence, a continued, accelerated rise in global mean temperature by 1.4-5.8ºC is expected by the year 2100 (Fig. 1-1). Global average precipitation is expected to rise slightly, with a very heterogeneous distribution over space and time.

Exact prediction of extreme clime events is currently impossible. However, extreme weather and climate events, such as hot summer days, summer drought and extreme rainfall will probably or very probably occur more frequently during the 21st century (IPCC, 2001). Moreover an increase in cyclone activity in the tropics is likely. A decrease in cold extremes is very likely.

1.2.3 Climate Change in Europe

Since 1990, global mean temperature has risen by 0.7 ± 0.2 ºC. During the same period, Europe has experienced and even stronger warming, namely by 0.95ºC (EEA, 2004). Similar to the global trend, temperatures have risen more strongly during winter than during summer. The warming was most pronounced in Northwestern Russia and on the Iberian Peninsula. Climate projections for Europe show a warming by 2.0-6.3ºC from 1990 to 2100. The "sustainable" EU-goal of a global warming by a maximum of 2ºC in comparison to pre-industrial temperatures will probably be surpassed already by the year 2050 (EEA, 2004).

Climate observations during the years 1900-2000 exhibit a rise in annual precipitation in Northern Europe (10-40% wetter), and a decrease in Southern Europe (up to 20% dryer). In most European regions these changes were most pronounced during winter (EEA, 2004). Climate projections show a rise in annual precipitation in Northern Europe by 1-2% per decade, and a decrease in annual precipitation by 1% per decade in Southern Europe (during summer, decreases of up to 5% per decade can occur). For Southern Europe serious water shortages and increased frequency of droughts are expected.

During the last one hundred years, the number of frost days has decreased in most European regions. At the same time, the number of summer days (temperatures above 25ºC) and heat waves has increased. In Central and Northern Europe, the frequency of extremely wet days has risen in recent decades, but in Southern Europe it has decreased significantly in many locations. Cold winters (defined as winters that are colder than 90% of all winters during the period of 1961-1990) will, according to scenario calculations, vanish almost entirely by 2080, while hot summers (defined as summers that are hotter than 90% of all summers during the period of 1961-1990) will be much more frequent. Moreover, it is likely that until 2080 both droughts and extreme rainfall events will be more frequent in Europe (EEA, 2004).

The glaciers in eight out of nine European glacier regions are declining, in accordance with the global trend. The current retreat of glaciers surpasses the extent of the last 5000 years. It is very probable that this trend will continue. Until the year 2050, probably ca. 75% of the glaciers in the Swiss Alps will have disappeared. In addition, between 1971 and 1994, the duration of snow cover of the Northern Hemisphere (between 45º and 75º latitude) has decreased by an average 0f 8.8 days per decade. According to climate scenarios, this trend will continue through the 21st century (EEA, 2004).

1.2.4 Other Drivers of Global Change

Global change is a far-reaching and widely used collective term. We understand this term not only to refer to climate change, but also to trends in other factors that reflect human influence on the Earth system, i.e. the era of the so-called *Anthropocene* (Crutzen, 2002).

The intensive use of our planet leaves traces in our environment. For example, by now humans have altered 30-50% of the Earth's surface (Vitousek et al. 1997b). The global population is growing; in the year 2050 probably 2-4 billion more people will inhabit the planet (Cohen, 2003). The production of fertilisers today binds more nitrogen through synthetic nitrogen fixation than the entire natural fixation of all terrestrial ecosystems (Vitousek, 1997a).

The research project reported here has primarily focussed on the global change drivers atmospheric carbon dioxide concentration, climate change and land-use change.

1.3 Impacts, Adaptation, and Vulnerability

1.3.1 The Interrelation Between Ecosystems and Society: Ecosystem Services

Ecosystems provide goods and services that are indispensable for human well-being (Daily, 1997, Millennium Ecosystem Assessment, 2003). Ecosystems and society are therefore inseparable. The wealth of ecosystem services (including goods), such as e.g. food and fodder production, fresh water retention, climate regulation, soil formation, inspiration and aesthetic value of landscapes is quite overwhelming. It is therefore practical to aggregate ecosystem services into four categories: provisioning, regulating, cultural and supporting ecosystem services (see Tab. 1-1).

Tab. 1-1: Aggregating ecosystem services into four categories, short explanations and examples (Source: Millennium Ecosystem Assessment 2003).

Provisioning ecosystem services	**Regulating ecosystem services**	**Cultural ecosystem services**
Products obtained from ecosystems.	Benefits obtained from regulation of ecosystem processes.	Nonmaterial benefits from ecosystems.
• Food • Freshwater • Fuelwood • Fiber • Biochemicals • Genetic resources	• Climate regulation • Disease regulation • Water regulation • Water purification • Pollination	• Spiritual and religious • Recreation and ecotourism • Aesthetic • Inspirational • Educational • Sense of place • Cultural heritage
Supporting Services		
Services necessary for the production of all other ecosystem services.		
• Soil formation	• Nutrient cycling	• Primary production

Because of this inseparability of humans and their environment, the term *human-environment system* has been coined in sustainability science (Schröter et al., 2005 (in press); Turner et al., 2003). This term stresses, that humans as users, actors and managers are not external to the environment, but act as integral parts of the system. Within the human-environment system, ecosystem services form a vital link between humans and their environment. We understand climate-sensitive systems as human-environment systems and choose ecosystem services as point of departure of this assessment.

1.3.2 Past and Current Impacts of Global Change on Ecosystem Services and Society

Global change influences ecosystems through changes in process rates and system structure (Schröter et al., 2004b). The impacts of global change on ecosystems and their services have become apparent on various scales. Anthropogenic climate change has left a “fingerprint” on ecosystems – the distribution of many species has shifted pole-wards (or to higher altitudes), and biological spring (e.g. bud break of trees and spring arrival of birds) arrives earlier in the year (Parmesan & Yohe, 2003; Stenseth et al., 2002; Walther et al., 2002). It is neither surprising nor new that climate change impacts animal and plant species. However, rate and degree of these impacts are greater than ever before (Root et al., 2003). Over the past few hundred years, humans have increased the species extinction rate by as much as 1000 times over background rates typical over the planet's history (Reid et al., 2005). Moreover, the distribution of species is becoming more homogenous; in other words regions are becoming less characteristic with respect to the species they host.

In the 140 years between 1850 and 1990, global land use change has led to an increase in agricultural area (from ca. 13 to 49 million km^2). This change took place at the expense of forest area (decrease from globally ca. 60 to 48 million km^2) and grassland (decrease from globally ca. 60 to 36 million km^2) (McNeill, 2001). The main part of these dramatic changes happened in the last sixty years. This land use change was accompanied by massive soil erosion and caused profound changes in the global cycles of carbon and nutrients, such as e.g. phosphorus and nitrogen (Houghton, 1999; McNeill & Winiwarter, 2004). Some studies estimate that the negative impacts of land use changes on global biodiversity will be even stronger than the impacts of climate change (Sala et al., 2000). Nitrogen deposition is recognised as the third important factor.

Today, agricultural lands and forests receive up to sixteen times more nitrogen through atmospheric deposition than prior to industrialisation (Holland et al., 1999). This leads to eutrophication and alters the structure and functioning of ecosystems (Matson et al., 2002; Smith et al., 1999). In aquatic systems, the eutrophication effect becomes visible quickly, through algal blooms and the dying of freshwater systems. Forests react more slowly. Often an increased in forest growth is observed at first, until the supply of nitrogen surpasses the demand, and nitrogen ions start binding other essential nutrients in the forest soil (e.g. calcium and magnesium). Together they are then leached into the groundwater. As a result, nutrient-deficient trees are more susceptible to frost, drought and parasites. The accompanying acidification poses a threat to soil biodiversity (Aber et al., 1998). In spite of the Gothenberg Protocol (1999) for the reduction of sulphur and nitrogen emissions, nitrogen deposition on central European ecosystems will remain very high (Alcamo et al., 2002). The long-term effect of this involuntary permanent fertilisation is currently unknown.

Global change alters the basic conditions for ecosystem functioning (soil formation, nutrient cycling, primary production, see also "supporting ecosystem services", Tab. 1-1) and consequently influences all other ecosystem services indirectly. Furthermore, global change directly impacts biodiversity and landscape diversity (biodiversity in the broader sense). In March 2005, the global ecosystem study "Millennium Ecosystem assessment" was completed. One of the main findings of this unique study is that the global degradation of ecosystems is a barrier in achieving the Millennium Development Goals of the United Nations (Reid et al., 2005). Over 1300 scientists agreed that the global reduction of child mortality, the overcoming of extreme poverty and hunger, the combating of diseases such as HIV/AIDS and malaria, as well as other development goals depend on the sustainable management of the human-environment system. Furthermore, the degradation of ecosystem services leads to problems far exceeding a slight decrease in our high quality of life even in economically rich countries. The executive director of the European Environment Agency (EEA) concludes:

"Climate change is already happening and has far-reaching impacts on people and ecosystems in the whole of Europe, often in combination with profound economic losses", Prof. Jacqueline McGlade, executive director of EEA.

The devastating Elbe flood in 2002 was not only a consequence of extraordinarily extreme rainfall events, but also of the lack of areas for water retention, such as e.g. natural polder areas. In this way the loss of water storing river-landscapes has become noticeable very abruptly.

1.3.3 The Concepts Vulnerability, Adaptation and Adaptive Capacity

The term "vulnerability" refers to the potential of harm of the human-environment system (see also Box 1-1). This study is about vulnerability to global change, in particular climate change. Global change influences humans directly (such as e.g. through floods and heat waves) and indirectly through impacts of global change on climate-sensitive sectors (e.g. water or agriculture).

Vulnerability to current and future global change depends strongly on the initial situation. A region or sector is often already stressed today. Present basic climatic or environmental conditions can pose constraints (e.g. insufficient precipitation or poor soils in agriculture and forestry). Many sectors are influenced by changes in socio-economic basic conditions (e.g. agriculture, forestry, health, tourism, transport). Such basic conditions strongly determine a region’s or sector’s predisposition in the context of global change and are decisive for the regional differentiation of vulnerability.

The vulnerability of a human-environment system, a region, a sector to global change depends mainly on three factors, in addition to its predisposition:

- What are the characteristics of climate change and other elements of global change in the respective region?
- How large are the potential impacts of global change within the region on the specific sectors?
- What is the degree of adaptation in the specific sectors within the region to the potential impacts?

The degree of adaptation depends on the implementation of adaptation measures, which mitigate damages or capitalize on opportunities.

Box 1-1 – Definitions of central terms

Most of the following definitions are based on the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001).

Potential impacts of global change – All impacts that may occur given plausible global change scenarios, without considering present or future planned adaptation.

Adaptation to climate impacts –Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or capitalizes on beneficial opportunities (unchanged, IPCC, 2001). In contrast, mitigation is the attempt to avoid or lessen climatic change.

Degree of adaptation – The extent of adaptation to current or future impacts of global change. The degree of adaptation is determined by the existence of adaptation measures, which moderates harm or capitalize on beneficial opportunities.

Spontaneous Adaptation (autonomous Adaptation) – Adaptation through ecological or biological changes in natural systems, as well as through market or welfare changes in human systems (Metzger & Schröter, 2005 (in review); Schröter et al., 2004a). Spontaneous adaptation does not constitute a conscious or planned response to global change. *Examples of spontaneous adaptation*: Tree species extending their bioclimatic envelope through evolutionary adaptation; decreasing demand as a consequence of increased prices due to supply shortages.

Adaptive capacity – The ability of a system to implement planned adaptation measures (unchanged, IPCC, 2001). Adaptive capacity does not incorporate potential spontaneous adaptation (autonomous adaptation). *Example of adaptive capacity:* The adaptive capacity of a region to flood hazards is high, if the regions has the political will, freedom, resources and know-how to build new flood polders etc. in expectation of more frequent and more extreme flooding events.

Vulnerability (to global change) – The likelihood of a specific human-environment system to experience harm due to changes in society or the environment, accounting for its adaptive capacity (Turner et al., 2003). *Examples of vulnerability:* Settlements on flood polders are vulnerable to extreme rain events. In a different way, people who use natural river landscapes for their recreation and inspiration are vulnerable to land-use change such as river regulation. Elderly who lack a social network of care are very directly vulnerable to summer heat waves.

Vulnerability without further adaptation (current vulnerability, business-as-usual scenario) – Future risk of harm of a human-environment system due to global change (particularly climate change) under the assumption that its degree of adaptation will not change in future.

Vulnerability with further adaptation (improved-business scenario) – Future risk of harm of a human-environment system due to global change (particularly climate change) under the assumption that present adaptive capacity will be fully used to improve its degree of adaptation in future.

A human-environment system is therefore only vulnerable, if it is not adapted to potential impacts of global change. The degree of adaptation is determined by the *adaptive capacity* of the human-environment system. Adaptive capacity is small, if necessary resources (financial, organisational, legislative, scientific etc.) are not available to realise a sufficient degree of adaptation. In this case, the human-environment system will not be able to adapt to the impacts of global change.

Vulnerability *without* further adaptation (business-as-usual scenario) results if the current degree of adaptation is maintained into the future. This kind of vulnerability is also referred to as *current vulnerability*. When assessing this vulnerability, we assume that no further adaptation measures beyond already existing ones (e.g. flood protection) are implemented. In this way we convey an impression of which damages are to be expected, if no further adaptation to global change (particularly climate change) is achieved.

If we assume that present adaptive capacity will be fully used to improve the future degree of adaptation, we obtain vulnerability *with* further adaptation (improved-business scenario). By comparing vulnerability *without* further adaptation (business-as-usual scenario) and vulnerability *with* further adaptation (improved-business scenario) we obtain an impression of the risks of damages due to global change (particularly climate change) with and without further measures of adaptation.

1.3.4 Adaptation Strategies and the Roles of Science and Policy

Adapting to changing environmental conditions is a natural part of our everyday live. Mostly, these adaptations are a reaction to changes that have already happened. Adaptation *strategies*, however, contain a perception of the future development of events. Global change is already reality. Further climate change is inevitable, even if we implemented the best mitigation measures (particularly greenhouse gas emission reductions) immediately. To react to global change only at the same moment as profound negative impacts occur would be more than negligent. Therefore, policy makers, private businesses and citizens need to work together to develop adaptation strategies.

As a starting point for the development of adaptation strategies, this study offers multiple plausible scenarios of global change. The scenarios are based on a range of assumptions about various possible socio-economic developments. They therefore represent a first range of options for action. The scenarios contain not only driving forces, but also potential impacts on essential ecosystem services. The scenarios represent the current state-of-knowledge, including the main uncertainties.

Socio-economic indicators can be used to characterise the general conditions for adaptation measures. However, in the end adaptation strategies depend on the specific context. We need adaptation strategies on various scales (European, regional, national and local) and for various sectors and relevant ecosystem services (e.g. water, agriculture, health, tourism).

Sustainable management of the human-environment system and its ecosystem services can reduce vulnerability to global change. In this report, we focus in on a number of specific ecosystem services, since sustainable management naturally depends on the specific context. To recognise and identify a specific ecosystem service is the first essential step. Then the dynamics of the ecosystem service under the influence of humans and the environment, and in interrelation with other ecosystem services needs to be examined. In doing so, numerical ecosystem models are useful tools, especially if they capture human management, such as models of forestry, agriculture and terrestrial carbon dynamics. Furthermore, it is important if the ecosystem service is seen and managed as a private or public good, because this specifies the interest groups and clarifies policy options.

The development of adaptation strategies cannot and should not be a pure scientific enterprise. Only stakeholders can provide a practical understanding of the economy of specific sectors. Moreover, the decision about suitable adaptation strategies is not only a question of facts and plausible scenarios, but also of values. Conflicts of interests and values are inevitable. They can only be resolved in an equitable dialogue between all actors and stakeholders.

The adaptation strategies illustrated in this study have been developed in a dialogue between scientists and stakeholders from private and public sectors. As options for action, they are the starting point for discussing the decision making process.

1.4 State-of-the-art in International and National Research

A number of developed countries have conducted integrated assessments of vulnerability to climate change on national level. These were in particular United Kingdom (many regions, selected sectors), Norway (all regions), USA (all regions), Canada (all regions) and Portugal (national and regional case studies), as well as, with certain constraints, Australia and France. To date a similar study of Germany for all regions and sectors does not exist. Generalisations of results from studies conducted in different countries should be drawn with caution, however, a few common features are apparent. In particular, it appears that vulnerability to climate change strongly depends on scale, that it is often regionally very heterogeneous, that uncertainties in future regional climate changes often do not allow robust predictions of regional climate impacts, that only in a few cases possible abrupt climate changes ("climate surprises") are considered, that an important prerequisite for the achievement of practical results and recommendations is the integration of scientific analyses with participatory approaches, and that climate change is mostly just one of many factors in political decision making.

Practice-oriented climate impact research in Germany is funded by various sources. Germany currently hosts no comprehensive integrated research program on national level, such as the exemplary *United Kingdom Climate Impacts Programme* (UKCIP). The Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF; funding focus areas F75010 and F75099, DEKLIM) is the main sponsor of climate impact research in Germany. It continues to fund a multitude of sectoral and regional, integrated research projects. Major funding domains particularly cover coastal and flood protection, water supply and distribution, as well as forestry. The German Research Foundation (Deutsche Forschungsgemeinschaft, DFG), which is traditionally focused on basic scientific research, so far has established only two funding areas (Sonderforschungbereiche, SFB) with direct relevance for adaptation to climate change (SFB 419: http://www.uni-koeln.de/sfb419/, und SFB 433, http://www.sfb607.de/deutsch/science/bedeutung/sfb_forstwirtschaft.html). Since the 4th framework programme, the European Commission (DG Research) has funded a number of integrated research projects on European level, which contribute results relevant for Germany (e.g. ACACIA, ATEAM, AVEC, cCASHh, CLAWINE, DINAS-COAST, ECLAT-2, EUROTAS, ENRICH, LTEEF, PRUDENS, SPRUCE GROWTH, WAKE, WISE). However, such projects usually cannot substitute detailed national studies, due to the necessarily coarser regional spatial resolution. The German federal states also play an important role in funding practice-oriented research, but there are profound differences between specific states. Integrated vulnerability studies on federal state level have so far been conducted for Bavaria (BayFORKLIM, 1990-1999), Brandenburg (Brandenburg-Studies, 1997 and 2003) and Baden-Württemberg (KLARA, 2003-2005).

These studies have applied very different methodologies and obtained different results. Further regions that have been studied in depth at least partly are the North and Baltic sea coasts, as well as the Island Sylt, the Weser estuary, the watersheds of Elbe, Oder and Danube, the city of Cologne, and the Bornhöveder Lakes.

A multitude of natural science-oriented sensitivity studies and climate impact studies for selected climate-sensitive systems are available for Germany, and are regularly published in the refereed literature. In contrast to this, results from the few integrated vulnerability assessments and adaptation studies often do not appear in the international refereed literature, but get published only in project reports or in the proceedings of one of Germany's 22 geographical societies.

In the face of these scattered research initiatives, the regionally and sectorally patchy coverage and the different methodologies (as well as barriers in the accessibility of some research results), it is very difficult to obtain a comprehensive impression of Germany's vulnerability to climate change, despite of a multitude of separate studies. Also, the comparison of regions that are exposed to very different risks (e.g. storm surges vs. decline in reliable snow cover for winter tourism) is conceptionally difficult and requires value judgments. A good amount of data is available for the sectors coastal protection (e.g. KRIM, case study Sylt, KLIMU, BALTEX), forestry (e.g. German forest study/GFS), water supply and distribution (e.g. KLIWA, GLOWA-Elbe, GLOWA-Danube, EMTAL), and hazard prevention (e.g. DFNK, DKKV). However, there are major gaps in knowledge concerning other sectors (e.g. agriculture, biodiversity, human health, tourism, energy supply). The recently completed Brandenburg-study identifies decreasing water availability and increased risk of forest fires as main risks due to climate change, where the latter can be minimised via a suitable forest conversion programme. The final report of BayFORKLIM identifies little critical danger, except in the sector flood protection (in spite of a pronounce climate change scenario). Detailed conclusions on regional threats need to be based on an in depth study on the available literature. For the above given reasons, it can however not be expected that such literature study would yield a general measure of vulnerability or a comprehensive set of sector-specific maps.

Comparison and integration of available studies are hindered especially by the fact that they are based on very different climate change scenarios. Oftentimes only a few scenarios are considered, in spite of the impossibility to justify such a selection. The European vulnerability assessment ATEAM is the first to be based on a comprehensive set of internally consistent scenarios of multiple factors of global change (socio-economic, climatic, land-use, N-deposition). In this way, results from different sectors from this study can be compared. Moreover, through the use of multiple consistent scenarios, uncertainty is treated more comprehensively than in previous studies. Our study is therefore based on scenario data from ATEAM (see chapter 2).

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2 Concepts and Methods

Parts of this report are based the European research project ATEAM[2]. ATEAM's vulnerability concepts and methodology were partly adopted and its results have been used in this study. The European vulnerability assessment was based on a set of consistent, spatially explicit scenarios of global change, a range of ecosystem models, indicators for ecosystem services, a generic index of macro-scale adaptive capacity, as well as a continuous dialogue with stakeholders (Schröter et al., 2004, Schröter et al., 2005). In the following, a few elements of the ATEAM vulnerability-methodology are described in more depth.

2.1 Socio-Economic Scenarios and Emission Scenarios

The Intergovernmental Panel on Climate Change (IPCC) recommends a set of future scenarios, which cover the range of uncertainties of driving forces, as well as of emission pathways, without assigning a *probability of occurrence* to any individual scenario (Nakicenovic & Swart, 2000). Through using multiple exposure scenarios, a wide range of possible future developments is covered. Although the current state of knowledge does not allow us to single out any of these scenarios as least or most probable, the comparative analysis of many scenarios enables us to identify regions, which are vulnerable under most scenarios, and regions, which appear vulnerable only under one specific scenario. Furthermore, regions will be recognised that do not appear vulnerable under any of the scenarios. Starting from scenarios of socio-economic development, emissions and atmospheric carbon dioxide concentration, the ATEAM assessment was therefore based on a set of internally consistent, spatially explicit scenarios on a 10'x10' latitude/longitude grid resolution (ca. 16 x 16 km) of the main driving forces climate and land-use change for the time slices 2020, 2050, 2080, and the baseline 1990. The time slices represent thirty-year averages (1990 is the average of the years 1961-1990, 2020 of 1991-2020, 2050 of 2021-2050, 2080 of 2051-2080). Furthermore, the ATEAM provides scenarios of atmospheric nitrogen deposition – however, these include only oxidised, but not reduced nitrogen compounds, which comprise ca. 50% of total deposition. The nitrogen deposition scenarios are currently developed further within the European project ALARM[3], reduced nitrogen compounds will now be added.

The so-called marker scenarios, or IPCC-SRES-Scenarios[4] are the starting point of scenario development (Nakicenovic & Swart, 2000). These scenarios are based on narrative descriptions of plausible future worlds ("storylines") that were developed by a large group of experts[5] and edited in a long-term open review process[6]. The storylines are based on explorations of the major driving forces, such as population growth, economic development and technological change. The SRES-scenarios are structured in four major families labelled A1, A2, B1 and B2, each of which emphasises a different set of social, environmental and economic ideals. These ideals are organised along two axes (see Fig. 2-1). The vertical axis distinguishes an economy-oriented (A) from a socially and environmentally compliant world (B). The horizontal axis represents the range between global (1) and regional (2) development. For example, the A1 scenario describes an economically and globally oriented development.

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[2] ATEAM – Advanced Terrestrial Ecosystem Analysis and Modelling (EU Project No. EVK2-2000-00075), www.pik-potsdam.de/ATEAM.

[3] ALARM – Assessing Large-scale Environmental Risks with Tested Methods (EU Project No. GOCE-CT-2003-506675).

[4] SRES = Special Report on Emission Scenarios.

[5] The group comprised of 50 experts from over 18 countries.

[6] Publicly available on the web from June 1998 to January 1999.

The narratives specify typical aspects and processes for each of the four quadrants identified by these dimensions. The A1 scenario was further elaborated by assuming different combinations of fuels and technology development to satisfy energy demand. A1f remains dominated by fossil fuels, in A1b a mixture of fossil fuels and renewable energy sources is used (b stands for "balanced"), in A1t the energy system is based on new energy-efficient technological developments and renewable energy sources. This differentiation of the A1 scenario was necessary since technological developments in the energy sector have a profound influence on emission trajectories and eventually greenhouse gas concentrations, particularly in this world of rapid economic growth. In this study we focussed on the SRES-scenarios A1f, A2, B1 and B2.

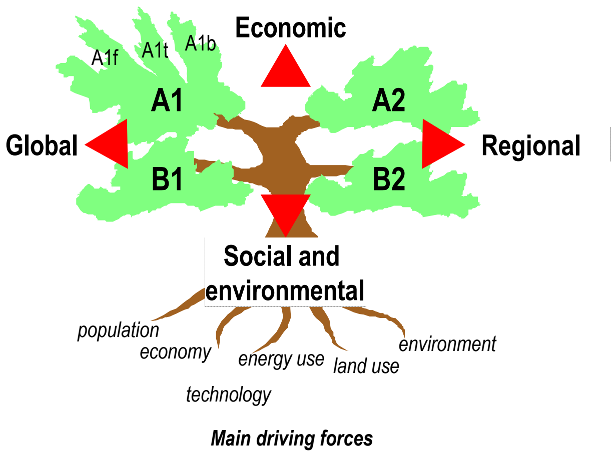

Fig. 2-1: Dimensions and main driving forces of the SRES-Scenarios (see text).

As an example of a socio-economic factor, let us examine population development in the different SRES-scenarios. In all scenarios except A2, population declines a little (toward the end of the 21st century in the scenarios A1 and B1 to just under 80 million, and to ca. 70 million in the B2 scenario). In the A2 scenario, population begins to rise slowly toward the end of the century, after an initial slight decline (Schröter et al., 2004).

In a similar form, the scenarios contain information about the economy, technological development, energy use etc. Integrated assessment models are used to gain quantitative scenarios of these factors from narrative descriptions. This study is based on trajectories of greenhouse gas emissions that were quantified using the integrated assessment model IMAGE 2.2 (IMAGE team 2001). Scenario-specific emissions of greenhouse gases lead to specific atmospheric greenhouse gas concentrations. In all scenarios, greenhouse gas concentrations increase throughout the 21st century. The steady incline of greenhouse gas concentrations starts differentiating more distinctly between scenarios only from the year 2050 onward. From 2050, the B1 scenario exhibits the weakest incline (to just about 520 ppmv in 2100), followed by B2 (to just about 610 ppmv in 2100). The economy-oriented scenarios lead to distinctly higher greenhouse gas concentrations, particularly the A1f scenario (ca. 960 ppmv in 2100), while the CO_2-concentration for the A2 scenarios reaches 870 ppmv by the year 2100.

2.2 Climate Scenarios

Four state-of the-art climate models (HadCM3, CSIRO2, CGCM2 and PCM) were forced with trajectories of atmospheric greenhouse gas concentrations, which resulted from the four emission scenarios. The climate models were chosen from internationally accredited models and according to availability. The 16 alternative climate scenarios represent 93% of the range of possible global warming scenarios presented by the IPCC in 2001. The outputs of the climate models are open to public access through the IPDD-data-distribution centre. However, their spatial resolution of 0.5ºx0.5º (ca. 50x50 km) is insufficient for the study of many climate-sensitive systems and particularly of the vulnerability of the human-environment system. For such studies, ecological and socio-economic processes need to be captured, which cannot adequately be represented at a 0.5ºx0.5º resolution. Therefore, the climate scenarios were downscaled to a resolution of 10'x10' (ca. 16x16 km; Mitchell et al., 2004). Furthermore, observed climate variability during 1901-2000 was used to produce realistic variability for the scenarios. The resulting scenarios are known as TYN SC 1.0 and are available to the public. A later version of these scenarios, including a few improvements is available from the ATEAM-project (Schröter et al., 2004).

2.3 Land-Use Scenarios

In parallel to the climate scenarios, a set of land-use scenarios at the same spatial resolution (10'x10') was developed (Ewert et al., 2004; Kankaanpää & Carter, 2004ab; Reginster & Rounsevell, 2005; Rounsevell et al., 2005a; Rounsevell et al., 2005b). The land-use types urban area, cropland, grassland, bioenergy production (biomass energy sources from agricultural production, such as e.g. barley and rape seed), forest, as well as protected and recreational areas were considered. The land-use scenarios are based on the emissions and socio-economic development described in the SRES-scenarios, as well as on the climate scenarios that were developed from those. For this, the socio-economic driving forces were downscaled to Europe, to Germany, and finally to the regional scale (so-called NUTS2-level, which is approximately the level of administrative districts). Changes in agricultural land area were calculated considering food supply and demand. For this, scenario specific changes in crop yield were accounted for, depending on climate change, increasing atmospheric carbon dioxide, and technological development. Demand for specific land-uses (food production, bioenergy, forestry, settlements) were taken from the integrated assessment model IMAGE and account for socio-economic development outside of Germany and Europe (IMAGE Team, 2001).

Tab. 2-1: Priority scenarios used in the ATEAM project.

7 Scenarios		4 climate models			
		CGCM2	**CSIRO2**	**HadCM3**	**PCM**
4 SRES Scenarios	**A1f**			A1f-HadCM3	
	A2	A2-CGCM2	A2-CSIRO2	A2-HadCM3	A2-PCM
	B1			B1-HadCM3	
	B2			B2-HadCM3	

The spatial allocation of land-uses was performed following scenario-specific assumptions about policy development. For this, scenario-specific hierarchies were developed, according to which the competing land-use types were distributed. In this way, the change in relative area over time and space per scenarios and for each 10'x10' grid cell was determined. The Scenarios were developed by a group of experts and with participation of stakeholders from agriculture, forestry, as well as the nature conservation sector (Rounsevell et al., 2005ab). The scenarios of forestry development are based on a country-specific analysis of forest policy (Kankaanpää & Carter, 2004b).

Due to budget constraints in ATEAM, seven priority scenarios were chosen for land-use change scenario development from the total set of 16 climate scenarios : A1f, A2, B1, B2 forced with climate projections from HadCM3, and additionally A2 forced with climate from the climate models CSIRO2, CGCM2 and PCM (referred to as A1f-HadCM3, A2-HadCM3, B1-HadCM3, B2-HadCM3, A2-CSIRO2, A2-CGCM2, A2-PCM). (see Tab. 2-1). This resulted in a set of consistent scenarios, which contain the uncertainties inherent in emission trajectories, as well as in climate projections. The land-use scenarios are based on the other scenarios (SRES socio-economic, emission, concentration and climate scenarios). Therefore, to force impact models, such as e.g. ecosystem models, the land-use scenarios are consistently used in combination with the respective other scenario.

2.4 Ecosystem Models – Quantification of Potential Impacts

Potential impacts of global change are changes in the supply of ecosystem services, such as yield losses in forestry due to drought and increased fire risk. A range of ecosystem was used to translate scenarios of global changes into potential impacts (see Tab. 2-2). Together with stakeholders from private and public sectors, indicators of ecosystem services were selected that are relevant for the sectors agriculture, forestry, carbon storage and energy, water, nature conservation, and tourism. In particular the ecosystem services agricultural and forestry production, carbon storage in vegetation and soils, river runoff and seasonality, species richness and snow safety were selected.

Tab. 2-2: Ecosystem models, which were used to simulate potential impacts, listed by sectors.

Sector	**Model**	**Reference**
Agriculture	ROTHC	(Coleman et al., 1997)
	IMAGE (biofuel demand)	(IMAGE team, 2001)
Forestry	GOTILWA+	(Sabaté et al., 2002)
	EFISCEN	(Karjalainen et al., 2003)
Carbon storage	LPJ	(Sitch et al., 2003; Thonicke et al., 2001; Venevsky et al., 2002)
Water	Mac-pdm	(Arnell, 1999 modified; Arnell, 2003)
Nature conservation	Statistical Niche Models - BIOMOD	(Thuiller, 2003; Thuiller, 2004)
Mountain ecosystems	RHESsys	(Tague & Band, 2004)

2.5 Results from Other Studies and Projects

Besides ATEAM, a multiple other studies and projects as sources of information on national and regional scale. Particularly for the sectors health, tourism and transport there were no, or only few results available from the ATEAM project, so that we relied entirely on results from the literature. References to the studies and projects that were included can be found in chapter 3 and 4 of this report.

2.6 Survey of Regional Experts

Going beyond the ATEAM project, for this German vulnerability assessment we conducted a survey on the seven climate-sensitive sectors (forestry, agriculture, water management, tourism, nature conservation, health, and transport) with regional experts from the sector-specific functional departments of each federal state.

Objectives of the Survey

The objectives of the survey were

a) To estimate the regional and sector-specific significance of potential impacts of global change, and

b) To appraise the present degree of adaptation and suitable adaptive measures to these impacts.

The estimation of the significance of potential impacts of climate change aims primarily at evidence for vulnerability assessment in specific sectors and regions, since climate impact research offers only little sector- and region-specific knowledge for such evaluation. Furthermore, through direct involvement of regional experts and their risk appraisal we included their concerns of protection and based the vulnerability assessment on a broader set of values.

Gaps in current knowledge further triggered the need to assess the present degree of adaptation and suitable adaptation measures. In Germany the process of adaptation to the impacts of climate change is just beginning. Specific sectors and regions already face the challenges. Therefore the aim of the interviews of regional experts was on the one hand to identify existing initiatives and collect their experiences, and on the other hand to appraise the degree of implementation of measures that are *suitable* to adapt to climate change, even if they were *motivated* by other intentions (e.g. conversion to mixed forests in forestry).

The Respondents

We exclusively questioned representatives from sector-specific functional departments of the federal states, e.g. from the state forestry administration or the ministries of health. Owing to budget constraints, only one representative per federal state and sector was interviewed.

Naturally, our assessment through this survey is influenced by the subjective views of the respondent. Moreover, only the viewpoints of federal state administrations were represented. The perspectives of associations, non-governmental organisations, businesses or citizens are not captured. Finally, from some federal states only few questionnaires were returned.

The Questionnaires

In the forestry sector, we conducted pilot-interviews via telephone with experts from the forestry administration of the federal states, to test the interviewing method. In the remaining climate-sensitive sectors we later conducted a slightly improved survey via written questionnaires, due to budget constraints.

Per sector and federal state we developed a specific questionnaire. All questionnaires were divided into two main parts: (a) Rating of risks and opportunities, and (b) appraisal of adaptation measures.

The rating of risks and opportunities focussed on climate change and specific potential elements[7] and sector-specific impacts[8] of climate change

- in the specific sector of the respondent,
- in specific environmental zones[9] within the federal state of the respondent (see Fig. 2-2),
- in different time periods (recently: 1990 to present; in the short-term: present to 2010; in the medium-term: 2010 to 2020; in the long-term: 2020 to 2050),
- on a qualitative scale (very negative – negative – slightly negative – neither positive nor negative – slightly positive – positive – very positive)[10].

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[7] Elements of climate change are for example the increasing average annual temperature and the increased frequency of extreme rainfall events. Respondents from all sectors contemplated the same elements (e.g. biodiversity, agriculture), so that positive evaluations sometimes occurred in one sector, while the same element was thought of as negative in another sector.

[8] Sector-specific impacts of climate change are for example in the biodiversity sector changes in the phenology (bud break, bloom etc.) of plants. In each sector, different sector-specific impacts were evaluated.

[9] Environmental zones were not defined by state borders, but were determined by biological and geographical factors. Respondents from several states may have evaluated the same environmental zone, but different state-specific parts of the environmental zone were considered.

[10] Pilot-interviews in the forestry sector on the evaluation of the significance of elements and impacts of climate change in the specific states were conducted without differentiation by time period or environmental zone.

Positive ratings are regarded as acknowledgments of opportunities, negative ratings as acknowledgments of risks.

For example, the respondent from the health sector in Baden-Württemberg rated the potential impact of climate change "more problems regarding heat waves (circulation problems, cerebral vascular diseases, respiratory diseases, heat-related deaths)" in the environmental zone 'upper Rhine rift' in recent times as "negative" and in the short-term as "very negative". Therefore the respondent sees this impact as a large risk.

We asked the respondents to consider (a) if they thought a specific climatic development would impact environmental zones in their federal state, and how strong the climatic phenomenon would be according to their view, (b) how positive or negative this development would impact their specific sector within the environmental zone during a specific period of time, and (c) how developed the adaptation and adaptive capacity of their sector is or will be concerning this climatic development in their federal state, so that risks could be avoided and opportunities exploited.

Besides enquiring about standardised elements and impacts of climate change, respondents were asked about further opportunities and risks they envisage for their sector in their federal state.

Furthermore we investigated the level of information about climate change and its impact, for example by asking if the respondents had access to analyses of the climatic development of the recent years or decades in their federal state, or to projections of future climatic development (scenarios). Knowing the level of information is useful to get an impression of the reliability of the judgements revealed by the survey.

Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen.

Fig. 2-2: Environmental zones that were evaluated with regard to potential impacts of climate change.

In the **appraisal of adaptation**, we were interested in the respondents' impressions

- of the effectiveness of various sector-specific measures, to respond to potential impacts of climate change in the specific federal state (i.e. to mitigate risks, and capitalize on opportunities); possible answers were "effective" or "not effective",
- of the present degree of implementation of measures within the specific federal state on a qualitative scale (not discussed – currently considered – planned – partially implemented – implemented),
- of the reasons for implementation or failed implementation of measures (for climate change or other reasons),
- of the obstacles for a successful implementation of the measure (financial, organisational, legislative, lacking knowledge, others obstacles), in case the measure is not yet fully implemented, and
- of how complicated it would be to implement the measure with regard to the obstacles, on a qualitative scale (not complicated – slightly complicated – complicated – very complicated).

We explicitly asked the respondents to answer these questions even if no adaptation measures to the impacts of climate change have yet been implemented in their federal state, since often measures that are suitable for climate change adaptation have already been implemented for other reasons (e.g. conversion to mixed forests in forestry).

In addition to the standardised questions on adaptation measures, the questionnaire enquires about further measures that would be suitable in the view of the respondent to adapt to the impacts of climate change in their sector and federal state.

Furthermore we explore the degree to which adaptation to climate change has been discussed in the specific functional department, in order to identify such measures and initiatives that are aimed specifically at climate change adaptation. For example, we enquire about the existence of practical programmes (i.e. projects that are not primarily research related) on adaptation to the impacts of climate change. The present significance of the topic “adaptation to climate change” relative to other topics discussed in the specific administration is assessed on a qualitative scale (unimportant – slightly important – important – very important).

The uncertainty of climate change impacts is a particular challenge in the field of adaptation. The assessment of climate change and its potential impacts always contains a certain uncertainty. Absolutely certain predictions about the future climatic development do not exist. Therefore the questionnaire enquires about how the specific administration deals with this uncertainty, and how this uncertainty is taken into account in the planning of adaptation measures.

2.7 Stakeholder-Workshop

In Germany, the public and political discourse on necessary responses to climate change has so far been focussed on measures for emission reduction. Such measures are necessary, because they reduce the cause of anthropogenic climate change. However, it is just as necessary to adapt to the impacts of climate change, a fact that only recently has drawn increased attention in Germany. Public awareness, as well as awareness of decision makers from the private and public sector and from the administration for this issue has to be increased.

The survey within the climate-sensitive sectors forestry, agriculture, water management, tourism, nature conservation, health, and transport that was described in the previous section addressed only representatives of the functional departments of the federal states. The Federal Environmental Agency, supported by the Potsdam Institute of Climate Impact Research (PIK) therefore conducted a stakeholder-workshop with representatives from free enterprises, policy, administration, and associations (including nature conservation groups), to gain additional insights also from the private sector.

Aims of the Workshop

The aims of the stakeholder-workshop were:

- To provide information and a forum for discussion of research results on climate impacts and adaptation in Germany, and to raise the awareness of relevant actors about the climate problem and adaptation needs,
- To initiate a dialogue between actors in order to improve the assessment of vulnerability,
- To check recommendations for adaptation measures with relevant actors,
- To communicate uncertainties, discuss decision-making under uncertainty and the use of research results with actors,
- Public relations, including accompanying press releases and press conferences (impacts of climate change, the necessity of mitigation and adaptation),
- To kick-off a network of actors working on adaptation to climate impacts in Germany through expansion of the existing network within administrations; particularly clarification of the role of such a network of actors, including an analysis of demands and requirements: Identification of needs for further information and guidance,
- Introduction of the aims, tasks and products of the *Centre of Competence for Climate Impacts* at the Federal Environmental Agency; including further competences.

The workshop program designed to fulfil these aims can be found in Box 2-1.

Box 2-1 – Program of the Stakeholder-Workshop

9:00 h	**Welcome; Introduction to the Aims of the Workshops** Dr. H. Lehmann (Federal Environmental Agency, UBA), Prof. W. Cramer (Potsdam Institute for Climate Impact Research, PIK)
9:15 h	**Participants' Expectations – From Interviews Prior to the Workshop** T. Grothmann (Potsdam Institute for Climate Impact Research, PIK)
9:30 h	**Short Introductory Statement by all Participants**
10:15 h	**Climate Impacts and Adaptation – Concepts and Definitions of Relevant Terms** T. Grothmann (Potsdam Institute for Climate Impact Research, PIK)
10:30 h	BREAK
10:45 h	**Probabilities of the Occurrence of Extreme Events in Germany** Prof. C.-D. Schönwiese (Meteorological Institute of Frankfurt University)
11:15 h	**Potential Impacts of Climate Change on Agriculture, Forestry, Water Management, Nature Conservation, Tourism, Transport and Health in Germany** Dr. M. Zebisch (Potsdam Institute for Climate Impact Research, PIK)
12:00 h	**Decision-making, Communication and Dealing with Uncertainties** Prof. G. Gigerenzer (Max Planck Institute for Human Development, Berlin)
12:30 h	LUNCH BREAK
13:30 h	**Adaptation Measures in Germany – Exploiting Opportunities and Mitigating Risks** T. Grothmann (Potsdam Institute for Climate Impact Research, PIK)
14:15 h	**Discussion**
15:00 h	BREAK
15:15 h	Continued Discussion
15:45 h	**Future Perspective: Tasks and Structure of the Centre of Competence for Climate Impacts at UBA** P. Mahrenholz (Federal Environmental Agency, UBA)
16:45 h	**Summary of the Workshop Results, Conclusions and Feedback** T. Grothmann (Potsdam Institute for Climate Impact Research, PIK)
17:00 h	**Farewell and Outlook** Dr. B. Hain (Federal Environmental Agency, UBA)

Workshop Participants

To facilitate discussion we limited the number of participants to 35. We tried to secure participation of 2-3 actors from each of the seven climate-sensitive sectors. For the sectors agriculture, forestry, water management, transport and tourism we particularly aimed at representatives from free enterprises, for the health sector we sought experts from related institutions, for biodiversity and nature conservation representatives from federal natures conservation agencies, as well as nature conservation associations. Furthermore, we invited representatives from the existing forum "climate impacts" of the Federal Environmental Agency that includes deputies from all federal states. Further participants were climate-policy consultants from the Lower House of German Parliament and representatives from the Federal Environmental Agency that are involved in the planning and implementation of the Centre of Competence for Climate Impacts. Finally, we invited speakers from the scientific community.

Participants' Interviews Prior to the Workshop

Prior to the workshop we conducted participants' interviews via written questionnaires. We particularly assessed the expectations participants had concerning the workshop. Furthermore, we enquired about their impression of risks and opportunities of climate change, as well as about the significance of the topic "adaptation to climate change" within their organisation – the same questions were asked in the survey of regional experts (see 2.6).

2.8 Integrated Vulnerability Assessment

The term "vulnerability" refers to the potential of harm of the human-environment system due to global change (see chapter 1.3.3). In the context of global change this study is particularly concerned with climate change[11], but also with the increase in atmospheric carbon dioxide concentration and with land use change. We distinguish to kinds of vulnerability:

- Vulnerability without further adaptation (current vulnerability, business-as-usual scenario) – Future risk of harm of a human-environment system due to global change (particularly climate change) under the assumption that its degree of adaptation (e.g. flood protection) will not change in future.
- Vulnerability with further adaptation (improved-business scenario) – Future risk of harm of a human-environment system due to global change (particularly climate change) under the assumption that present adaptive capacity will be fully used to improve its degree of adaptation in future.

By comparing vulnerability *without* further adaptation (business-as-usual scenario) and vulnerability *with* further adaptation (improved-business scenario) we obtain an impression of the risk of damages due to global change (particularly climate change) with and without further measures of adaptation.

Both kinds of vulnerability are assessed on a qualitative scale with three steps (low – moderate – high vulnerability). We deliberately avoided a quantitative vulnerability index; since such an index would give the impression of a level of precision that is neither realistic concerning the potential impacts of global change, nor concerning the adaptation to these impacts.

To assess vulnerability we integrated results on scenarios of potential impacts of global change in Germany (see 2.1 to 2.4), findings from other studies and projects (see 2.5) and results from regional expert surveys (see 2.6). This was done through a dialogue between the participating researchers and with consideration of the regional experts' assessment of risks and vulnerabilities. It was initially planned to also consider the views of representatives from free enterprises, non-governmental organisations, administration and policy, which participated in the stakeholder-workshop (see chapters 2.7 and 5). However, the participants' interviews prior to the workshop revealed that their knowledge of the topic was not sufficient for an estimation of vulnerability.

We present vulnerability assessments of the seven climate-sensitive sectors (forestry, agriculture, water management, tourism, nature conservation, health, and transport) (see chapters 4 and 6.1.2). Furthermore, chapter 6.1.1 presents a comparative vulnerability assessment of various regions and environmental zones in Germany.

Finally, we wish to stress that our qualitative vulnerability assessment is a preliminary and highly aggregated statement that mainly serves to summarise risks in the different regions and sectors in Germany. More concrete and practice-oriented information on potential impacts of global change, and climate change respectively can

[11] Since this report is primarily concerned with climate change, we often speak of "vulnerability to climate change" instead of "vulnerability to global change".

be found in the sections “Impacts of Climate Change” within chapter 4. Future studies should include stakeholders and affected groups of people in the process of vulnerability assessment even more than this study was able to, in order to produce more robust estimates of vulnerability.

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3 Global Change in Germany: Climate Change, Land Use Change and Carbon Balance

3.1 Climate Change

3.1.1 Historical Trends

Temperature

Long-term weather recording shows that Germany is already affected climate change. The 1990s were the warmest decade in the 20th century, in accordance to the global observation. The annual average temperature increased by ca. 0.8 to 1.0ºC between 1900 and 2000 (Rapp, 2000; DWD, 2004). However, this warming did not occur linearly (Fig. 3-1). A strong warming up to 1911 was followed by a heterogeneous period. The 1940s were exceptionally warm. After a cooling trend up to the 1970s we now observe a continuous and rapid temperature increase that still continues today. There is strong regional variation. In the last decade (1990s), the temperature rise in southern and south-western Germany was exceptionally strong.

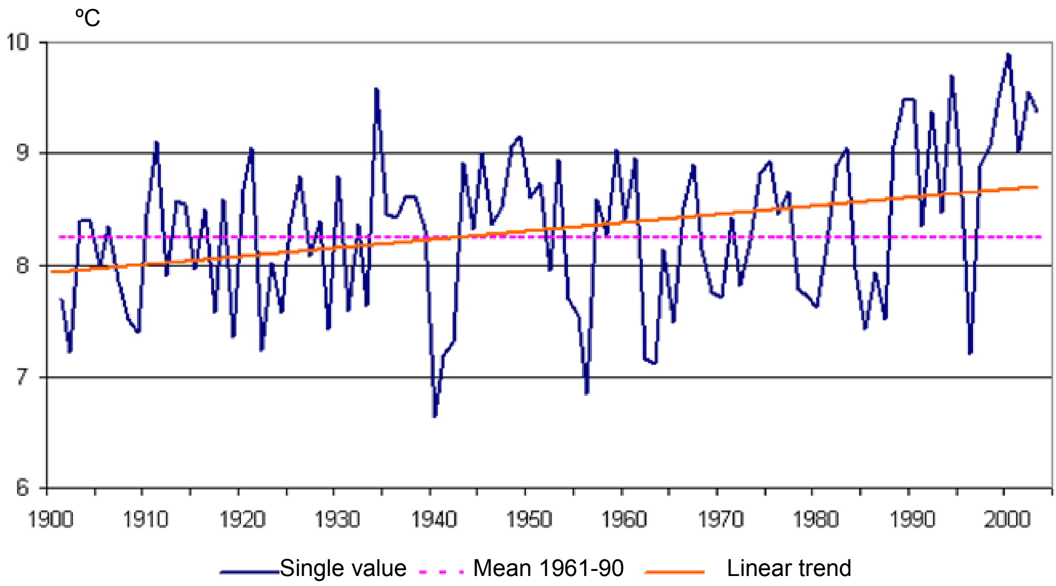

Fig 3-1: Annual average mean daily temperature in Germany 1901-2003 (DWD, 2004).

Tab. 3-1: Overview of climatic trends in Germany (Jonas et al., 2005).

Climatic element	Spring	Summer	Autumn	Winter	Year
Temperature, 1901 - 2000	+ 0.8 °C	+ 1.0 °C	+ 1.1 °C	+ 0.8 °C	+ 1.0 °C
Temperature, 1981 – 2000	+ 1.3 °C	+ 0.7 °C	- 0.1 °C	+ 2.3 °C	+ 1.1 °C
Precipitation, 1901 – 2000	+ 13 %	- 3 %	+ 9 %	+ 19 %	+ 9 %
Precipitation, 1971 - 2000	+ 13 %	+ 4 %	+ 14 %	+ 34 %	+ 16 %

Observations on seasonal trends in the warming depend on period in time and method. During the last twenty years a trend toward stronger temperature increase in winter than in summer has been observed. For example, the temperature increase in the winter months in Germany during the period between 1981 and 2000 was 2.3ºC, while in the summer months it was merely 0.7ºC (Tab. 3-1). This is often attributed to a higher frequency of zonal weather conditions in winter that bring mild oceanic weather to Germany (Günther, 2004).

Precipitation

Precipitation in Germany is characterised by strong regional and seasonal variations. In the long term, neither the average values nor the seasonal or regional distribution show significant trends (Fig. 3-2). During the last 100 years there has been a small trend towards increased winter precipitation, but this trend is not significant (Müller-Westermeier, 2001). In the last 30 years, however, there was indeed a definite increase in winter precipitation. Summer precipitation in contrast showed little change (Tab. 3-1). Again this trend can probably be attributed to an increased frequency of zonal circulation patterns in winter that bring plenty of precipitation with them.

Changes in the duration of snow cover are also relevant. Since 1950, a decrease by 30-40% in the duration of snow cover has been observed in altitudes below 300m in Bavaria and Baden-Württemberg. In the medium altitudes (300-800m) the decrease was 10-20%. In higher altitudes over 800m only small decreases and in places even increases were observed, due to increased winter precipitation and sufficiently low temperatures for snowfall (Günther, 2004).

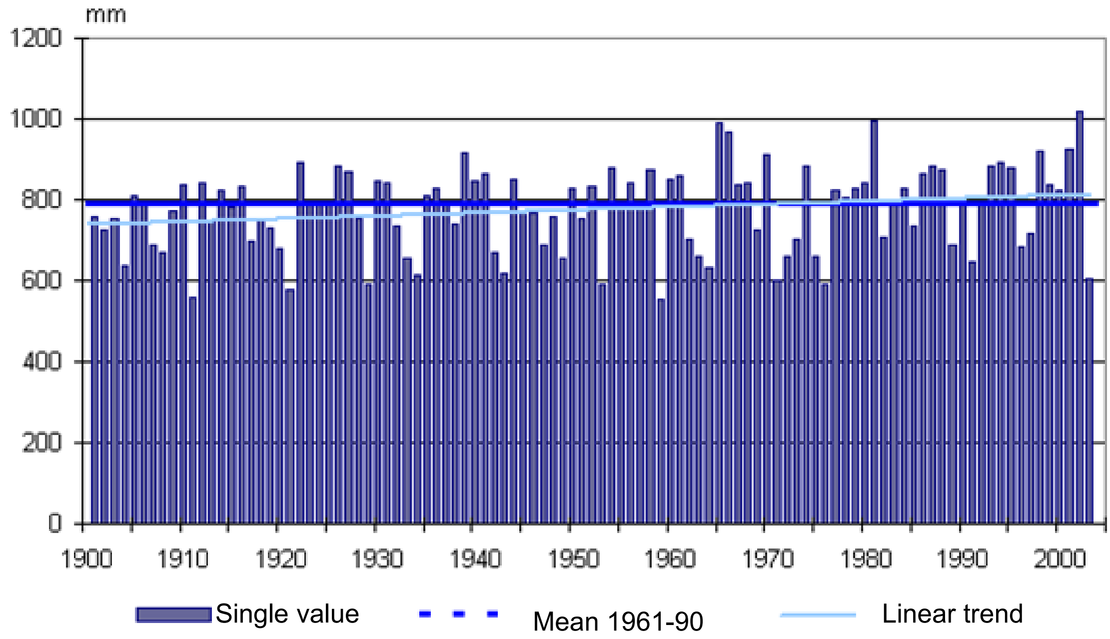

Fig. 3-2: Annual precipitation in Germany 1901–2003 (DWD, 2004).

Climate Extremes

There is only partial evidence for an increase in climate extremes, such as heat waves, extreme rainfalls and storms.

Extreme heat events, such as heat days (T > 30ºC) or heat waves (intervals of more than three days during which the maximum daily temperature lies above a certain high threshold, relative to the specific temperature standard of the weather station) exhibit a definite trend. For example, the probability of occurrence of heat days in the months of July and August has risen over the last one hundred, and especially markedly during the last twenty years at almost all weather stations in Germany. The probability of occurrence of an extremely hot summer such as in the year 2003 increased in the course of the 20th century by more than a factor of 20. Nevertheless, 2003 was an extraordinary year even for today's standards. It was the hottest year in Germany since the beginning of weather recording. With summer temperatures of 3.4ºC above the 30-year mean, 2003 also exhibited the strongest summer anomaly (Schönwiese et al. 2003). Moreover, the year 2003 was exceptionally dry. The continuing long-term dry phase between February and August was extraordinary.

The intensity and frequency of occurrence of extreme rainfall events have increased especially during the last forty years of the 20th century. In general, this trend is more pronounced in the winter than in the summer (Grieser & Beck, 2002).

The intensity and frequency of occurrence of squalls have also been investigated. However, at present no statistically significant trend can be found. There is a tendency of increased probability of occurrence of extremely high daily wind speed maxima (Bft > 8) during winter (with the exception of coastal regions), and decreased occurrence of such maxima in summer (with the exception of southern Germany) (Jonas et al., 2005).

3.1.2 Scenarios of Future Climate Change

Data Sources and Methods

Climate change is s global phenomenon driven by global factors. Therefore, climate modelling needs to be performed by global climate models. Mostly, these are coupled ocean-atmosphere models, which calculate processes within the climate system in grid cells of a resolution of several 100km. These models are called *General Circulation Models* (GCMs).

GCMs produce scenarios for assessments at global scale. For assessments on national scale these model outputs are too coarse. There are various methods for *downscaling* to obtain information at a higher resolution. On the one hand there are regional climate models, such as the model REMO from Hamburg, Germany (Jacob & Podzun, 1997), which simulate atmospheric processes at a higher resolution (10-50km) for a specific study area and use GCM results only for the edges of the study area. On the other hand, there are a number of statistical methods that use historical high-resolution information on climate, atmospheric conditions and weather to downscale the coarse GCM results to finer resolutions. Both methods have advantages and disadvantages. Regional climate models can capture complex weather phenomena (extremes, winds). However, they are difficult to calibrate, sometimes produce unrealistic results due to their complexity and sensitivity, and require very extensive computation. Statistical methods are comparatively robust and less extensive with regard to computation. However, they will partly reproduce errors and uncertainties from the GCMs, and they often produce only average values of climatic parameters. Most statistical methods cannot capture extreme events.

A number of projections of future climate change are available for Germany and specific regions. Among others, these are results from the model REMO, and from statistical methods by Werner and Gerstengarbe (Werner & Gerstengarbe, 1997), and by Enke (Enke, 2003)

This study was mainly based on results from the ATEAM project (see chapter 2). In this project a statistical method (pattern scaling; Mitchell et al. 2004) was used to downscale results from four GCMs (also used in the IPCC report: HadCM3, PCM, CSIRO2, CGCM2) driven by four different emission scenarios (SRES-scenarios, see chapter 2.1) to a grid cell resolution of ca. 16x16 km. The ATEAM climate scenarios cover Europe. ATEAM-results are available as long-term averages for various climate variables for the time slices 2020 (1991-2020), 2050 (2021-2050) and 2080 (2051-2080). Seven priority scenarios were chosen out of the full set of 16 climate scenarios (see Tab 2-1 in chapter 2).

Temperature

All seven ATEAM-scenarios show a distinct warming of Germany (Fig. 3-3). The warming of the long-term average annual temperature in these scenarios ranges from

+1.6 to +3.8ºC by the year 2080.

Regionally, many scenarios show a particularly strong warming in the south-west, and partly also in the far east of Germany (Fig. 3-8 in the Annex). The scenarios show differences in seasonality. The trend of stronger warming in winter, which was observed in historical data, is not maintained in the future scenarios.

The results depend strongly on the choice of emission scenario, as a comparison of temperature scenarios calculated by the climate model HadCM3 shows (A1, A2, B1, B2, red lines in Fig. 3-3). While temperature increases "only" by 2.1ºC until the year 2080 under the two "environment-oriented" scenarios B1 and B2, the "economy-oriented" scenario A1 shows an increase of up to 3.8ºC until 2080 under the assumption of continued use of fossil fuels.

Comparing the results of the different climate models (HadCM3, PCM, CSIRO2, CGCM2, see chapter 2.2) for the A2 scenario, the range of warming by the year 2080 is 1.6 to 2.9ºC. One of the reasons for this large range is the relatively small degree of warming simulated by the model PCM (green line in Fig. 3-3). This model is characterized by particularly low climate sensitivity (warming resulting from a doubling in the atmospheric CO_2-concentration) (Meehl et al., 2005), and therefore produces the low end of the range.

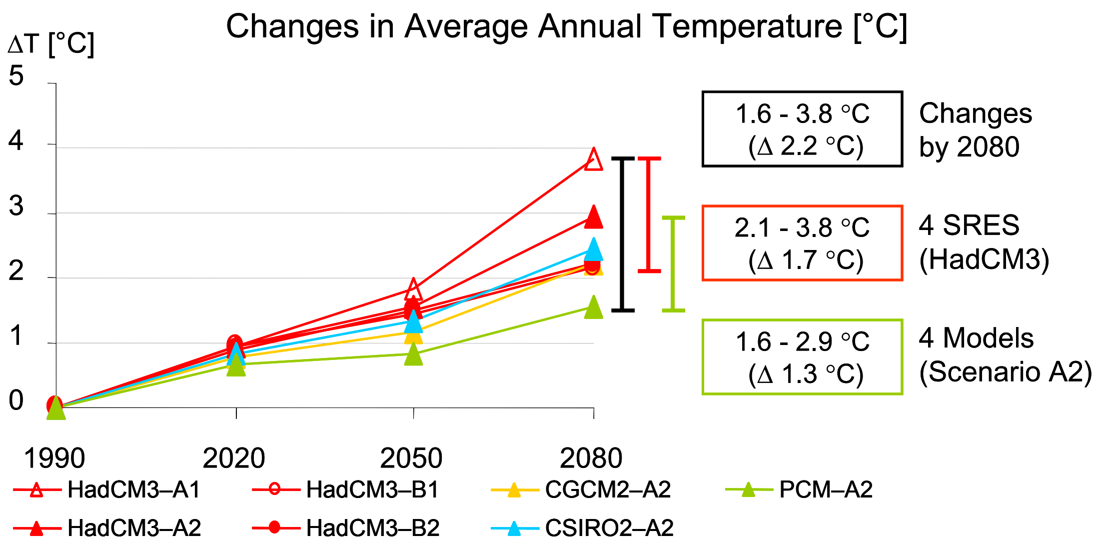

Fig. 3-3: ATEAM-scenarios of long-term annual average temperature change compared to 1990 in Germany up to 2080.

This comparison stresses two sources of uncertainty in climate scenarios. On the one hand, uncertainty in climate projections results from the range of possible greenhouse gas emission trajectories. However, this also indicates a range of choices and future options, since the reduction of greenhouse gas emissions could significantly reduce the expected warming. On the other hand, different climate models produce different results for one and the same emission scenario. This kind of uncertainty results from the difficulty to model the global climate system and the many non-linear processes and feedbacks it contains for a time period of several decades. This uncertainty cannot be entirely removed, even if great advances have been achieved in the recent years.

Regarding temperature, we conclude that at least on long time scales the uncertainty within climate modelling is smaller than the variation brought about by different emission trajectories.

Precipitation

Regarding annual precipitation all scenarios show only very little changes that mostly lie below 10% until 2080. Stronger changes become apparent when contrasting summer and winter precipitation. All seven scenarios show an increase in winter precipitation (Fig. 3-4), while summer precipitation decreases in most scenarios (Fig. 3-5). This is in accordance with the observed trend of a shift of precipitation into winter. This shift is more marked in the scenarios with high greenhouse gas concentrations (A1, A2), than in the "environment-oriented" scenarios (B1, B2).

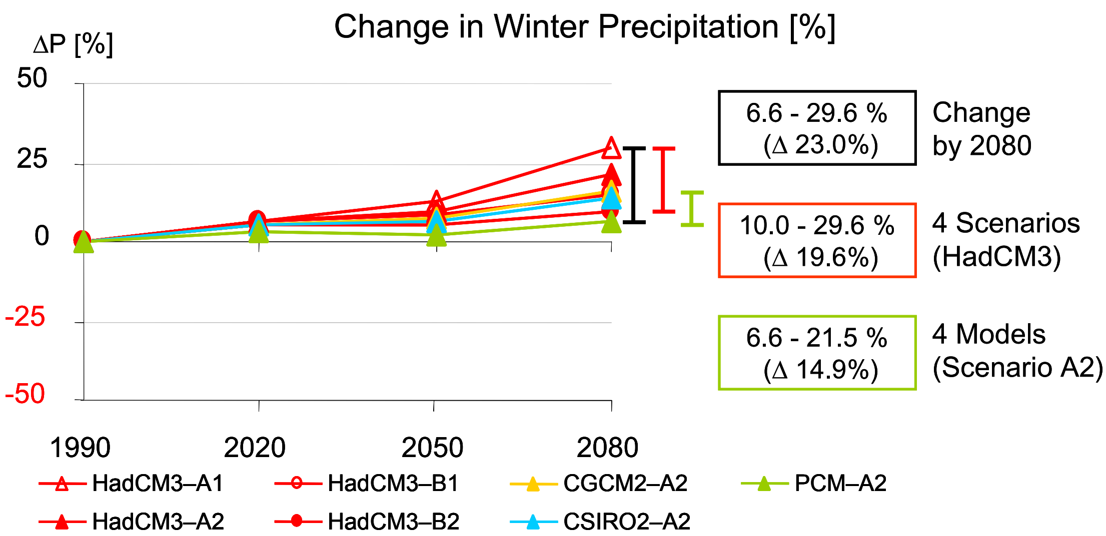

Fig. 3-4: Change in winter precipitation compared to 1990 for seven ATEAM scenarios in Germany up to 2080.

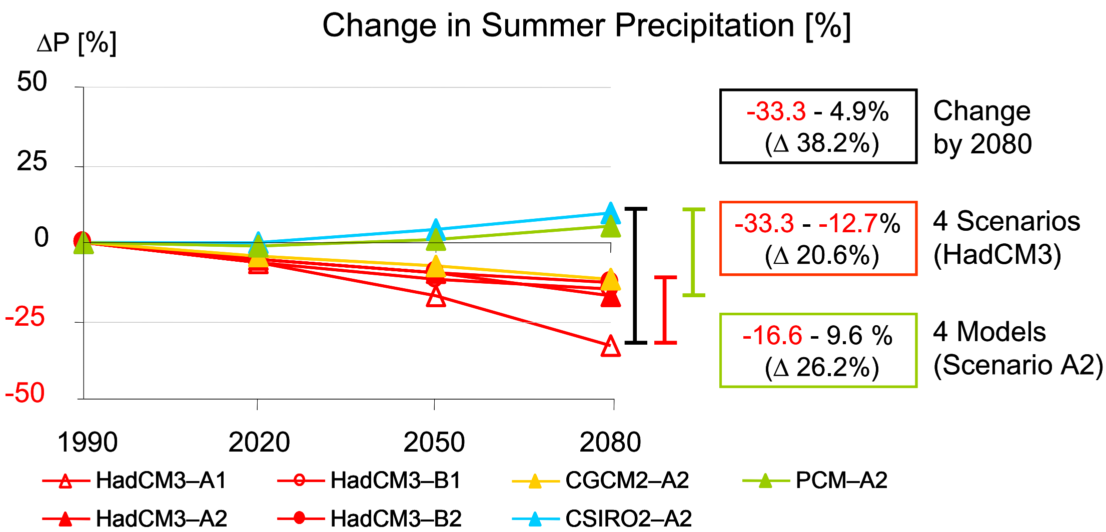

Fig. 3-5: Change in summer precipitation compared to 1990 for seven ATEAM scenarios in Germany up to 2080.

Regionally the most distinct increase of winter precipitation is projected for southern Germany, at least in the scenarios based on HadCM3 (Fig. 3-9 in the Annex). Decreasing summer precipitation in these scenarios is concentrated on Southwest Germany (Rhineland) and the central parts of Eastern Germany (Fig. 3-10 in the Annex). However, the projections of the other climate models partly produce regionally contradicting trends.

In comparison of the different climate models, uncertainty appears much larger in projections of precipitation than of temperature. Particularly the regional distribution of precipitation trends varies strongly.

Results from other Climate Models

In the following we summarise exemplary results from other projects.

For the Elbe-watershed, scenarios by Werner and Gerstengarbe are available (in Wechsung et al., 2004). These show a moderate warming of 1.4ºC by 2055 and a partly distinct decrease in precipitation of up to 200mm, particularly in summer. Ridges of low mountain ranges are exceptions to this trend.

The project KLIWA produced several climate scenarios of the time period 2021-2050 for Bavaria and Baden-Württemberg (Weber, 2004). This project compared results from the regional climate model REMO (Jacob & Podzun, 1997) with the two statistical methods by Enke (Enke, 2003) and by Werner and Gerstengarbe (Werner & Gerstengarbe, 1997). Depending on the model, a temperature increase of 1.2 –1.7ºC in summer was found, and of 1.0 – 2.0ºC in winter. Changes in precipitation by 2050 range from +5% to +13% in summer, and in winter from 0% to +34%. The general trends of warming and increased winter precipitation are corroborated. However, uncertainties also become apparent, particularly in the regional precipitation trends.

Enke (Thüringer Landesanstalt für Umwelt und Geologie, 2004) produced climate scenarios of the time period 2021-2050 for Thuringia. These estimate a warming by 1.5ºC. Winter precipitation is calculated to increase by 23%, while summer precipitation is estimated to decrease by 8%.

Similar scenarios are available for other federal states, for example for Saxony (Enke, 2003), Brandenburg and North Rhine-Westphalia (both using the method by Werner and Gerstengarbe), or are currently developed. By order of the Federal Environmental Agency, climate scenarios at high resolution are currently prepared for the whole of Germany using the regional model REMO. These scenarios are planned to build a consistent database for future research on climate change and its impacts.

3.2 Land-Use Change

Besides climate change, land-use change has a pronounced effect on ecosystems and the services they provide. Therefore, in the ATEAM project, land-use change scenarios were developed in addition to climate change scenarios, and their feedbacks to the climate scenarios were considered.

The most significant land-use change Germany will experience is the abandonment of agricultural areas. As a consequence of cutbacks of subsidies, the eastward enlargement of the EU, liberalisation of the market and falling world prices agricultural areas will be given up, especially on poorer soils. The extent of this abandonment will depend on socio-economic conditions.

This is also the case in the ATEAM-scenarios – land-use change is mostly dependant on the SRES storyline. Agricultural land is projected to decrease by approximately 12% in the environment-oriented B- scenarios (B1, B2), and by up to 25% in the economy-oriented scenarios (Fig. 3-6). The development of forest area shows a different trend. Particularly in the environment-oriented scenarios wood-demand is projected to increase owing to increasing demand for renewable primary products. This leads to afforestation and an increase in forested area by approximately 10% (Fig. 3-6). In contrast, forest area decreases slightly in the economy-oriented fossil fuel based A-scenarios (by approximately 5%).

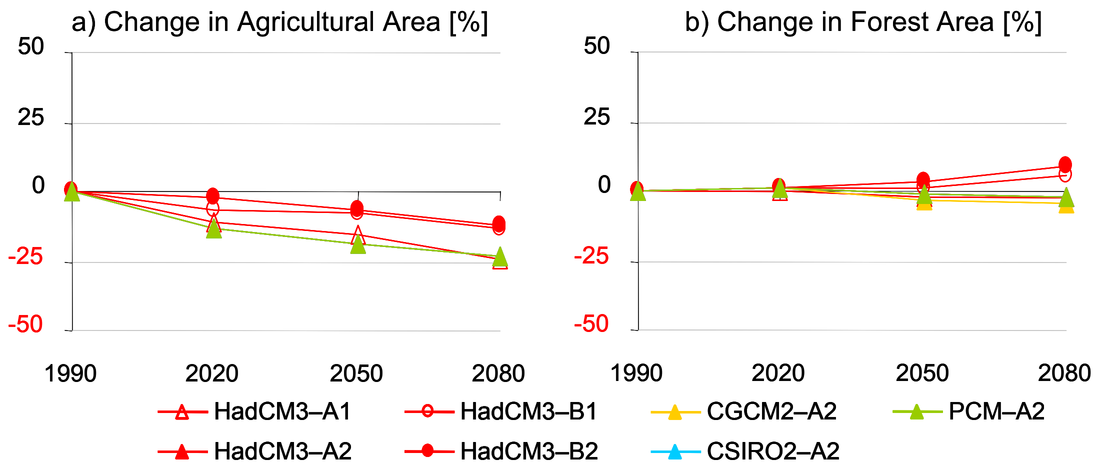

Fig. 3-6: Land-use change (% of total land-use area) for (a) agricultural area and (b) forest area in Germany in comparison to 1990 for all seven ATEAM-scenarios up to the year 2080.

Land abandonment may reflect economic impairment particularly in rural areas. On the other hand, abandoned areas offer an opportunity as production area for renewable primary products (and therefore sources of income for agriculture). Moreover, such areas could be used for nature conservation. Agriculture could also undergo extensification, including a higher proportion of organic farming.

3.3 Net Carbon Balance of the Terrestrial Biosphere

Ecosystems absorb carbon in the form of carbon dioxide (CO_2). Large amounts of this carbon are released again, for example through autotrophic respiration and decomposition of soil organic matter. The balance between carbon uptake and carbon release is referred to as "net carbon balance". Ecosystems with a positive net carbon balance are sources of carbon dioxide to the atmosphere. Ecosystems with a negative net carbon balance are sinks of carbon. Carbon sinks can contribute to the reduction of atmospheric greenhouse gas concentration through the uptake of carbon dioxide, and can therefore contribute to climate protection.

The ATEAM project has produces scenarios of the net carbon balance up to the year 2080 (Fig. 3-7). According to these results, the net carbon balance of Germany's terrestrial biosphere is neutral (neither sink nor source) in the baseline year 1990. All scenarios then show increasing sink strength up to the year 2020. This trend is due to an increased uptake of carbon dioxide by the vegetation owing to enhanced plant growth under CO_2-fertilisation and moderate warming.

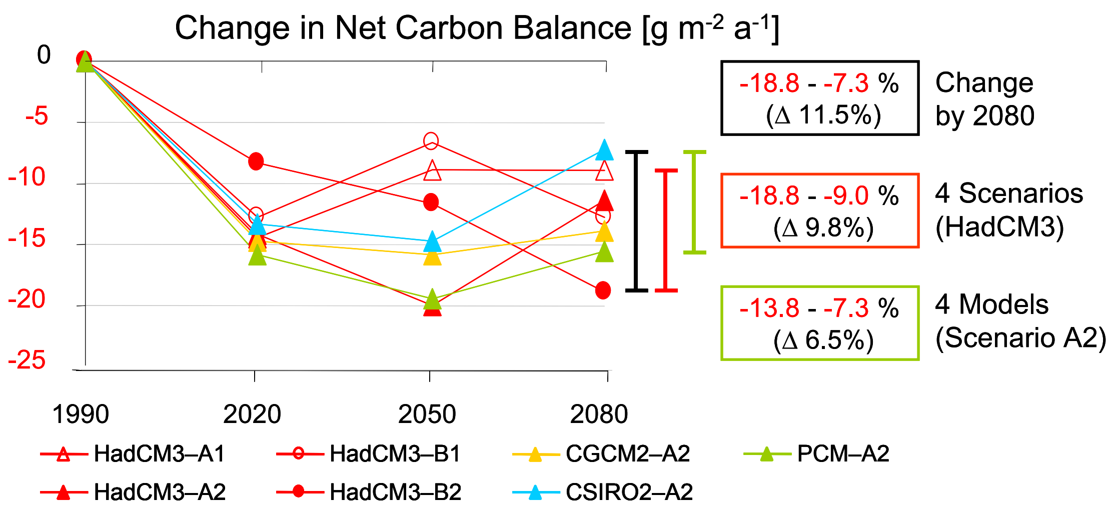

Fig 3-7: Change in net carbon balance in comparison to 1990, up to the year 2080 in Germany, based on all seven ATEAM scenarios. Negative values denote fluxes to the terrestrial biosphere, and therefore carbon sinks.

This trend is sustained until 2050, particularly in the scenarios of strong increases in greenhouse gas concentrations and pronounced warming (A1- and A2-scenarios). From then on the sink strength weakens. On the one hand, no further enhancement of plant growth is possible in response to enhanced CO_2-concentration, due to a saturation effect. On the other hand, rising temperatures lead to enhanced decomposition and releases of soil carbon, so that in the long-term carbon sinks can turn into sources.

However, the trend of increases in carbon sink strength is sustained until 2080 in the environment-oriented scenarios (B1 and B2). This is due in part to a less pronounced warming in these scenarios. Furthermore, in these scenarios afforestation leads to an increased proportion of young carbon-absorbing forest stands.

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3.5 Annex

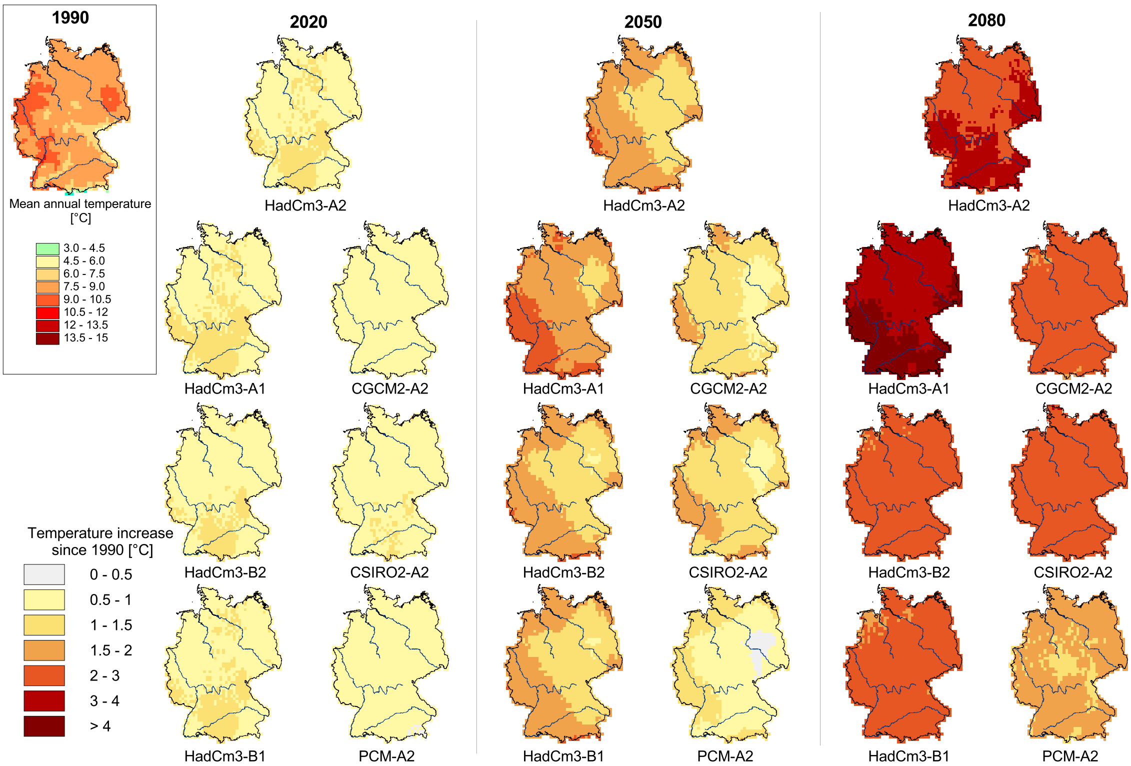

Fig. 3-8: Regional changes in mean annual temperature (ºC) across Germany, seven ATEAM scenarios up to 2080 compared to 1990.

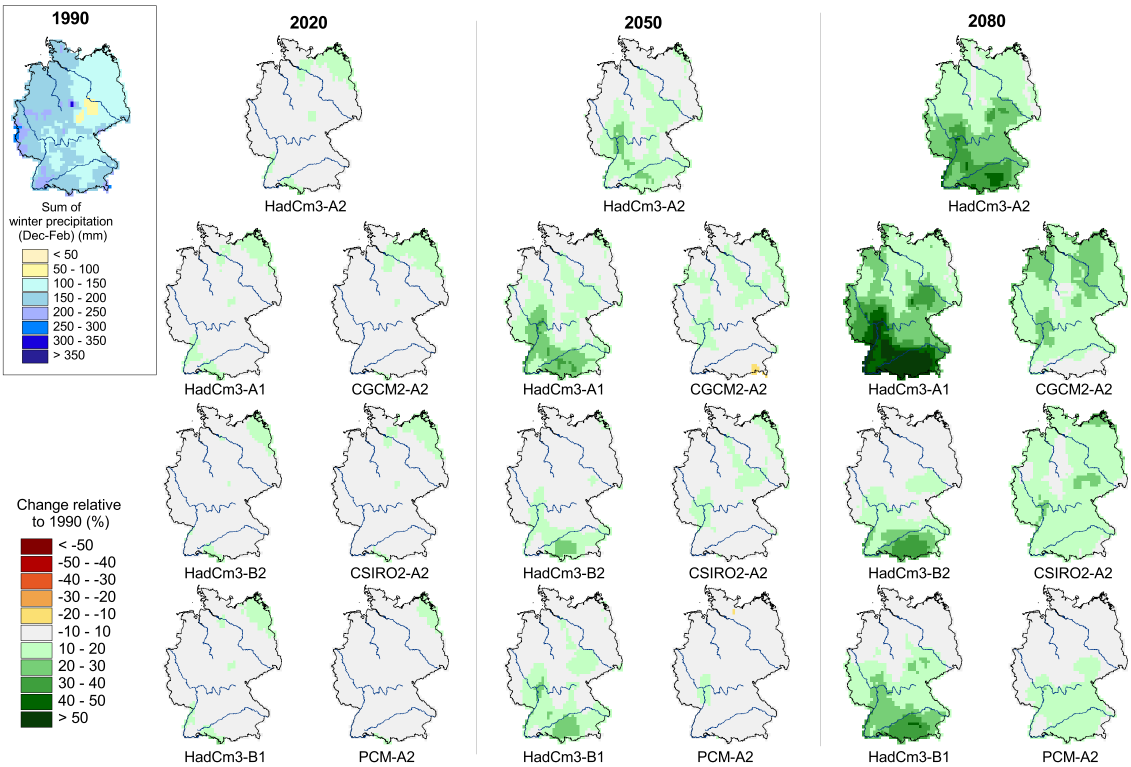

Fig. 3-9: Regional relative changes in the sum of winter precipitation (%) across Germany, seven ATEAM scenarios up to 2080 compared to 1990. Dec = December, Feb = February.

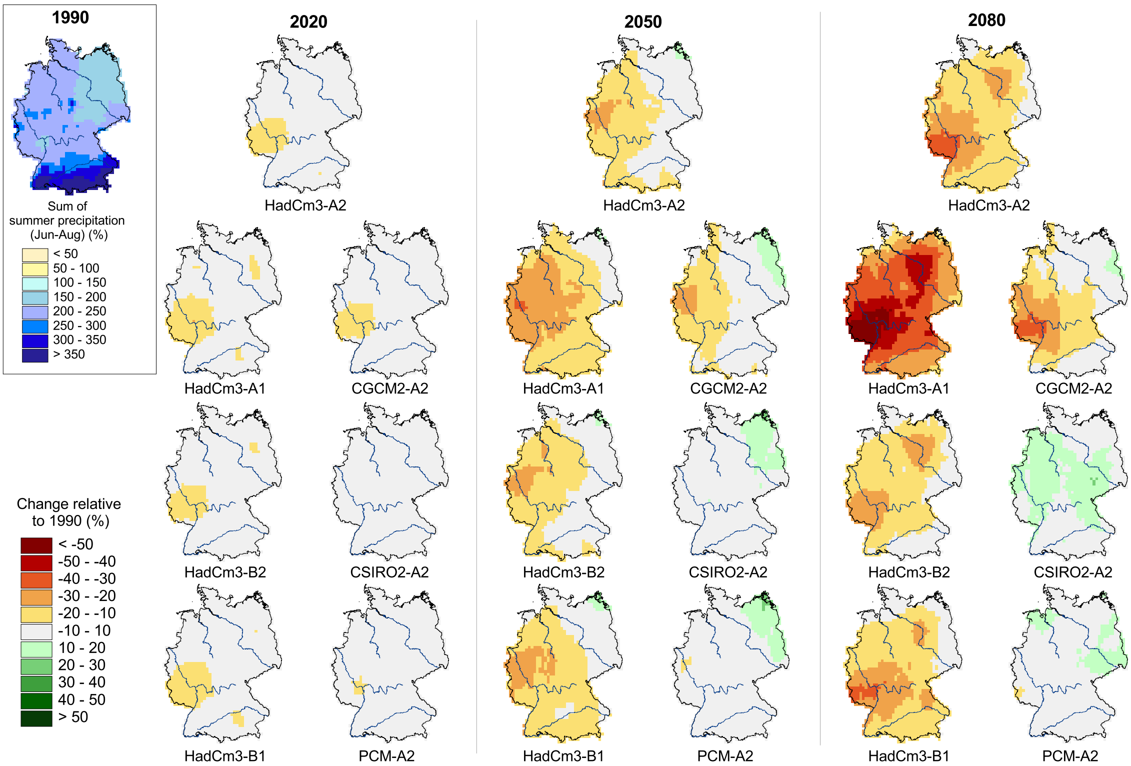

Fig. 3-10: Regional relative changes in the sum of summer precipitation (%) across Germany, seven ATEAM scenarios up to 2080 compared to 1990. Jun = June, Aug = August.

4 Impacts of Global Change and Adaptation Strategies in Selected Climate-Sensitive Systems

4.1 Water Balance, Supply and Distribution

4.1.1 Summary: Vulnerability of the Water Sector

Among the potential negative impacts of climate change, the increased risk of flooding and the decrease in water supply during summer are of primary importance.

These impacts are the result of an observed shift, which is expected to become more pronounced in future, of precipitation from summer to winter, as well as higher evaporation owing to increased temperature. Additionally, the probability of extreme rainfall events is increased particularly in winter and the duration of snow cover is projected to decrease.

Presumably mostly in the months of winter and spring the risk of flooding increases across Germany. The Alpine region and highly built-up regions without sufficient retention areas are particularly at risks. It is as yet unclear to what extent the risk of summer floods will increase.

Especially the central and eastern areas of Germany will suffer from a decreased supply of water in the summer months. The risk of drought increases and is accompanied by constraints in agriculture, forestry, energy supply and navigation, and possibly also in drinking water supply.

A reduction of groundwater recharge is a further potential negative impact of climate change. Hitherto, constraints in drinking water supply due to climate change have not been expected, despite an increasing eutrophication in many areas.

So far, the water sector is little adapted to the impacts of climate change. In the planning of flood protection the impacts of climate change find little consideration in most federal states. Therefore, we presently consider the vulnerability of the water sector as "high" across Germany (business-as-usual scenario, see chapter 2.8). As yet, water supply and distribution is not prepared for water shortages in summer. If no adaptation measures are implemented, the vulnerability of impacted regions (eastern Germany) will be "high". In the remaining areas, vulnerability to water shortages is "moderate".

In general, the water sector should be able to adapt to future climate impacts, since a full range of sufficient adaptation options are available, even if their implementation is mostly considered to be complicated. Saving water and rebuilding natural rivers are considered to be most effective in adapting to a multitude of uncertain impacts of climate change. However, adaptation measures in water supply and distribution can presumably not be implemented without special support (particularly financial resources). If the necessary adaptation measures are implemented, a reduction to "low" vulnerability of the water sector to climate change can be expected (improved-business scenario, see chapter 2.8).

4.1.2 Water and Climate

Water is the basis for almost all processes of life and an important element in all ecosystems. The supply of water in sufficient quantities and quality is the direct prerequisite for various provisioning ecosystem services (see chapter 1.3). Humans rely on water as essential nutritional source, as well as for sanitary purposes. Water is used by industry of the production of goods and services. Other ecosystem services dependant indirectly on water. Rivers, lakes and oceans host plants and animals that are a worthwhile source of nutrition for humans (Lozan et al., 2005). All other sectors covered in this report (forestry, agriculture, water management, tourism, biodiversity/nature conservation, health, and transport) also depend directly or indirectly on the supply of water in sufficient quantity and quality.

Besides the long-term availability of water in sufficient quantity and quality, society is in need of keeping the risk through hydrological extreme events as small as possible (regulating ecosystem service). A deficiency of water leads to droughts that have negative impacts on nature (aquatic ecosystems and wetlands) and society (agriculture, forestry, navigation, industry, energy generation, drinking water supply). Too much water leads to flood events that can cause high human and physical damages.

The water cycle is part of the climatic system, and therefore closely intertwined with climatic factors. Terrestrial ecosystems receive water mostly through precipitation. A large part of the water evaporates directly (evaporation) or is returned to the atmosphere via plants (transpiration). The sum of these processes, the so-called evapotranspiration, depends of climatic factors such as temperature, radiation, vapour pressure, and wind. Furthermore, the structure and composition of land cover plays a major role.

The part of precipitation that does not evaporate or transpire runs off above- or belowground, feeding the surface waters and ground water resources. The size of this runoff is an important indicator for water surplus and the amount of water that is available to the human-environment system. Furthermore, short term "stores" (e.g. the soil) are recharged or emptied.

Besides runoff, the amount of groundwater resources, the geological conditions for groundwater recharge, and the connection to surface waters are important for water availability. The availability of water to nature and society also strongly depends on regional water demand. If tis demand is high, water availability can be limited.

4.1.3 Baseline Situation: Water Supply and Distribution in Germany

Water in Germany

Germany is a country rich in water; 2.2% of its surface area is covered by water. The water surface is comprised of eleven large rivers (Elbe, Danube, Rhine, Weser, Ems, Warnow/Peene, Elder, Schiel/Trave, Oder, Rhône, Maas; categorised according to the Water Framework Directive of the European Commission (EG-Wasserrahmenrichtlinie, EG-WRRL)) and their receiving streams. Natural lakes contribute approximately 0.85% of the surface area. Furthermore, Germany has 291 dams. Approximately 11.7% of the surface area are designated to drinking water protection and underlie restrictions of use to protect existing water resources.

Water Supply

The supply of water depends strongly on the climatic water balance. Within Germany, the climatic water balance, defined as the difference between precipitation and potential evapotranspiration, is highly heterogeneous on large and small scales (Fig. 4.1-1). While significantly more precipitation falls on the Alpine region than is lost through evapotranspiration (positive water balance), the climatic water balance is negative in large parts of eastern Germany. The largest deficits in climatic water balance occur in the eastern foreland of the lower mountain range Harz and in the fault of the river Oder, where the lowest amounts of precipitations within Germany fall. In the summer months large parts of Germany exhibit a negative balance. If the weather is low in precipitation, a negative balance can occur in all months except November and December. Regions with an unfavourable water balance have potentially low water supply and therefore are more at risk to suffer from drought and aridity than other regions.

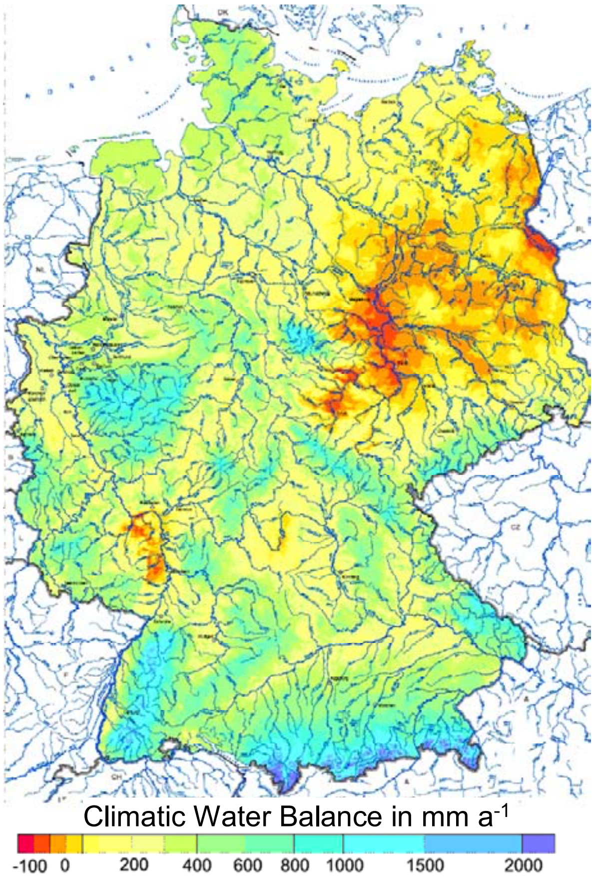

Fig. 4.1-1: Climatic water balance of Germany (BMU, 2003).

Water Demand

German water demand is regionally and locally heterogeneous. It depends on the degree of colonisation and industrialisation, as well as on seasonally varying water supply and demand. The largest amount of water, approximately 56%, is used as cooling water by power authorities. Mining and industry together use approximately 18%. Approximately 13% of water use goes to public water supply. Agriculture and forestry use less than 1% of the water (Fig. 4.1-2; Federal Statistical Office, 2005).

Between 1990 and 1998, the amount of water used by industry and heat power plants declined sharply. For example, particularly in eastern Germany the daily water demand decreased from 142 L $day^{-1}capita^{-1}$ (1990) to 93 L $day^{-1}capita^{-1}$ (2000) (BGW, 2001). This was achieved by water saving technologies and investments in more effective water supply and distribution facilities. Increased prices of water and wastewater treatment furthermore changed consumption behaviour of inhabitants, methods of production and the elimination of water losses in conduit.

Momentarily, Germany’s water resources are judged as sufficient, since only approximately 24% of available resources are used (UBA, 2001). However, even today water shortages occur regularly in regions with unfavourable water balance (particularly Brandenburg). In particular, this region lacks water to keep the water level of rivers constant and to flood the pits remaining after strip mining.

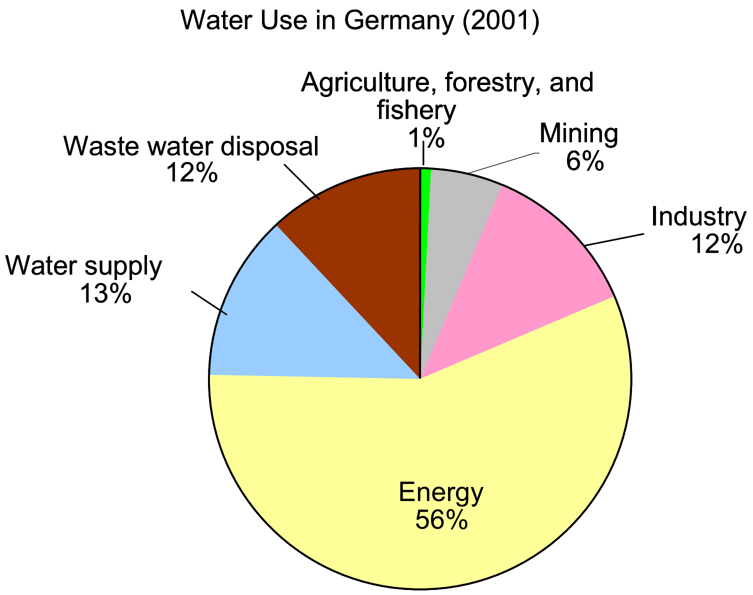

Fig. 4.1-2: Extraction of water from the environment in Germany in the year 2001 (Federal Statistical Office, 2005).

The Risk of Periods of Aridity and Drought

In general, arid periods are a natural and recurring phenomenon in Europe (EEA, 2001). The hot and dry years in the 1990s, and particularly the year 2003 have shown that Germany can be hit by low water and drought, in spite of lying in the temperate climate zone. In Germany this exceptionally long dry and hot phase has led amongst other things to increased risk of forest fires and losses in the agricultural sector. There were constraints in inland navigation, as well as in heat, water and nuclear power plants. The reinsurance company Munich Re estimates the costs of the heat wave of 2003 in Germany at more than 1.2 billion € (Eisenreich, 2005). However, the supply of drinking water was not threatened during 2003 (Demuth, 2004).

Risk of Flood Events

The occurrence of flood events is determined by the characteristics of precipitation (intensity, volume, duration), initial conditions (soil moisture), conditions of infiltration, geomorphology, event size, as well as by temporal and spatial scales of the precipitation (Niehoff, 2002).

Extreme rainfall events in the past have regularly caused severe flood catastrophes, accompanied by physical damages and losses of lives (EEA, 2001). Flood events are a frequently occurring danger in Germany and should be taken seriously, as the hundred-year-flood at the Rhine in the winter of 1993/1994 and 1995, at the Oder in the summer of 1997, and the thousand-year-flood at the Danube, Elbe and their tributaries in August 2002 have shown. The Elbe flood alone caused 20 casualties and a physical damage of approximately 9 billion € (BFG, 2002). Flood events in large watersheds are mostly caused by long-lasting, advective rainfall events (land rain), with or without contributions of snow melting. On the other hand, convective extreme rainfall events (local extreme rainfall events) often cause small-scale floods with high damage potential. Such small-scale floods cause approximately half of all flood damages in Germany (Bronstert, 1996).

A plausible cause of the observed increase in the frequency of flood events (e.g. in southwest Germany; Caspary, 2004) is, among others, the statistically evident increasing frequency of extreme rainfall events (Grieser & Beck, 2002; Schönwiese, 2005). However, this increase can only be substantiated for the winter months. Therefore, it is believed that the probability of winter floods, such as e.g. the Rhine floods, is already increased. Summer floods, such as e.g. the floods at the Oder 1997 and the Elbe 2002, are often caused by specific general weather situation (e.g. the so-called "Vb weather condition"). Again, a number of studies substantiate at least the increased frequency of such weather conditions (Fricke & Kaminski, 2202).

Besides climatic conditions, a number of other factors are important for flood risk, such as decreased regional water retention capacity due to river regulation, the construction of barrages, the loss of floodplains and wetlands, and the increased sealing of surface areas. For example, the river Rhine has already lost four-fifth of its natural floodplains. Similarly, at the river Elbe only 15% of the natural floodplains remain (IKSE, 1996; BMU, 2002). Moreover, agriculture causes more frequent floods by the usage of heavy machinery on arable fields and the consequent condensation of soils, which hampers the infiltration capacity. At present, the influence of these anthropogenic factors is more pronounced than climate change.

Other Factors

Besides water extraction for industry, households and agriculture, the draining of strip mines for brown coal is an important factor for the water balance. This is done in the Rhineland, the Niederlausitz, and in the region between Helmstedt and Leipzig/Halle. The draining of mines causes a gradual drying up of wetlands, sometimes the running dry of creeks and rivers, and a decrease in the water available for public water supply. Moreover, the water demand for the flooding of pits remaining after strip mining can threaten regional water supply (e.g. at the Spree).

Society depends not only on sufficient water quantities but also on sufficient water quality. In Germany, agriculture hampers the water quality of groundwater and receiving streams through the use of fertilisers and pesticides on arable land. These are leached to the groundwater or are transported to the surface waters through erosion, leading to eutrophication of surface waters and oceans. Charging groundwater with nutrients, such as e.g. nitrate, causes a profound loss in the usability of the aquifer as drinking water resource and can negatively impact groundwater biology. Moreover, water resources are burdened with heavy metals, organic chemicals, and pesticides.

4.1.4 Impacts of Climate Change – Trends and Projections

Water Supply and the Risk of Droughts

The future impacts of climate change on the water sector are highly dependent on how the regional and seasonal distribution of precipitation develops, since precipitation and the water sector are tightly linked. However, the projection of regional precipitation by climate models comes with large uncertainties. Depending on the model, the scenarios may differ sharply from each other. Therefore, statements about water demand also come with large uncertainties. The expected temperature increase mainly causes an increase in evapotranspiration and therefore potentially decreases the climatic water balance. Moreover, indirect consequences such as e.g. changes in winter snow cover and increased water use through elongated vegetation period also affect the water balance.

We analysed scenarios of mean annual runoff, "drought runoff" (Q90), and summer runoff across Germany from the ATEAM project (see chapter 2; Schröter et al., 2004). Here we understand runoff as the difference between precipitation and actual evapotranspiration (vegetation-dependent transpiration). The amount of runoff is therefore comparable with the climatic water balance.

The annual runoff is tightly linked to annual precipitation. Due to the small changes in annual precipitation under most scenarios, changes in annual runoff in Germany also lie below 10% in all seven climate scenarios studied here (Fig. 4.1-3). The regional distribution is however different (Fig. 4.1-9 in the Annex). In the North and Northeast of Germany there appears to be a trend of decreasing runoff, while there is a trend of slightly increasing runoff in the South, particularly in the scenarios based on the climate model HadCM3. However, the results based on the climate model CSIRO2 exhibit the exact opposite trend.

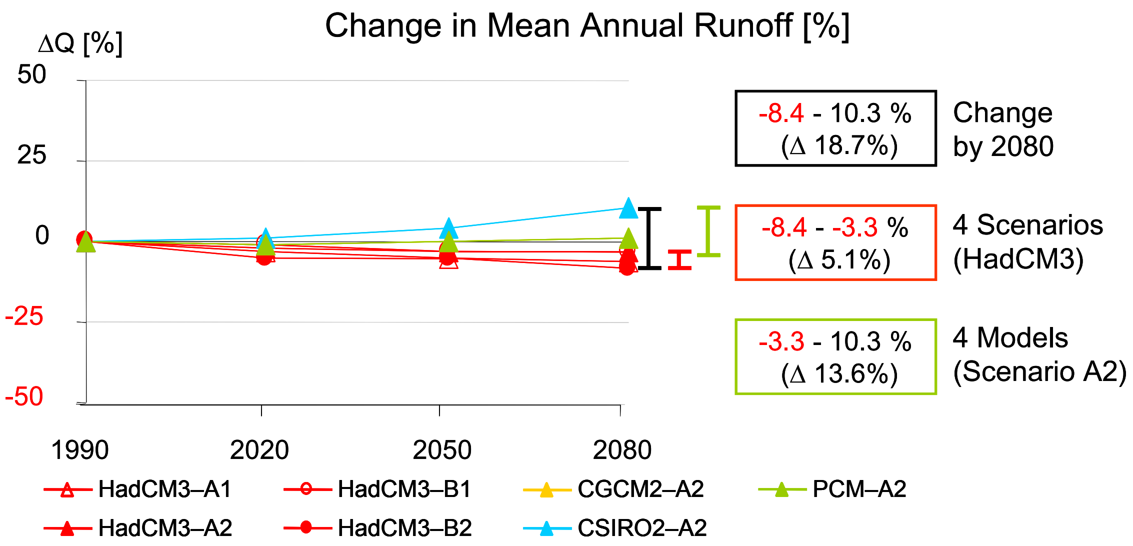

Fig. 4.1-3: Relative change in mean annual runoff up to 2080 compared to 1990 for seven ATEAM scenarios.

The interpretation of drought runoff (Q90) is more revealing than the analysis of annual runoff. Q90 (drought runoff) is the annual runoff that is exceeded in nine years out of ten. That is, the runoff in one out of ten years lies under the Q90 value. Therefore this value is an indicator of the runoff to be expected in arid years. On the whole, the development of drought runoff over time within this century in Germany shows a similar picture as annual runoff (Fig. 4.1-4).

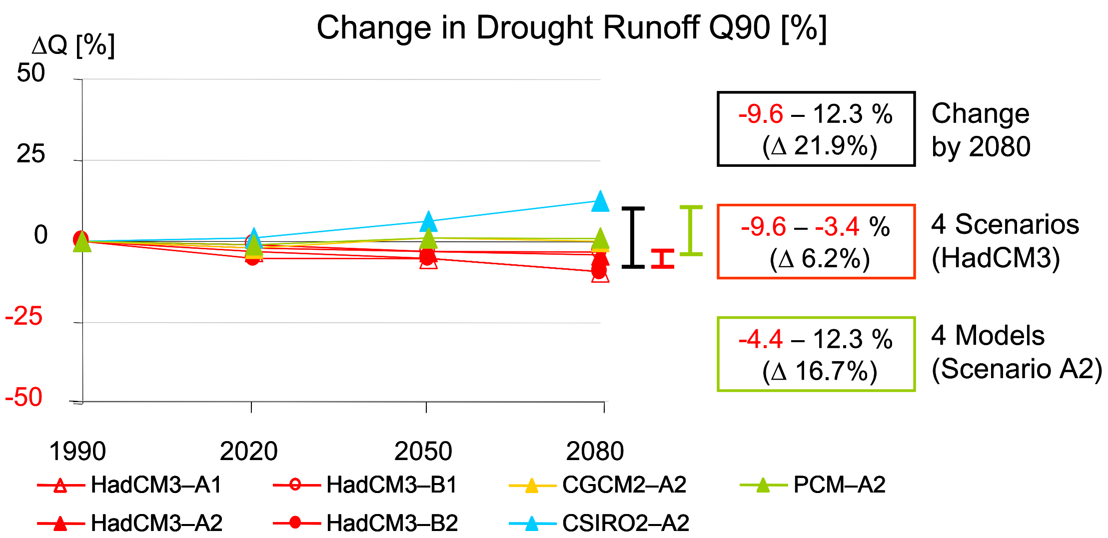

Fig. 4.1-4: Relative change in drought runoff Q90 up to 2080 compared to 1990 for seven ATEAM scenarios. Q90 (drought runoff) is the annual runoff that is exceeded in nine years out of ten.

The range of change in drought runoff by 2080 is −10% to +12%. There are strong regional differences, with local decreases of over 50% in some parts of Northern and Eastern Germany (Fig. 4.1-10 in the Annex). However, again different climate models produce different regional patterns.

Results for summer runoff (runoff during the months June, July and August; Fig. 4.1-5) show an even more differentiated pattern. Water availability is distinctly reduced in summer according to five of the seven climate scenarios, due to the shift of precipitation from summer to winter that is projected by many climate models, and owing to the temperature increase, which increases evapotranspiration, and particularly transpiration (through plants) (change by 2080 in comparison to 1990 of –43% to +5%). This reduction in water availability is projected across all parts of Germany (Fig. 4.1-11 in the Annex).

The degree to which a region is hit by changes in runoff depends strongly on the size of the change and on the initial situation. Especially regions that presently have an unfavourable water balance and low runoff, such as e.g. the central regions of Eastern Germany (Fig. 4.1-1), can be strongly impacted by climate change. In these regions, the shift of precipitation from summer to winter leads to further decreases in summer runoff, when the situation has already been difficult in arid years, and causes further water shortages. Even if the results vary between climate models, there is considerable evidence that climate change will increase the risk of arid periods and droughts.

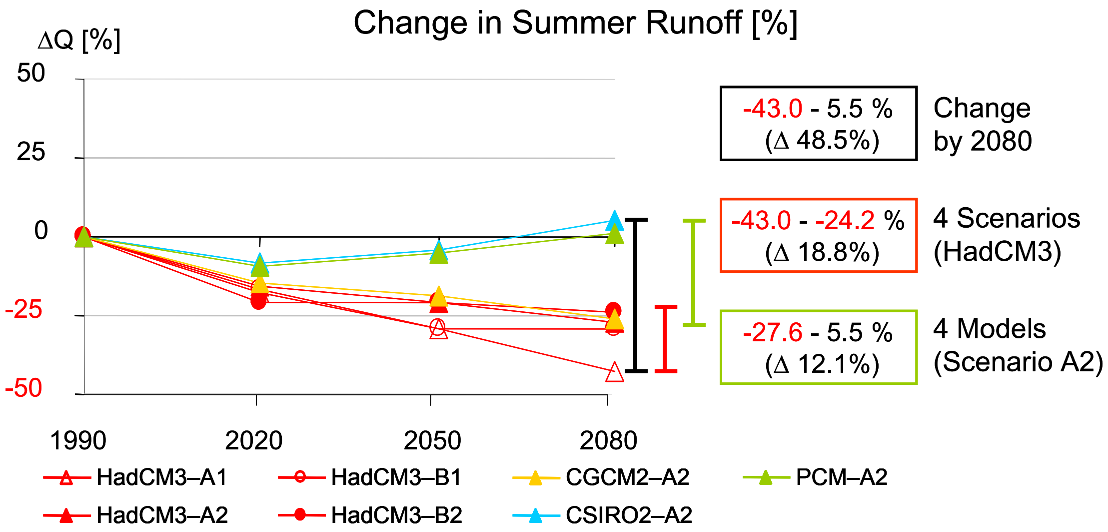

Fig. 4.1-5: Relative change in summer runoff (June – August) up to 2080 compared to 1990 for seven ATEAM scenarios.

Low water and droughts have severe consequences for almost all sectors considered in this study. Agriculture, forestry, energy and drinking water providers, as well as public bodies will have to prepare for recurring arid periods in Germany. Moreover, wetlands and aquatic ecosystems are threatened. In general, there is a clear need for a well-balanced adaptation strategy, which includes storage, limitations in water demand, and alternative sources of water.

Risk of Flood Events

A number of scientists expect a generally increased risk of extreme rainfall events and floods as a consequence of climate change (Palmer & Räisänen, 2002; Milly et al., 2002). Climate change is also expected to impact flood development in Germany, due to changes in precipitation characteristics (Bronstert, 1996). This concerns not only the absolute amount of precipitation, but also intensity, duration and frequency of rainfall events. Regional trends in precipitation development are ambiguous (Eisenreich, 2005), however, there is considerable evidence for a decrease in summer precipitation and an increase in winter and spring precipitation, leading to an increase in the probability of winter floods.

Decreased snowmelt owing to temperature-induced decreases in snow accumulation could, however, reduce the flood peaks (Eisenreich, 2005). Furthermore, decreased frequency of the freezing up of rivers due to temperature increase reduces the probability of floods triggered by ice accumulation, such as have been primarily observed at the Elbe river in the past (Bronstert, 1996).

Integrated Results for Specific Watersheds

Runoff at the river Rhine is expected to shift to early spring, owing to the shift of precipitation from summer to winter (Middlekoop & Kwadijk, 2001). The ATEAM scenarios also project this shift (Fig. 4.1-6). The HadCM3-A2 scenario shows a shift of monthly peak flows of the Rhine (at the water gauge Kaub) from May/June (1990) to March (scenario for 2050).

Detailed case studies for three study regions in the Rhine watershed from the project LAHoR (Bardossy et al., 2003) estimate a decrease in precipitation in November and December, accompanied by an increase in precipitation during the months of March and April by 2080. Based on these finding, the probability of the typical "Christmas floods" at the Rhine will potentially decrease. On the other hand, the probability of flood events in spring increases. This is caused by the increase in precipitation in early spring, as well as by the simultaneous snowmelt in the Alps and higher low mountain ranges.

These results are in accordance with findings of the research group KLIWA, which also project a potential increase in flood risk during winter and early spring for the Rhine (Krahe et al., 2004).

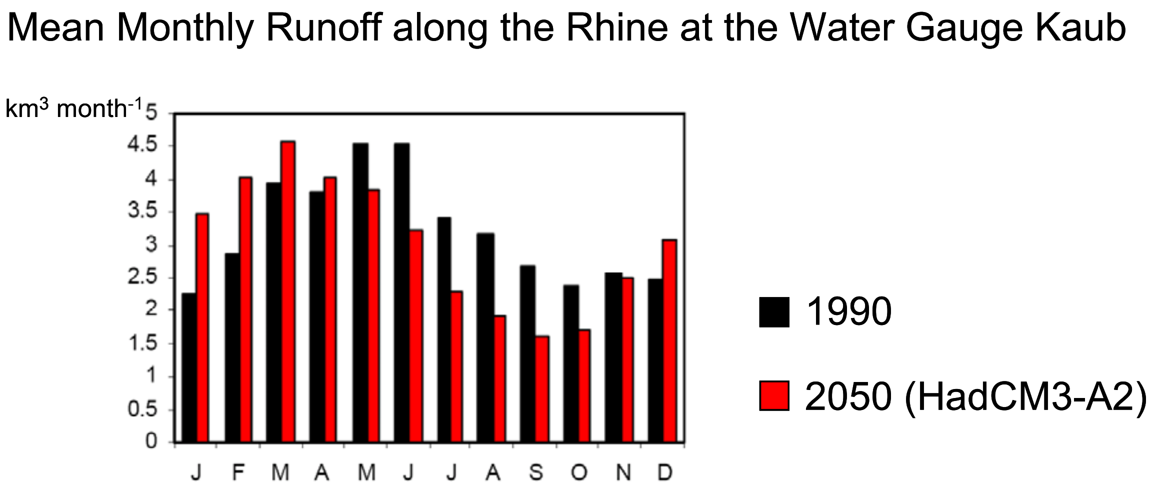

Fig. 4.1-6: Mean monthly runoff along the river Rhine at Kaub 1990 and 2050, climate scenario calculated by climate model HadCM3 with A2 emissions (ATEAM result).

The research group KLIWA also offers results for the watershed of the upper Main (Barth et al., 2004) and the Neckar (Gerlinger, 2004). These results corroborate the trend of shifting runoff to the months February, March, April, as well as a potential increase in flood risk during this time.

Some studies project decreasing water availability in the Elbe watershed. In this region a decrease in runoff by approximately 40% (Wechsung, 2004) and of groundwater recharge of next to 50% (Hattermann et al., 2004) is expected, on the assumption of decreasing annual precipitation up to 2050.

Further Impacts of Climate Change

Changes in river runoff impact water levels and water quality of lakes and canals directly (Eisenreich, 2005). Particularly in shallow and warm water bodies, the growth of zoo- and phytoplankton and therefore the risk of eutrophication can increase, due to declining water levels, increasing warming and increasing suspension of sediment. This development impacts not only drinking water provision, but also sectors such as tourism. For example, decreasing summer precipitation and declining inflow from the headwater threaten the tourism region Spreewald (forested region around the river Spree near Berlin) (Dietrich, 2004).

Potential decreases in water supply especially in the summer month also cause problems in the recultivation and flooding of the remaining pits after strip mining in Eastern Germany (Kaltofen et al., 2004).

Currently no detailed studies are available on the impact of climate change on drinking water supply in Germany. In general no shortages in drinking water are expected, despite decreasing amounts of groundwater storage in North and West Germany, as well as parts of East Germany (BMU, 2001).

4.1.5 Impacts of Climate Change – Assessment by Regional Experts

As described in chapter 2.6, we conducted expert surveys in various climate-sensitive sectors, including water supply and distribution. Sector-specific assessments of potential elements and impacts of climate change are available for different environmental zones (see chapter 2.6) from seven federal states: Schleswig-Holstein, Hamburg, Berlin, Saxony, Thuringia, Hesse and Baden-Württemberg. Positive ratings are regarded as acknowledgments of opportunities, negative ratings as acknowledgments of risks. The results of the survey are depicted in Fig. 4.1-7. The assessment, which is discussed in the following, must be seen as preliminary, since only one expert per federal state was approached and the return of the questionnaires from the 16 federal states was scarce. On the other hand, more than half of the respondents base their assessment on studies of past and future climate development and its impacts in their federal state.

General Assessment of Climate Change

The respondents rated the outcome of climate change for the water sector in recent times (1990 to today) mainly as "neither positive nor negative", although some responded "slightly negative" (responses were averaged over all environmental zones and federal states). In the short (today to 2010), medium (2010 to 2020) and long (2020 to 2050) term climate changes is judged on average as "slightly negative", with increases in the number of "negative" ratings for the more distant future. No respondent used the rating "very negative", neither for any environmental zones nor for a specific time period. Also, there are no positive ratings of climate change. Therefore the outcome of climate change for the German water sector is seen uniformly as negative.

Risk Assessment

Respondents thought of increased extreme rainfall events as the greatest risk in the short term, with an average rating of this potential *element of climate change* as "negative". In the medium and long term, this risk is seen as increasingly negative. Increasing summer temperature, more heat days and heat waves, the decrease in annual precipitation[12] and larger variation of precipitation between years were rated as "slightly negative" in the short term. Increasing average annual temperature, increasing winter temperature and fewer frost days were seen as neutral in the short term, but were rated as risks in the medium to long term. In general, negative rating increased with time.

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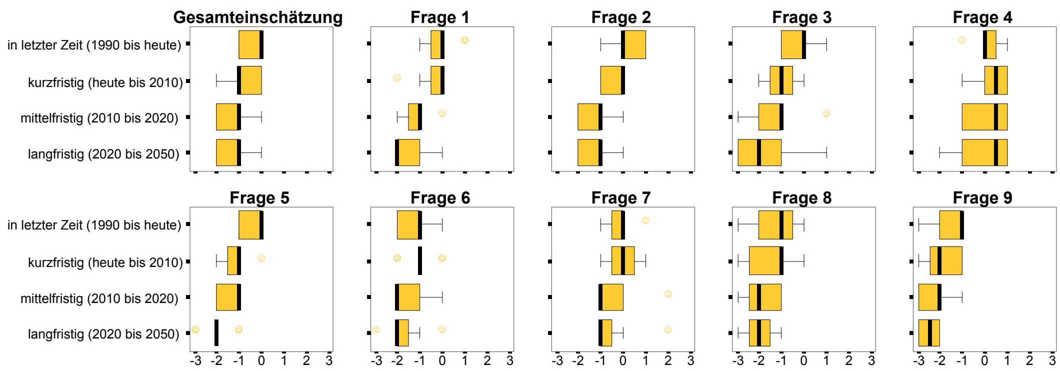
[12] According to the present state of knowledge increases and decreases in annual precipitation are possible, depending on the region. Therefore, both developments were offered to the respondents for rating.

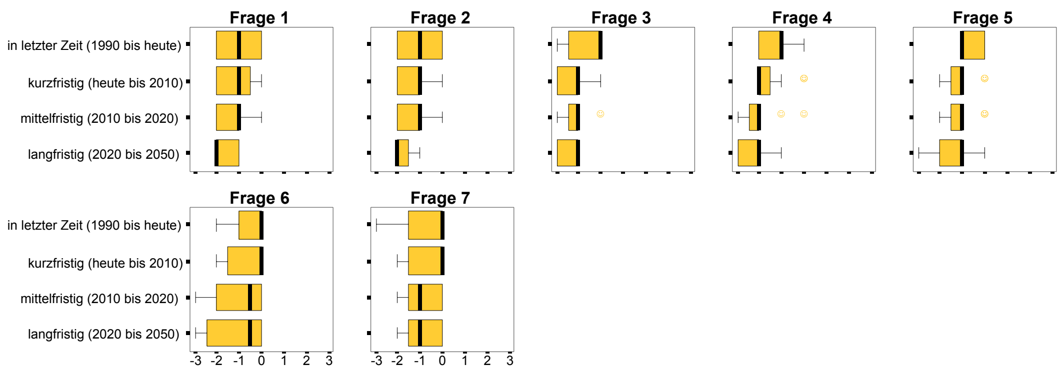
Experts' ratings of climate change and some of its particular elements



In your opinion, how positive/negative for your sector is/are ... ...

Question 1: … increasing mean annual temperature?	Question 4: … an increase in the annual sum of precipitation?	Question 7: … less frost days?
Question 2: … increasing winter temperatures?	Question 5: … a decrease in the annual sum of precipitation?	Question 8: … more hot days and heat waves?
Question 3: … increasing summer temperatures?	Question 6: … stronger inter-annual variations in precipitation?	Question 9: … more extreme rainfall events?

Experts' ratings of climate change and its potential impacts



In your opinion, how positive/negative for your sector is/are ...

Question 1: … less runoff (precipitation – evaporation) => less water supply?	Question 5: … changes in groundwater tables?
Question 2: … stronger fluctuations in water supply?	Question 6: … change in quality/quantity of drinking water?
Question 3: … the increasing risk of floods?	Question 7: … change in quality/quantity of industrial water?
Question 4: … the increasing risk of low water?	

Response scale

-3 =	Very negative	Gesamteinschätzung	=	Overall rating
-2 =	Negative	Frage 1, 2….	=	Question 1, 2…
-1 =	Slightly negative	In letzter Zeit (1990 bis heute)	=	In recent times (1990 to today)
0 =	Neither positive nor negative	Kurzfristig (heute bis 2010)	=	Short-term (today to 2010)
1 =	Slightly positive	Mittelfristig (2010 bis 2020)	=	Medium-term (2010 to 2020)
2 =	Positive	Langfristig (2020 bis 2050)	=	Long-term (2020 to 2050)
3 =	Very positive			

Illustration of the frequency distribution of ratings for environmental zones and federal states as box-plot: Each box represents the central 50% of the distribution and therefore illustrates the values between the lower and the upper quartile. The more to the left the box is shown, the more negative a specific impact of climate change is rated. The thick vertical line represents the median value. The whiskers to the left and right of the box illustrate the range of responses. Yellow boxes mark outliers and extreme values, which stand out from the upper or lower quartile by 1.5 to 3 times the box length.

Sample size: 7 questionnaires from the federal states Schleswig-Holstein, Hamburg, Berlin, Saxony, Thuringia, Hesse, and Baden-Württemberg.

Fig. 4.1-7: Experts' ratings of climate change and its potential impacts in the water sector.

All seven potential *impacts of climate change* were rated as risks to the water sector. The most negative ratings were given to the increased risk of floods (consistent with the rating of extreme rainfall events) and the increased risk of low water. Already in the recent past (1990 to today), these impacts were on average rated as "slightly negative". For the future, the ratings mostly are "negative", and in some environmental zones "very negative". Decreased runoff, the consequently decreased water availability, the larger variations in water availability, and the changed groundwater tables were rated as "slightly negative" in the short term. Changes in quality and quantity of drinking and industrial water were on average rated neutrally to "slightly negative", with large differences in the ratings between environmental zones particularly for drinking water (ranging from "very negative" to neutral).

Opportunity Assessment

Respondents rated only one element of climate change on average as an opportunity: the possible increase in annual precipitation. In the short, medium and long term this trend is on average seen as neutral to "slightly positive". However, the differences between specific ratings increase over time, and tend to be drawn toward the negative range.

Further Impacts

Furthermore, we asked about additional possible impacts of climate change in the water sector. Respondents listed impacts on the limnology of lakes, changes in temperatures of flowing and standing water bodies (each depending of the range of temperature increase), and the expansion of wetlands.

4.1.6 Adaptation to the Impacts of Climate Change

In the water sector, adaptation to future changes in climate plays a central role, because water management is concerned not only with extreme events like floods and low water, but also with keeping a steady balance between water supply and demand. All sectors depend directly or indirectly on sufficient water availability and some have very specific demands concerning water quality. Adaptation measures therefore have to be well-balanced and should be grounded in a national and international framework.

Flood protection has been a central in Germany since centuries. The probable increase in flood frequency and the possible increase in runoff need to be taken into account in the adaptation to future climate conditions. To do this, present measures of flood protection need to be adapted. This includes sufficient flood retention on flood plains, a regulation that limits construction and other development on the likely flood plains, precaution in constructions, behavioural foresight, hazard protection and technical flood protection. There needs to be a stronger discussion of potential impacts of climate change by river catchment's commissions (UBA, 2001).

The likely occurrence of periods of low water and aridity call for sustainable land use management, which secures the retention of water in the landscape. Such improvement of the landscape water balance has additional advantages for flood protection. As a further measure of precaution the infrastructure should be built to store sufficient amounts of water in dams, and to open the possibility of transporting water through long-distance pipelines. Suitable water saving measures should be implemented in industry, agriculture, forestry and private households, to avoid restrictions of usage. Agriculture and forestry will have to prepare for water shortages by adapted cultivation techniques and modern water-saving irrigation devices. Water use in industry can also be decreased further through improved production processes.

Surface waters should be managed nature-oriented, and if necessary reconstructed (e.g. through the creation of flood plains or the revival of bayous), to sustain the natural capacity of ecosystems. The sensitivity of aquatic ecosystems to impacts of climate change decreases with improved water quality and ecological state of surface waters, as is already called for in the European Water Framework Directive.

Further adaptation strategies to expected climate change in Germany are financial safeguarding through insurances against flood damage and drought-related yield losses, as well as the creation of reserve funds for damage reparation and future adaptation measures.

4.1.7 Effectiveness, Degree of Implementation and Obstacles in Adaptation – Assessment by Regional Experts

We have responses from the expert survey (method described in chapter 2.6) on measures that are suitable for climate change adaptation from the following eight federal states: Schleswig-Holstein, Hamburg, Berlin, Saxony, Thuringia, Hesse, Saarland, and Baden-Württemberg. The following results of the survey must be seen as very preliminary assessment of the measures that are suitable to adapt the German water sector to climate change, since only one expert per federal state was approached and the return of the questionnaires from the federal states was scarce.

In the survey, different dimensions of the adaptation measures were evaluated; the effectiveness of the measure to mitigate the risks introduced in section 4.1.5, alternatively to capitalize on the opportunities of climate change (see Tab. 4-1), and the present degree of implementation of the adaptation measure (see Fig. 4.1-8).

Measures of Flood Protection

Almost all respondents rate the first six measures listed in Tab. 4-1 as effective to respond to a potentially increased risk of flood due to climate change: natural flood retention, precautionary land use, precautionary construction planning, precautionary behaviour, risk prevention, and technical flood protection. Only a few respondents expect effects of these measures on other sectors – with the exception of precautionary land use, which respondents thought of having wide-ranging effects.

Regarding the degree of implementation of the six measures of flood protection (see Fig. 4.1-8), most measures were rated as already "partially implemented", but precautionary construction planning was only rated as "planned", and technical flood protection as nearly "implemented". However, there are great differences between federal states. The degree of implementation usually ranged from "currently considered" to "implemented". These differences are partially explained by differences in exposure to flood risk. For example, low ratings of the degree of implementation of measures of flood protection are often found in Schleswig-Holstein, while high ratings are found in Hesse, Saxony, and Saarland. The reasons respondents named for implementing measures of flood protection were mostly protection against floods and reduction of the damage potential. Only one respondent named climate change as one of the reasons for the implementation of some of these measures.

Tab. 4-1: Rating of the degree of effectiveness of adaptation measures to mitigate risks and capitalize on opportunities of climate change in the water sector. The number of respondents that rated a particular measure of mitigation resp. exploitation as effective is shown. Sample size: 8 questionnaires from the federal states Schleswig-Holstein, Hamburg, Berlin, Saxony, Thuringia, Hesse, Saarland, and Baden-Württemberg.

	Impacts						
Measures	Less runoff (precipitation - evaporation) => less water supply	Stronger fluctuations in water supply	Risk of floods	Risk of low water	Changes in groundwater tables	Change in quality/quantity of drinking water	Changes in quality/quantity of industrial water
Natural flood retention (retention areas)	-	2	6	-	2	-	-
Precautionary land use (limited development, restrictions and obligations, change sin use)	1	2	5	-	1	1	2
Precautionary construction planning (flood-adapted)	-	-	5	-	-	-	-
Precautionary behaviour (forecasts + recommendations)	-	1	5	1	-	-	1
Risk prevention (hazard protection)	-	-	6	-	-	-	-
Technical flood protection	-	2	6	1	-	-	-
Saving water	2	2	-	1	5	4	3
Improving water quality	1	-	-	1	-	4	5
Nature-oriented reconstruction of rivers	-	2	3	1	1	-	2
Restrictions of water and water body use (navigation, water- and heat-use)	1	1	-	1	-	-	4
Measures integrating several risks Insurance against damages through climate change	-	1	2	-	-	-	-
Creation of reserve funds for future adaptation measures and damage reparation payments	-	-	4	1	-	-	-

The main obstacles to implement measures of flood protection according to respondents are *financial restrictions* (and lacking time due to the lack of budgetary funds). *Organisational obstacles* were seen mostly in precautionary land use, but also in natural flood retention, precautionary behaviour and risk prevention. *Legislative obstacles* were seen as hurdles only for natural flood retention, precautionary land use, and technical flood protection, *lacking knowledge* only for precautionary construction planning, precautionary behaviour, and technical flood protection ("lack of fundamental planning"). In addition to this, respondents identified conflicts of use and lacking readiness to turnover land area as obstacles for natural flood retention and precautionary land use. Given these obstacles, respondents on average rated most measures of flood protection as "complicated". Precautionary land use is rated as "very complicated" and precautionary behaviour as "slightly complicated".

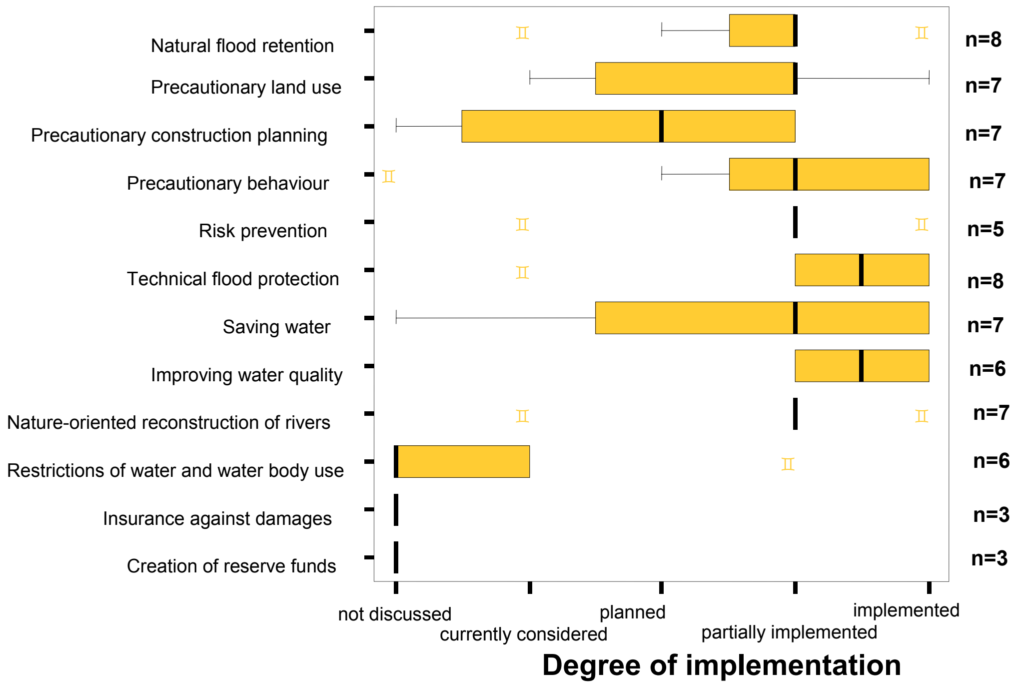


Fig. 4.1-8: Assessment of the degree of implementation of measures that are suitable to adapt to climate change in the water sector. Sample size: 8 questionnaires from the federal states Schleswig-Holstein, Hamburg, Berlin, Saxony, Thuringia, Hesse, Saarland, and Baden-Württemberg. The n-values give the number of questionnaires each box-plot is based on. For further explanation of the graphical representation see Fig. 4.1-7.

Saving Water and Improving Water Quality

Respondents thought saving water would have a wide range of positive effects with regard to potential impacts of climate change (see Tab. 4-1). Most respondents thought saving water would be an effective measure with regard to changing groundwater tables. They attributed a lesser range of positive effects for improving water quality. Most respondents rated this measure as effective with regard to changes in quality/quantity of drinking and industrial water.

The degree of implementation was rated on average over eight federal states as already "partly implemented" for water saving, and as nearly "implemented" for improving water quality (see Fig. 4.1-8). The variation between federal states with regard to rating the degree of implementation of saving water was very high, while the degree of implementation for improving water quality was rated uniformly high. Among other things, the respondents named high water demand, resource protection, and the legal obligation through EU-directives as reasons to implement measures to save water and improve water quality. No respondent identified climate change as a further reason to implement these measures.

Again, the obstacles to implement the measures were identified as mostly financial. As additional hurdles for saving water respondents named the current ample water supply, low water prices, and the low motivation of citizens. The improvement of water quality was said to be hindered by resistance in industry and politics. With regard to these obstacles, respondents rated the implementation of measures to save water on average as "complicated", and of measures to improve water quality as "slightly complicated" to "complicated".

Nature-oriented Reconstruction of Rivers and Restrictions of Water and Water Body Use

Respondents thought the nature-oriented reconstruction of rivers would have a broad range of positive effects concerning potential impacts of climate change (see Tab. 4-1). Most respondents rated this measure as effective flood protection. Restrictions of water and water body use were seen as less broadly effective. Those measures were mostly estimated to be effective concerning changes in the quality/quantity of industrial water.

Nature-oriented reconstruction of rivers was on average rated as already "partially implemented", while restrictions of use were on average "not discussed" (Fig. 4.1-8). For both measures, the degree of implementation varies only slightly between federal states. Among other things, flood protection and nature conservations were named as decisive reasons for the implementation of nature-oriented reconstruction of rivers. Presently sufficient supply of water, the lack of demand for restrictions of use, and presently decreased trends of usage were identified as reasons for not discussing restrictions of use as an adaptation measure in most federal states. Climate change played no role in the implementation of the measures.

An overwhelming proportion of respondents see financial obstacles as a hurdle in realising nature-oriented reconstruction of rivers. The vast demand of area, the existing dense development, the high maintenance costs, and the lack of wider recognition of the problem were identified as further obstacles. With regard to these obstacles, respondents on average rated the implementation of nature-oriented reconstruction of rivers as "very complicated". No responses were given concerning obstacles or complexity of implementation of restrictions of water and water body use, since this measure was not seen as necessary most respondents.

Measures integrating several risks: Insurances and Reserve Funds

Respondents rated insurance against damages through climate change and the creation of reserve funds for future adaptation measures and damage reparation payments respectively as effective concerning flood protection (see Tab. 4-1).

Only three of eight respondents were able to comment on the implementation of such measures (see Fig. 4.1-8). However, they agreed that measures of this kind are "not discussed" in their federal states – such measures were not believed to fall into the responsibility of the administration and no funds were available for them. Obviously respondents understood the question about insurances and reserve funds in relation to their administration. A higher level of implementation would undoubtedly be found if the existence of insurances and reserve funds for citizens and businesses were taken into account.

Further Measures

The survey also enquired about further measures in the water sector that would be suitable to mitigate the risks and capitalize on the opportunities of climate change. The respondents listed the following measures, some of which are particular forms of the previously discussed measures: Securing ample groundwater balance through water supply planning (ensuring supply), management of water supply and distribution in settlements, creation of integrated water supply systems, expansion of water conservation areas to secure drinking water supplies, minimisation of nutrient deposition, and collaboration of flood warning stations across borders.

Adaptation to Climate Change in Water Departments

Only three out of eight respondents from functional departments of federal states that are responsible for water supply and distribution reported that adaptation to climate change is a subject discussed in their administration. The following concrete projects and practical programmes for the adaptation to climate change were named: "Control TS" in Saxony (determination of target levels for damming, point of contact: LTV Saxony), the project "INKLIM 2012" in Hesse, and the project "KLIWA" in Baden-Württemberg, in which Bavaria also takes part (focuses so far on adaptation to floods and low water). It is not clear whether further projects exist in those federal states that did not return the questionnaire. Two respondents said the current significance of the topic of adaptation was "important", relative to other topics in their administration; four rated the current significance as "slightly important", and one respondent rated it as "unimportant". The topic is currently not seen as "very important" in any of the administrations. Hence, within the functional departments of most federal states that were included in the survey climate change currently is of little concern.

Adaptation in the Water Sector: Summary and Conclusions

The following can be concluded from the results of our survey[13]: Water saving and nature-oriented reconstruction of rivers are thought to have a broad potential to mitigate various potential impacts and capitalize on opportunities of climate change. There was no potential impact for which no respondent could envisage a suitable adaptation measure. However, it is striking that few respondents identified suitable measures to meet the risk of reduced water supply. Also, the rating of effectiveness of different adaptation measures differs strongly between federal states, which may partly reflect varying conditions.

Most measures that are suitable to adapt to the impacts of climate change in the water sector were on average rated as already "partially implemented". However, there are vast differences between federal states. Furthermore, the minority of measures was rated as already "implemented", and there is considerable doubt if the existing and planned measures are sufficient to prepare the water sector for the changes expected due to climate change. According to the respondents, climate change was usually not among the reasons to implement a specific measure, and the issue of climate change adaptation is only discussed in very few functional departments that are responsible for the water sector. We therefore conclude that impacts of climate change were not at all, or only marginally considered in the planning of adaptation measures, and that water supply and distribution in most federal states is not yet prepared for climate change.

Respondents mostly named financial restrictions as obstacles for the implementation of adaptation measures. Most measures were rated as "complicated" to implement. The implementation of precautionary land use and nature-oriented reconstruction of rivers (a measure with a broad range of positive effects) were even rated as "very complicated".

Therefore, the adaptation to climate change of water supply and distribution in Germany can rely on existing climatic knowledge and can be based on many existing or planned measures. However, so far planning in the water sector has only scarcely considered climate change and is currently probably not prepared for its impacts. The extent of necessary changes in existing adaptation measures to adequately address climate change depends on the specifics of each case.

In general, the water sector should have the capacity to prepare for climate change in future. A range of suitable adaptation options is available, even if they are mostly rated as complicated. However, the adaptive capacity with regard to decreasing water supply seems to be limited – few respondents identify suitable adaptation measures to this impact, the implementation of which was furthermore rated as "complicated" or "very complicated".

Federal states should use the opportunity to exchange their experience and knowledge, since the degree of implementation of adaptation measures and the state of present discussion on adaptation to climate change was very different between some federal states.

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[13] On measures integrating several risks, i.e. insurances and reserve funds, we cannot draw any conclusions due to the lack of survey results.

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4.1.9 Annex

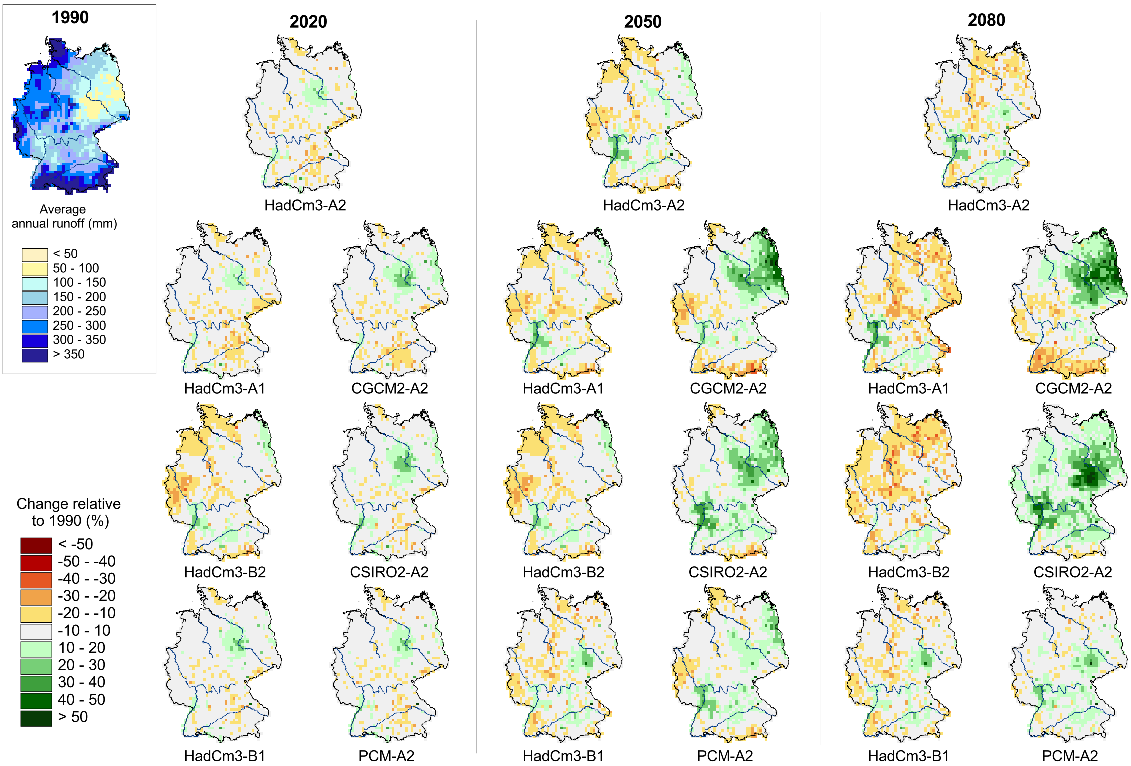

Fig. 4.1-9: Regional relative change in average annual runoff (%) across Germany up to 2080 compared to 1990 for seven ATEAM scenarios.

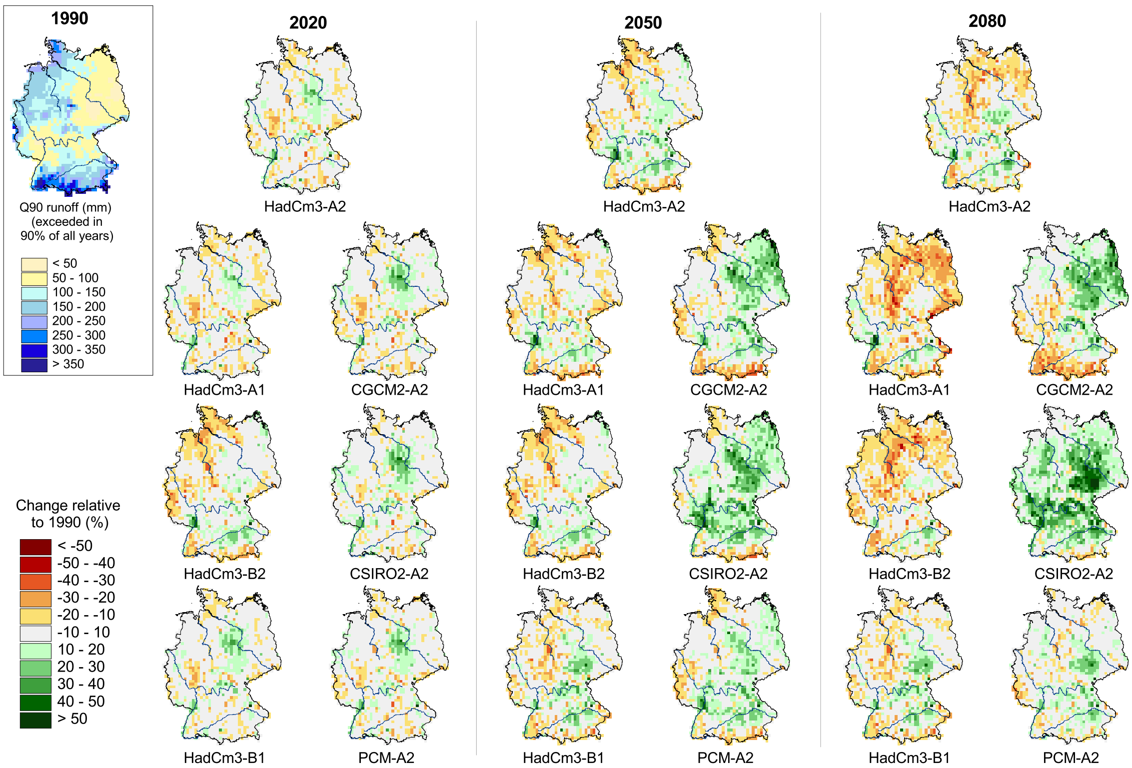

Fig. 4.1-10: Regional relative change in drought runoff Q90 (%) across Germany up to 2080 compared to 1990 for seven ATEAM scenarios. Q90 (drought runoff) is the annual runoff that is exceeded in nine years out of ten.

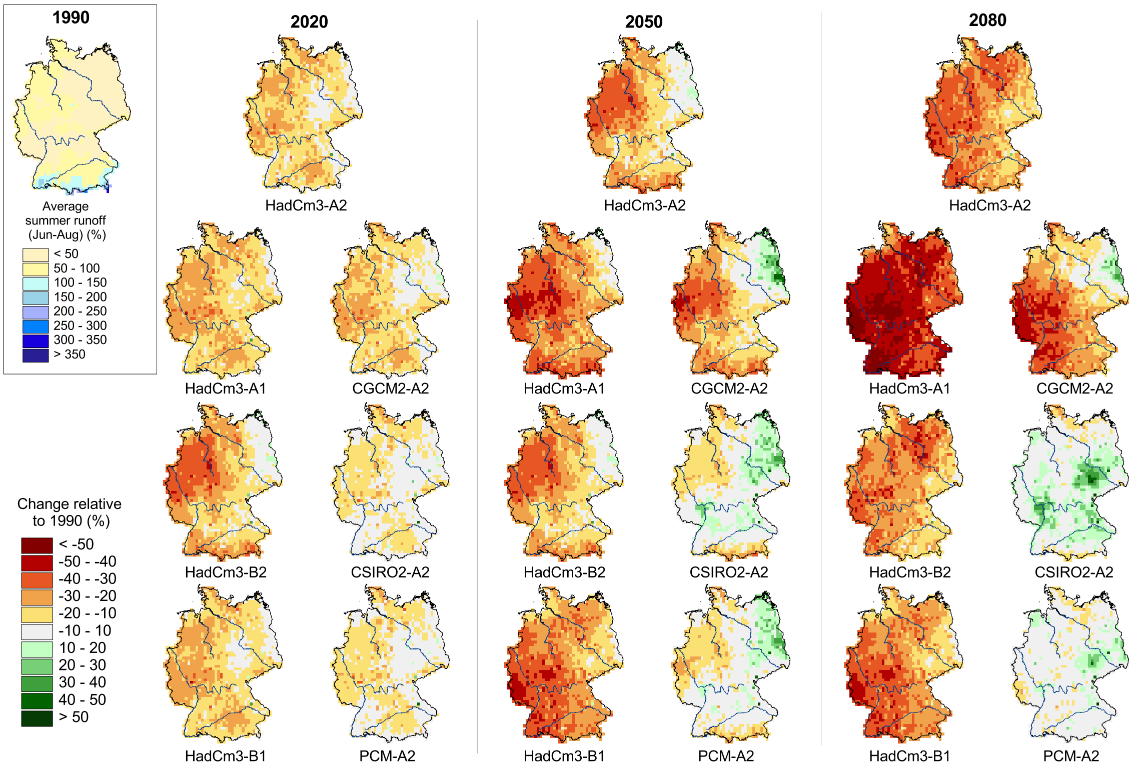

Fig. 4.1-11: Regional relative change in average summer runoff (%) across Germany up to 2080 compared to 1990 for seven ATEAM scenarios. Jun = June, Aug = August.

4.2 Agriculture

4.2.1 Summary: Vulnerability of the Agricultural Sector

Potential impacts of climate change on the agricultural sector in Germany are yield losses due to high temperatures and insufficient water supply. The expected increase in climate variability can lead to increased yield variability and hampers adaptation through choice of suitable crop varieties. However, moderate temperature increase and sufficient water supply would increase the yield potential of many crop types.

The agriculture sector may possibly profit from the impacts of climate change, particularly in regions that presently are too cool or too wet for agricultural use (e.g. in Northern Germany). Worrisome developments are the expected decrease in water supply, owing to decreasing summer precipitation, especially in regions that already suffer from unfavourable water balances under present conditions (particularly Brandenburg); the increase in climate variability (variations from year to year), which increases the probability of yield losses and hampers adaptation (across Germany); the increase in weather extremes; as well as a long term temperature increase beyond the optimum of many cultivated plants (particularly in South-western Germany).

Currently German agriculture is only partly adapted to the impacts of climate change. In most federal states climate change does not seem to be considered in present planning, and measures that would also be suitable to adapt to climate change are mostly not yet fully implemented. However, agriculture can adapt relatively quickly to changing climate and weather conditions, and has done so again and again in the past. Consequently, we rate the vulnerability of agriculture to climate change without further specific adaptation measures as “moderate” (business-as-usual-scenario, see chapter 2.8). Only in the Eastern German regions that are prone to drought and often have poor soils we rate current vulnerability as “high”.

However, agriculture should have a high capacity to realise measures that specifically address climate *change*; many diverse and uncomplicated adaptation options are available. Especially the use of new cultivars and new, adapted cultivation methods that maintain soil fertility and save water are promising to address a wide range of uncertain impacts of climate change. The cultivation of new crop types and adapted irrigation measures are also rated as effective. However, the cultivation of new crop types requires additional knowledge, and the implementation of adapted irrigation techniques relies on financial support. Agricultural adaptive capacity will further depend on economic pressures. In this regard, smaller farms and farms in the less-favourable areas in Eastern Germany need special support. If the adaptation measures are implemented, the vulnerability of the agricultural sector to climate change might be lessened to “low” (improved-business-scenario, see chapter 2.8).

4.2.2 Agriculture and Climate

Agriculture secures the direct supply of food and raw materials to society, and contributes to maintaining a cultural landscape through landscape conservation. Therefore, agriculture strongly affects provisioning and cultural ecosystem services. In Germany, the surface area that is used for agricultural is greater than for any other land use. Consequently, agriculture influences important factors in a landscape and a diverse set of ecosystem functions. For example, the water balance of a landscape is shaped by irrigation and drainage for agriculture and by the water use through agricultural crops. The agricultural use of nitrogen, phosphorus and pesticides impacts water quality. Species diversity is fundamentally determined by the creation, alteration, fragmentation and destruction of habitats, as well as by the maintenance or loss of old crop species. Finally, agriculture influences the appearance of a landscape and can add to the recreational value of a region.

Agriculture is tightly linked to climate and weather conditions. Climatic conditions largely determine the range of possible crop types and the potential yield of specific crops. Unfolding weather conditions determine variations in the timing of sowing and harvest, as well as in crop yield. Extreme weather events, such as hail or extreme rainfall events, as well as drought or heat, can harm arable culture and diminish yields.

In the following we give a general overview of the influence of climate factors on plant growth and plant development.

Temperature

In general, temperature influences plant phenology (the timing of growth and developmental stages) and essential metabolic processes.

Rising temperatures lead to an earlier onset of phonological stages and to en elongation of the vegetation period. Perennial crops, which continue growing after reaching maturity (sugar-beet, grassland), and plants with long maturity stages (some maize cultivars, millet) will profit from this. On the other hand, many cereals show a shortened phase of grain-growth by up to 10% per 1ºC warming, due to accelerated growth. This can lead to reduced yields (Weigel, 2004; van Ojen & Ewert, 1999). Increasing temperatures can also negatively impact the yield of winter grain, which needs certain minimum temperatures in winter for its development (vernalisation). Furthermore, and early onset of the growing season bears the risk of damages through late frosts.

In general, increasing temperatures increase photosynthesis and other metabolic processes, until a crop type specific temperature optimum is reached. Thermophilic crops that have not reached their optimum under current conditions (e.g. maize) can therefore bring higher yields under moderate warming. Moreover, higher winter temperatures decrease the risk of frost damages. However, when the optimum is surpasses, yields of all crop types decrease. Extreme temperatures can harm plants permanently.

Carbon Dioxide – CO_2

Carbon dioxide is an important nutrient for plant photosynthesis. For so-called C3-plants, which comprise most of the German cultivated crop plants, the CO_2-concentration of the air is suboptimal and a limiting growth factor. In C_3-plants, an increase in atmospheric CO_2-concentration therefore increases the rate of photosynthesis and increases yields ("CO_2-fertilisation effect"; Pinter et al., 1996; Kimball et al., 1993). Field experiments showed an increase in wheat yield by up to 28% following a doubling of CO_2-concentration (Downing et al., 2000). In Germany field experiments showed increases by 8-14% for winter barley, sugar beet, and winter wheat (Manderscheid et al., 2003a; Manderscheid et al., 2003b). It is not yet clear if this increased yield would be sustained in the long term or if there will be a certain "acclimatisation effect". For C_4-plants (e.g. maize, millet) hardly any increase in yield is found, since these plants use CO_2 more efficiently and experience optimal CO_2-supply already under present conditions.

Another important aspect of increased atmospheric CO_2-concentration is the decrease in water use per unit biomass produced (improved water use efficiency). Further effects of increased CO_2-concentration are increased carbohydrate content of leaves and fruit, along with lower protein content, as well as an increased allocation of carbon to the root system. In food and fodder production, the decreased protein-content of agricultural products is seen as deterioration in quality (e.g. impaired baking characteristics in wheat).

Water

Water is another important factor in photosynthesis and other metabolic processes. During CO_2-uptake the plant loses water through transpiration. The amount of this transpiration depends on the rate of photosynthesis, temperature, and other climatic factors, such as vapour pressure and wind speed. The transpiring water has a cooling effect and protects the plant from excessive heat. Water stress occurs if less water is available than the plant needs. The plant closes its stomata and the rate of photosynthesis is strongly reduced. Persistent undersupply with water therefore leads to yield losses. Extreme aridity leads to permanent damages to fine roots and other plant parts. On the other hand, too much water can damage the plant through oxygen deficiency at the roots.

Interaction of Temperature, CO_2, and Water

The interplay between the above-mentioned factors determines how crops will react to climate change. To a certain degree, increased CO_2-concentration potentially increases yields; increasing temperatures have positive and negative effects. Sufficient water supply is a decisive factor. If there is enough water, most crops will tend to profit from climate change. If water is limiting, decreases in yield must be expected (Olesen & Bindi, 2002).

Agriculture and Climate Protection

Agriculture is a potential source of greenhouse gases, and therefore contributes to climate change, through methane (CH_4) and nitrous oxide (N_2O) emissions, as well as carbon dioxide emissions from organic soils. At present, German agriculture contributes 8.7% to German greenhouse gas emissions (UBA, 2005). This estimate does not include carbon dioxide emissions through mineralization of soil carbon, for example from drained fens, which have so far not been quantified. On the other hand, agriculture could contribute to climate protection through the cultivation of renewable primary resources.

4.2.3 Baseline situation: Agriculture in Germany

Following France and Italy, Germany is the third larges producer of agricultural goods in the European Union. In 2004, approximately 372 400 farms operated in Germany. In 2004, an estimated number of 1.27 million workers were employed full- or part-time in German agriculture (Federal Government, 2005). The contribution of agriculture to gross national product is, however, only approximately 1% (Federal Statistical Office, 2005b).

In Germany, 53% of the surface area is used for agriculture. Of this land, 29% are grassland and 69% are cropland. The main products produced on croplands are wheat for bread making, barley for fodder and industrial use, as well as other fodder crops (clover, lupine etc.) (Fig. 4.2-1). Four percent of the arable area is under organic farming (Federal Statistical Office, 2005a). The proportion of arable land used to grow renewable primary products was approximately 6% in 2004, and has doubled since 1998 (Federal Government, 2005).

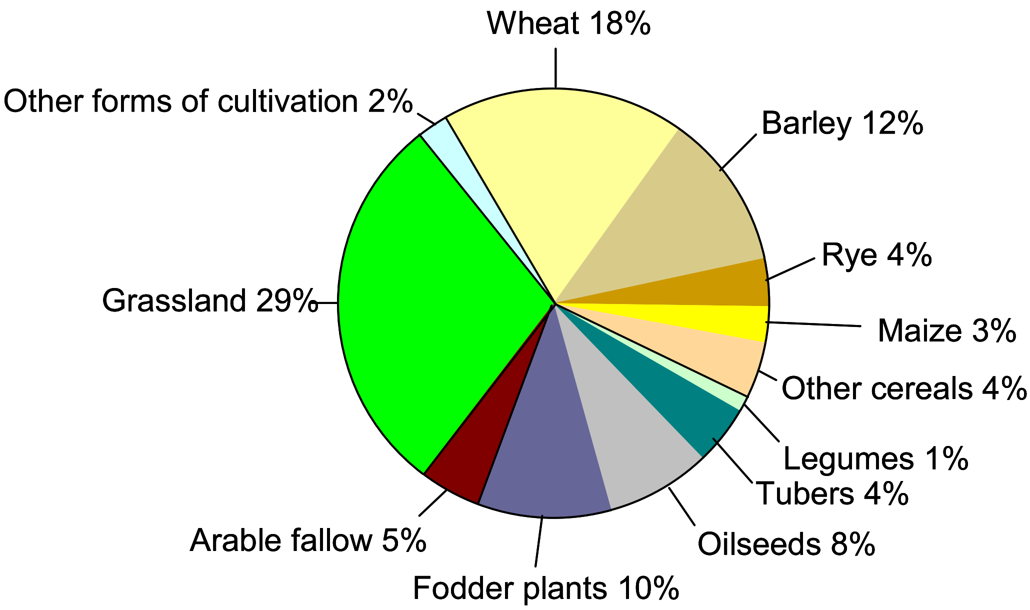

Fig. 4.2-1: Division of agricultural area by arable practice (Federal Statistical Office, 2005b).

Agricultural suitability is distributed heterogeneously over Germany (Fig. 4.2-2). In large parts of Germany, agricultural suitability is intermediate to good. The sandy and poor soils in Brandenburg and in the "Geest" landscapes of North-western Germany show the lowest suitability. The highest suitability, and their for the highest yield potential is found on the loess soils of the plains ("Börden") of Magdeburg and Lower Saxony, as well as on the soils of the upper Rhine rift. In large parts of Germany the climatic conditions are very good for agriculture (with the exception of the lower mountain ranges and the Alps). In the North, low average temperatures and short vegetation times cause some limitations, in the outer East of Germany very low precipitation is partially restraining.

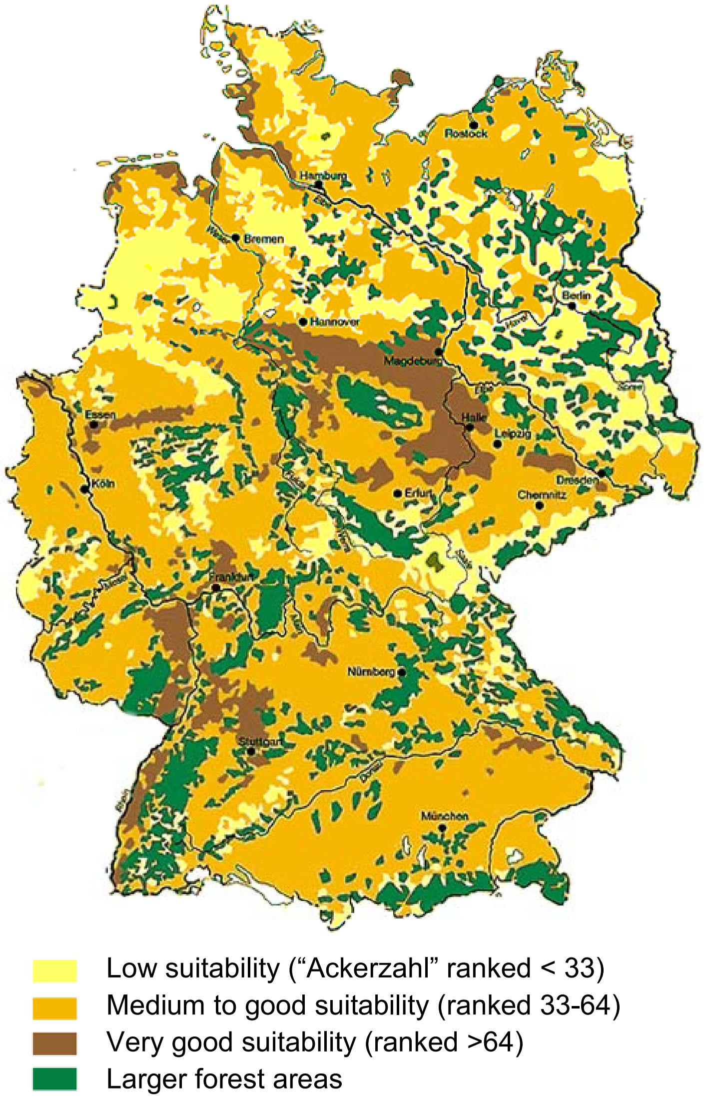

Fig. 4.2-2: Suitability for agricultural use in Germany (Liedtke & Marcinek, 2002, adapted).

Agricultural Reform an Economic Pressure

The German agricultural sector is under pressure. The reduction of market supporting measures (e.g. subsidies), increasing globalisation, eastward enlargement of the EU and the liberalisation of prices since the EU agricultural reform (1992) and Agenda 2000 (1999) come with considerable economic risks to farmers. These developments caused strong competition and declining prices, which led to a destabilisation of incomes in agriculture (Ortlof, 1998). In the last decades, this pressure caused a reduction in the number of farms by an average of 3% per year, while farm size grew continuously (Federal Government, 2005).

Yields and Climate Change, Impacts of the Heat Wave in 2003

In the last fifty years, agricultural yields in Germany have increased steadily and more than tripled since 1950 (Fig. 4.2-3). This development can be observed worldwide and is mainly a consequence of technological progress (Hafner, 2003). This includes progress in the development of new seeds, improvements in plant protection, new and improved sowing, cultivation and harvest techniques and enhanced fertilisation. If and how much climate change contributed to this development can so far not be quantified. However, presumably the effect is small.

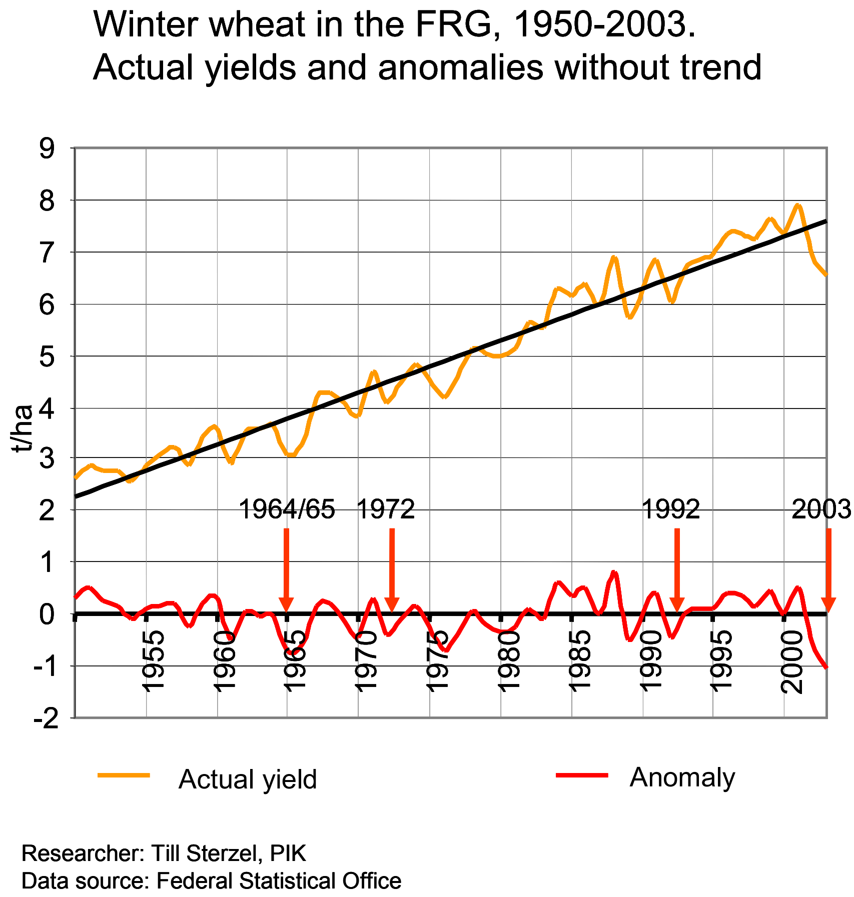

Fig. 4.2-3: Yields of winter wheat in Germany from 1950 to 2003. The yellow line shows actual yields, the upper black line marks the trend in yields. The red line shows the deviation from the expected value. Arrows mark dry years that caused distinct yield losses (Sterzel, 2004).

A different impression is gained when looking at inter-annual differences in yields. This reveals that climate variation, particularly climate extremes with long arid periods, such as in the years 1964/65, 1972. 1992 and 2003, have repeatedly caused yield losses (Fig. 4.2-3). The year 2003 with it hot and dry summer was the year with the strongest yield losses in the history of the Federal Republic of Germany (Sterzel, 2004). Across Germany, the yields per hectare were approximately 12% below multiple year averages. Regionally, the damages were distributed very heterogeneously. While Schleswig-Holstein, with its generally cool and moist climate, profited in the warm and dry year of 2003 with an increase in yields by 7.9%, Brandenburg was the federal state that was most severely hit, with yield losses of 40%

compared to multiple year averages (BMVEL, 2003). As a consequence of the yield losses, German federal states reported about 12,600 existentially threatened farms and damages of approximately 600 million € (Federal Government, 2004).

Concerning the assessment of impacts of climate change it is interesting to look at the events in 2003, since there is a consensus that the probability of hot and arid periods has already measurably increased and will further increase distinctly with climate change and the shift of precipitation from summer to winter (Schönwiese, 2005). Some authors even see the year 2003 as a proxy for what expects us within the next 50-100 years (e.g. Beniston, 2004). This year also showed how important local conditions are for the sensitivity to climate extremes. Regions that are less suitable for agricultural use were most severely hit by yield losses, e.g. regions with poor soils of low water retention capacity (sandy soils), an unfavourable climatic water balance (see chapter 4.1) and high summer temperatures (see chapter 3). Such regions are found primarily in the federal state Brandenburg, parts of Saxony, as well as parts of South-western Germany.

In the past, there were also a number of other climate and weather extremes that caused considerable damages, such as hail, extreme rainfall and flood events. For example, the flood events at Elbe and Danube caused damages of approximately 200 million € to farms and approximately 1.9 billion € to agricultural infrastructure (including dykes), with Saxony and Saxony-Anhalt reporting the largest damages (Federal Government, 2004).

The elongated vegetation period and changes phenology of crops are impacts of climate change that can already be observed in Germany. For example, the development of ears in winter rye has moved to approximately 7 days earlier since 1960 in Germany (DWD, 2004).

4.2.4 Impacts of Climate Change – Trends and Projections

Impacts of Climate Change of Yield Potential

Studies on the impacts of climate change generally expect an increase in agricultural yield in Europe. For example, an increase in wheat yield by 1-3 t ha^{-1} is estimated for Central Europe by 2050 (Harrison et al., 2003; IPCC, 2001). However, the significance of water supply and the risk of yield losses through water stress are not yet adequately accounted for in these studies. Currently there are no explicit scenarios of crop yield across the whole of Germany.

For example, more explicit scenarios, which account for possibly insufficient water supply, are available for the Elbe watershed. Model runs estimated decreases in yield of wheat, rye and barley by 9% to 14% by the year 2055, under the assumption of a temperature increase by 1.4ºC and a decrease in annual precipitation by 10%. This was mainly caused by insufficient water supply in summer. According to these scenarios only maize, as a thermophilic plant profiting from temperature increase and with good water use efficiency, did not exhibit any impairment and showed regional yield increases in areas with good water supply (Wechsung et al., 2004).

Further results for Baden-Württemberg are available from the project KLARA (PIK, 2005). Similarly, the assumption of decreased precipitation in summer leads to a decrease in wheat yield by 14% by 2055. This was caused by insufficient water supply, but also by negative impacts of temperature increase (shortening the phase of grain maturation). As in the Elbe watershed, maize was fairly insensitive to climate change and profited slightly.

Besides long term climate trends, climate variations from year to year (inter-annual variability) and climatic extremes play a big role in agriculture. These climate variations possibly pose the greatest threat to agriculture. Results from regional climate models indicate that inter-annual variability of temperature and precipitation will distinctly increase in future in Europe, particularly in summer (Schär et al., 2004; Giorgi et al., 2004). Climate variations hamper adaptation and have regularly led to yield losses in the past. The increased probability of heat extremes and arid periods, a simple consequence of warming and shifts of precipitation into winter alone, is of particular significance in this respect. Other climate and weather extremes (hail extreme rainfall) may also occur more frequently, but currently no unambiguous results are available for this.

Viticulture is a special case, since here the quality of the yield is of utmost importance, rather than the quantity. Temperature has a strong influence on the sugar content of the grapes and the choice of vine variety. Studies of selected regions show that the wine-growing area in Germany will shift northward and vine varieties of higher quality may be cultivated. According to one study, by 2045 the cultivation of Cabernet Sauvignon would be possible in the Rheingau, and Potsdam could grow high-quality Riesling or Chardonnay (Stock et al., 2004).

Further Impacts of Climate Change

Temperature increase will lead to further shifts to earlier dates and shortening of phonological phases. Due to this, sowing and harvesting can shift to earlier dates, and the harvest security of crops with long development, such as e.g. maize and millet, increases. On the other hand, a more rapid development through phenological phases may decrease yields.

Moreover, a shift in the range of suitable crops to the North and into higher altitudes is expected. While Northern regions such as Scandinavia can strongly profit from this, for Germany only minor changes are expected. In a study of 27 crop types that could potentially be used as renewable primary resources (among which the common cereal types), the range of suitable crops within Germany was slightly decreased (Fig. 4.2-4; changes between +8 and −17%). On the one hand, the cultivation of some new crops will be possible by 2080, such as e.g. soy bean in parts of Germany (South-western Germany), on the other hand the suitability of some classic crops such as rye, oats and potato decreases.

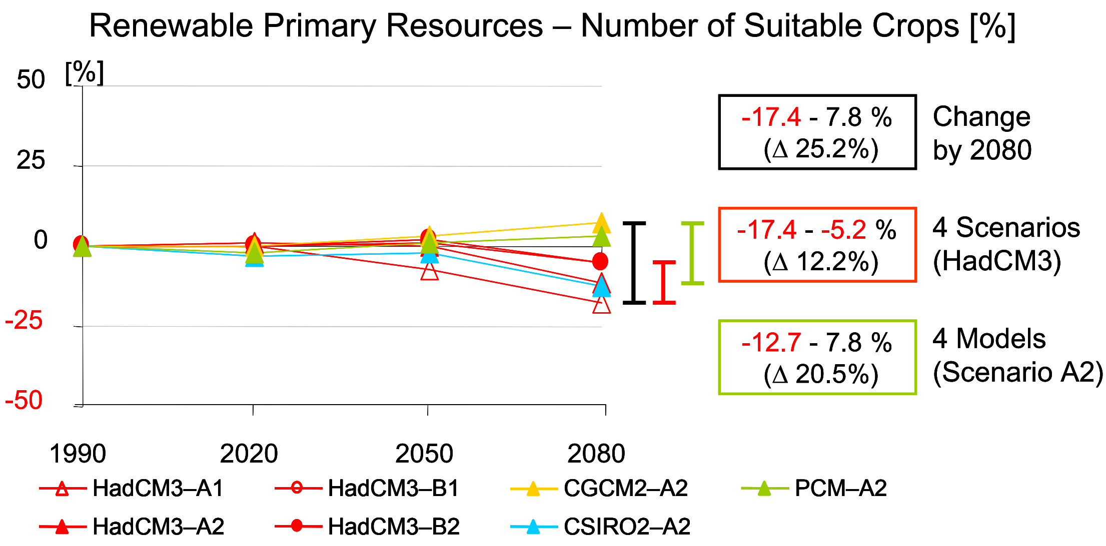

Fig. 4.2-4: Change in number of suitable crops that can be used as renewable primary resources in Germany in 2080 compared to baseline (1990) in percent (%). Results for seven ATEAM scenarios are shown (see chapter 2).

Another effect of rising temperatures is the loss of organic carbon from soil due to an accelerated rate of decomposition and mineralization of organic material in agricultural soils. This loss of organic carbon decreases soil fertility and contributes to the greenhouse effect through emissions of carbon dioxide. Results from the ATEAM project (see chapter 2) show that due to temperature increase by 2100 alone, 20-30% of European soil carbon will be lost. A decrease of soil organic carbon by 40-60% is possible if climate change induced changes in crop productivity and expected land use changes are taken into account (Smith et al. in Schröter et al. 2004).

An indirect threat of climate change to agriculture is the possible spread of plant pests and diseases, as well as the invasion with new pest species (Olesen & Bindi, 2002). Many pest species profit in general from higher temperatures, particularly higher winter temperatures. In consequence, pests can establish earlier in the year and can produce more individuals and generations. Fungal pests will only profit from warmer and simultaneously moister weather conditions. Exemplary results concerning this issue for pests and diseases in apple orchards are available from the project KLARA. According to these results, warmer and slightly moister climate in the region around Lake Constance will increase pest pressure on apple production through the codling moth (larvae of the butterfly *Cydia pomonella*) and apple scab (caused by the fungus *Venturia inaequalis*) (PIK, 2005).

Further impacts of climate change include decreasing quality of the crops, mainly through decreasing protein content (IPCC, 2001), damages of crops through increased atmospheric ozone concentrations (Welling, 2000), and increased risk of (wind) erosion because of more arid soils (Olesen & Bindi, 2002).

Impacts of the Agricultural Reform and Changing Economic Conditions

Besides climate change, changes in socio-economic conditions determine the future of German agriculture. A polarisation of agricultural landscapes is expected, dividing regions with favourable arable conditions from areas that will not be able to sustain profitable agriculture in a changing market. This is a consequence of the agricultural reform, liberalisation of the market, and the decrease of world prices for many agricultural products. These trends are currently under debate, but most experts expect a decrease in the total area used for agriculture, especially in less favourable areas. The proportion of abandoned land in Germany could increase by up to 40%, the area used for cereal production could decrease by 12-25%, and grassland could be widely extensified (Kleinhanß et al., 2003).

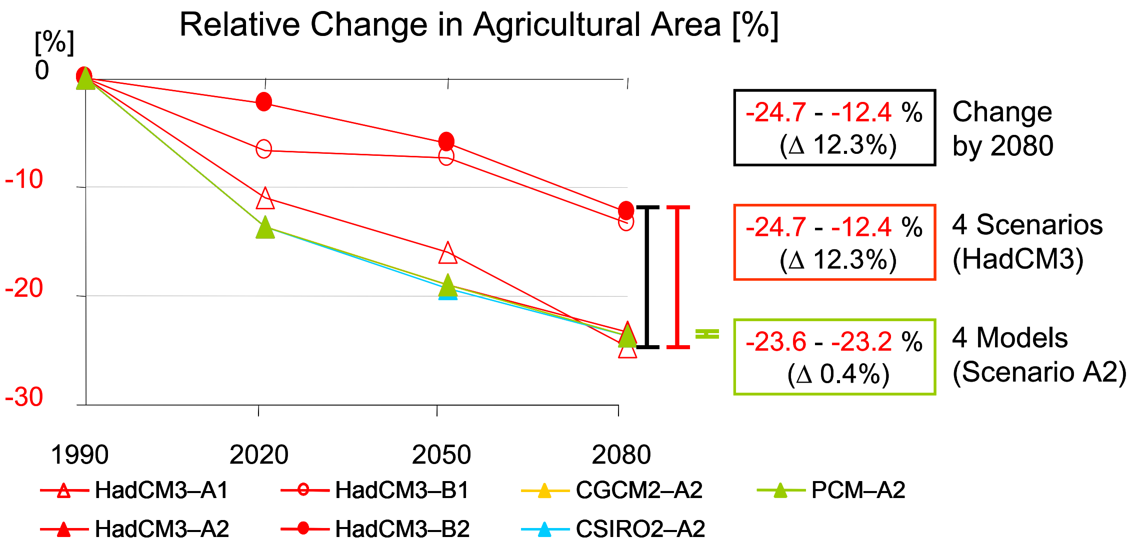

Fig. 4.2-5: Relative change in agricultural area by 2080 compared to 1990 in Germany for seven ATEAM scenarios.

Some scenarios show a decrease in agricultural area in the Elbe watershed by up to 34%, on the less favourable areas in Eastern Germany regionally even by up to 60%, under the assumption of a continued liberalisation of the market (Wechsung et al., 2004). Similar projections are available for Germany from the ATEAM project (chapter 2; Schröter et al. 2004). Depending on the scenario, these show a decrease in agricultural area by 2080 of 12% to 25% (Fig. 4.2-5). Again, these changes are mainly caused by socio-economic changes. Here impacts of climate change are but an additional stress on a system already under strong pressure.

4.2.5 Impacts of Climate Change – Assessment by Regional Experts

As described in chapter 2.6, we conducted experts' surveys in the various climate-sensitive sectors of Germany – including the agricultural sector. Sector-specific ratings of potential elements and impacts of climate change are available for various environmental zones (see chapter 2.6) in the following six federal states: Schleswig-Holstein, Mecklenburg-Western Pomerania, Brandenburg, Thuringia, Saxony, and Hesse. Positive ratings are regarded as acknowledgments of opportunities, negative ratings as acknowledgments of risks. The results of the survey are depicted in Fig. 4.2-6. The assessment, which is discussed in the following, must be seen as preliminary, since only one expert per federal state was approached and the return of the questionnaires from the 16 federal states was scarce. On the other hand, more than half of the respondents base their assessment on studies of past and future climate development; two respondents were also familiar with studies on the impacts of climate change on agriculture.

General Assessment of Climate Change

Respondents rated the impacts of climate change on agriculture on average over all environmental zones and federal states in recent times (1990 to today) as "slightly negative". The responses for specific environmental zones and federal states ranged from "negative" to "neither positive nor negative". In the short (today to 2010) and medium (2010 to 2020) term ratings were on average "slightly negative", in the long term (2020 to 2050) on average "negative". It is striking that – in spite of existing opportunities in agriculture due to climate change – the general assessment of climate change for almost all environmental zones and federal states is in the negative range, and that the ratings increase in negativity into the future.

Risk Assessment

Experts rated two potential *elements of climate change* as on average "negative" already in the short term: the potential decrease in annual precipitation[14] and the potential increase of hot days and heat waves. Stronger variations in precipitation, less frost days, and more frequent extreme rainfall events were rated as "slightly negative" in the short term. In the medium and long term most ratings become more negative. The pattern of responses for increasing average annual, winter and summer temperatures are interesting. For some environmental zones and federal states these increases were rated positively, in the medium term, however, they are rated neutrally, and in the long term negatively. On the other hand, these temperature changes are often rated extremely differently depending on environmental zone, ranging from "very negative" to "positive".

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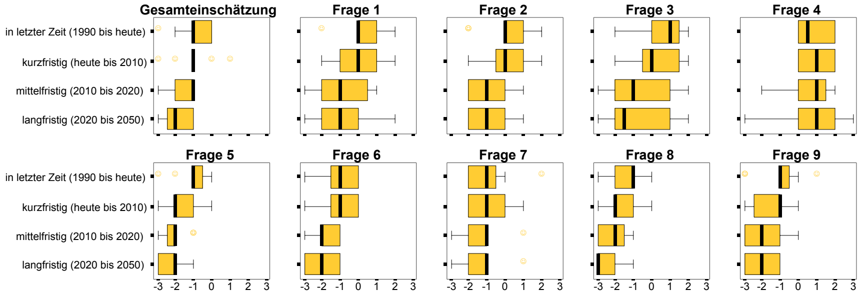
[14] According to the present state of knowledge increases and decreases in annual precipitation are possible, depending on the region. Therefore, both developments were offered to the respondents for rating.

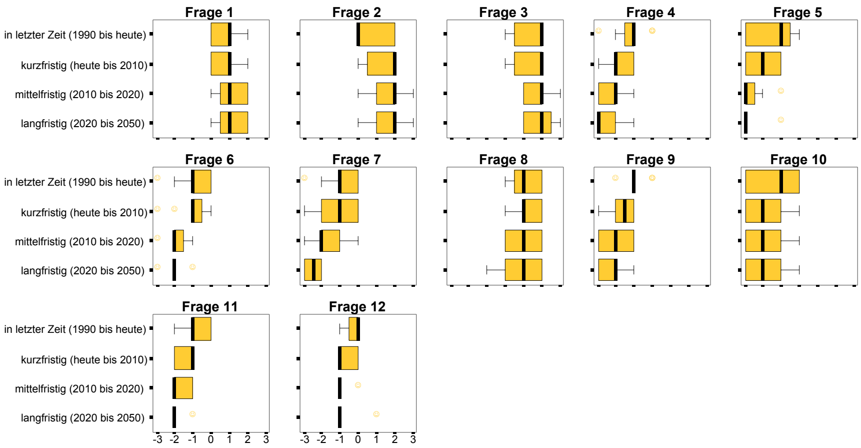
Experts' ratings of climate change and some of its particular elements



In your opinion, how positive/negative for your sector is/are ... ...

Question 1:	… increasing mean annual temperature?	Question 4:	… an increase in the annual sum of precipitation?	Question 7:	… less frost days?
Question 2:	… increasing winter temperatures?	Question 5:	… a decrease in the annual sum of precipitation?	Question 8:	… more hot days and heat waves?
Question 3:	… increasing summer temperatures?	Question 6:	… stronger inter-annual variations in precipitation?	Question 9:	… more extreme rainfall events?

Experts' ratings of climate change and its potential impacts



In your opinion, how positive/negative for your sector is/are ...

With regard to cropland		With regard to grassland	
Question 1:	… an increase in yield potential (owing to increasing temperature and CO2-content)?	Question 8:	… an increase in yield potential (owing to increasing temperature and CO2-content)?
Question 2:	… the possibility of earlier sowing dates?		
Question 3:	… improved cultivation potential for specific crops (e.g. maize, millet)?		
Question 4:	… yield losses through drought stress in summer?	Question 9:	… yield losses through drought stress in summer?
Question 5:	… yield losses through extreme events (storm, hail, flood)?	Question 10:	… yield losses through extreme events (storm, hail, flood)?
Question 6:	… the expansion of pests, new pests?	Question 11:	… the expansion of pests, new pests?
Question 7	… decline of soil fertility (through erosion, eluviation, decomposition of organic material etc.)?	Question 12:	… decline of soil fertility (through erosion, eluviation, decomposition of organic material etc.)?

Response scale

-3 =	Very negative	Gesamteinschätzung =	Overall rating
-2 =	Negative	Frage 1, 2…. =	Question 1, 2…
-1 =	Slightly negative		
0 =	Neither positive nor negative	In letzter Zeit (1990 bis heute) =	In recent times (1990 to today)
1 =	Slightly positive	Kurzfristig (heute bis 2010) =	Short-term (today to 2010)
2 =	Positive	Mittelfristig (2010 bis 2020) =	Medium-term (2010 to 2020)
3 =	Very positive	Langfristig (2020 bis 2050) =	Long-term (2020 to 2050)

Illustration of the frequency distribution of ratings for environmental zones and federal states as box-plot: Each box represents the central 50% of the distribution and therefore illustrates the values between the lower and the upper quartile. The more to the left the box is shown, the more negative a specific impact of climate change is rated. The thick vertical line represents the median value. The whiskers to the left and right of the box illustrate the range of responses. Yellow boxes mark outliers and extreme values, which stand out from the upper or lower quartile by 1.5 to 3 times the box length.

Sample size: 6 questionnaires from the federal states Schleswig-Holstein, Mecklenburg-Western Pomerania, Brandenburg, Thuringia, Saxony, and Hesse.

Fig. 4.2-6: Experts' rating of climate change and its potential impacts in the agricultural sector.

Respondents rated none of the potential *impacts of climate change* on German agriculture as on average neutral in the short term. Negative ratings are the majority. This holds already for the ratings of the past since 1990. Yield losses on croplands through drought stress, and yield losses through extreme events (storm, hail, flood) on cropland and grassland, are rated as "negative" already in the short term – with marked differences in grassland losses between different environmental zones and federal states. Respondents rated the yield losses due to drought stress on grassland in summer, the expansion of (new) pest species, and the decline of soil fertility in crop- and grassland as slightly less negative. With almost all risks, there is a trend toward increasingly negative ratings in the medium and long term.

Opportunity Assessment

Only one of the potential *elements of climate change* is on average rated as an opportunity: the possible increase in annual precipitation. In the short, medium and long term this is seen as "slightly positive". However, differences between ratings increase over time, and range in the long term across the entire scale from "very negative" to "very positive", depending on environmental zone.

Among the potential *impacts of climate change*, respondents rated the possibly earlier sowing dates and improved cultivation potential for specific crops (e.g. maize, millet) in the future on average as "positive". Increases in yield potential (owing to increasing temperature and CO_2-content) on crop- and grassland are seen as "slightly positive". Positive ratings on average stayed constant, while in contrast the negative ratings became increasingly negative over time from the short, over medium to long term.

Further Impacts

We also asked about further potential impacts of climate change in the agricultural sector. Respondents listed CO2-enrichment that increases photosynthesis, crop type rotations that increase soil organic matter in bioenergy crop plantations on potentially retired land, the cultivation of new, drought-resistant varieties, the use of genetic engineering, and later sowing in winter crops.

4.2.6 Adaptation to the Impacts of Climate Change

In the past, agriculture has proven to be very adaptable to changes in environmental conditions, as linearly increasing yields show. This high adaptive capacity is based on the one hand on short term planning horizons (few years), and on the other hand on the possibility to maintain high yields through changing conditions through the use of new cultivars or technological development.

Changes in cultivation and management are adaptation measures available to agriculture:

- *Change in sowing date*: Summer cereals can be sowed earlier due to increasing temperatures. This brings the advantages of higher soil moisture levels in the early year, potentially increased yield through longer growth phase, and decreased risk from water stress. On the other hand, the risk of damages through late frosts increases. Winter cereal should be sowed later than currently customary, to avoid damages through a late onset of the cold phase, which is important for development.
- *Choice of suitable cultivars*: These include cultivars that are less sensitive to drought stress. Generally, robust varieties with wide climatic tolerance and low susceptibility to pests should be preferred over sensitive high-performance cultivars.
- *Adaptation of crop rotation and introduction of new crop types*: More suitable crop types should replace crop types that prove to be less suitable under changed climatic conditions. Thermophilic crop types with high water use efficiency seem especially suitable, such as e.g. some maize cultivars or millet. Diversification of

the range of crop types lessens the risk of yield losses through climate extremes and damages through pest outbreaks.

- *Use of soil-fertility maintaining and water-saving management options*: These include application of mulch and plough-less soil treatment. These practices lower water losses through transpiration, and decrease the release of carbon and the risk of erosion.
- *Adaptation of fertilisation and pest management*: The use of fertilisers needs to be adapted to an increased demand for nitrogen with increasing CO_2-content. On the other hand, increased nitrogen fertilisation increases water use, so that a suitable balance needs to be achieved. Pest management should take account of risks through new pest species early on. Integrated methods should be favoured. The choice of robust cultivars and a diverse range of crop types contribute to plant protection.
- *Cultivation of renewable primary resources for energy generation*: This adaptation measure contributes to emission reduction, and is furthermore an alternative use for many agricultural areas in Germany that will probably cease to be needed for food and fodder production in the long term.

Moreover, *financial safeguarding* in the face of risks of yield losses plays an important role. In Germany, insurances for the agricultural sector are currently largely restricted to insurance against hail. Damages like the yield losses through the 2003 heat wave are only covered partly by federal ad hoc measures. The introduction of a "multiple risk insurance", which has long been common practice in the USA, is an option for an expanded coverage of risks.

4.2.7 Effectiveness, Degree of Implementation and Obstacles of Adaptation: Assessment of Regional Experts

We have responses from the expert survey (method described in chapter 2.6) on measures that are suitable for climate change adaptation from the following seven federal states: Schleswig-Holstein, Mecklenburg-Western Pomerania, Brandenburg, Saxony, Thuringia, Hesse, and Saarland. The following results of the survey must be seen as very preliminary assessment of the measures that are suitable to adapt the German agricultural sector to climate change, since only one expert per federal state was approached and the return of the questionnaires from the federal states was scarce.

In the survey, different dimensions of the adaptation measures were evaluated; the effectiveness of the measure to mitigate the risks introduced in section 4.2.5, alternatively to capitalize on the opportunities of climate change (see Tab. 4-2), and the present degree of implementation of the adaptation measure (see Fig. 4.2-7).

Cultivation of Adapted Crop Types

Respondents assigned the cultivation of adapted crop types a wide range of positive effects with regard to the impacts of climate change on agriculture, both regarding opportunities (increasing yield potential, possibly earlier sowing, improved cultivation conditions for some crop types) and regarding risks of climate change (yield losses through drought stress and extreme events, expansion of pest species; see Tab. 4-2). Merely with regard to the risk of declining soil fertility, no respondent sees the cultivation of adapted crops as effective.

Tab. 4-2: Rating of the degree of effectiveness of adaptation measures to mitigate risks and capitalize on opportunities of climate change in the agricultural sector. The number of respondents that rated a particular measure of mitigation resp. exploitation as effective is shown. Sample size: 6 questionnaires from the federal states Schleswig-Holstein, Mecklenburg-Western Pomerania, Brandenburg, Saxony, Thuringia, and Hesse.

Measures	Impacts: Increase inpotential yield	Possibility of earlier sowing dates	Improved cultivation potential for specific crops	Yield losses through drought stress in summer	Yield losses through extreme events	Expansion of pests, new pests	Decline of soil fertility
Cultivation of adapted cultivars	5	4	3	4	2	3	-
Cultivation of new crop types	3	-	5	2	1	3	2
Adapted irrigation techniques	6	-	4	3	1	-	2
New cultivation techniques to maintain soil-fertility and save water	4	1	3	4	3	1	3
~~*Measures integrating several risks*~~ Insurance against climate change damages	-	-	-	4	6	1	-
Creation of reserve funds for furture adapatation measures and damage resparation payments	-	-	2	3	5	1	-

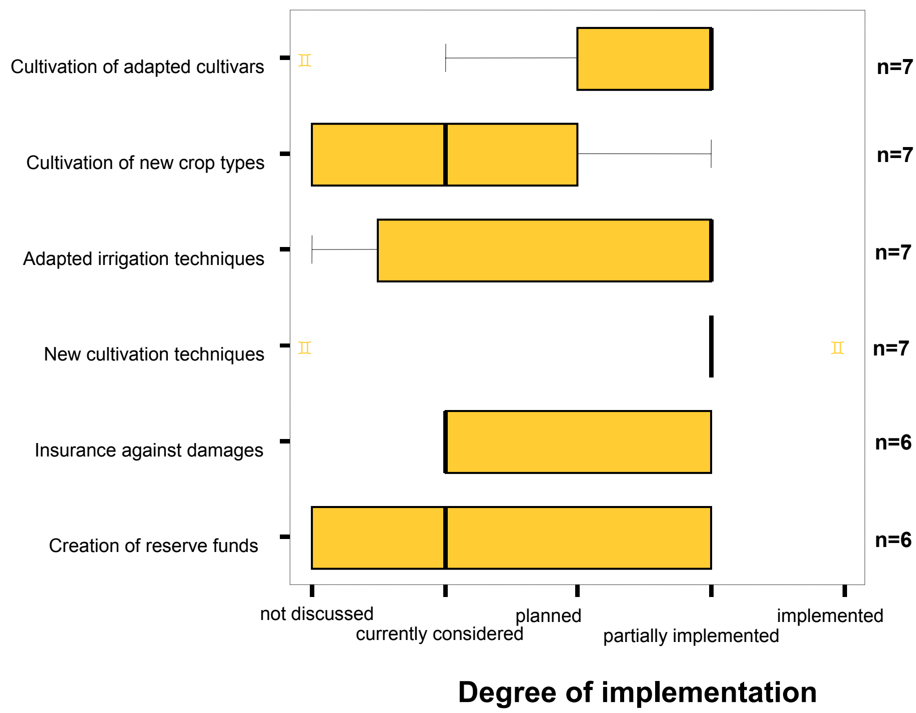


Fig. 4.2-7: Assessment of the degree of implementation of measures that are suitable to adapt to climate change in the agricultural sector. Sample size: 6 questionnaires from the federal states Schleswig-Holstein, Mecklenburg-Western Pomerania, Brandenburg, Saxony, Thuringia, and Hesse. The n-values give the number of questionnaires each box-plot is based on. For further explanation of the graphical representation see Fig. 4.2-6.

The degree of implementation of this measure was on average across federal states rated as "partially implemented" – with relatively little variation between ratings from different federal states (Fig. 4.2-7). Respondents named as reasons for already using adapted crops that variability in weather and soil conditions are a constant factor in agriculture, and that drought stress has been increasing. Only one respondent identified climate change as a reason for implementation of this adaptation measure in his/her federal state.

Cultivation of New Crop Types

This measure also has a broad effectiveness, and naturally most respondents think of it as appropriate to profit from improved cultivation potential of specific crop types (see Tab. 4-2).

On average across the seven responsive federal states, the cultivation of new crop types was rated as "currently considered" (see Fig. 4.2-7). But the variation between federal states is large. The highest degrees of implementation ("partially implemented") are reported from Brandenburg and Saxony. Reasons for the cultivation of new crop types were said to be the creation of new income sources for farmers, the increase of biodiversity, as well as the improved drought resistance of the new crop types. Again, only in one federal state the measure was implemented because of climate change.

According to three respondents, lacking knowledge is an obstacle in cultivating new crops. One respondent names organisational hurdles as further problem. Specific obstacles are mainly related to yield variability due to lacking experience with the cultivation of new crop types and to "undesired" climatic conditions (e.g. late frosts). Owing to these difficulties, respondents rated this measure as more complicated than the cultivation of adapted crop types. The average rating lies between "slightly complicated" and "complicated".

Adapted Irrigation Systems

Adapted irrigation systems are thought of being slightly less broadly effective with regard to adapting to impacts of climate change than the cultivation of adapted or new crop types (see Tab. 4-2). All respondents regard this measure as suitable to capitalize on the opportunity of increased yield potential. In the context of climatic risks, the measure is seen as particularly effective to avoid yield losses through drought stress.

On average, adapted irrigation systems are rated as "partially implemented", with large variations between different federal states (see Fig. 4.2-7). Eastern German federal states are the main contributors to the high degree of implementation, because they have in the past been more affected by aridity than Western federal states, and probably will be even more affected in future due to climate change. However, only one respondent from Eastern Germany identified this risk of climate change as a decisive reason to implement adapted irrigation systems. Respondents from other federal states list as reasons to implement adapted irrigation systems among others securing yield stability, the option to alleviate arid periods, and the strive to efficient water use.

Almost all respondents see financial obstacles as main hindrances in implementing irrigation systems. They name particularly the high investment costs in relation to irregular usage of the systems. Moreover, there are said to be legislative (water use restrictions) and ecological hurdles. On average, respondents rated the measure as "complicated". Two respondents even replied "very complicated".

New Cultivation Methods to Maintain Soil-Fertility and Save Water

This measure has been rated to have the broadest spectrum of effectiveness among the discussed measures (see Tab. 4-2). For every listed potential impacts of climate change, at least one respondent saw new cultivation methods as effective adaptation measure.

The degree of implementation is rated on average as "partially implemented", with only slight differences between federal states (see Fig. 4.2-7). Two of the seven respondents named climate change explicitly as a reason to implement new cultivation methods. As further reasons reduced costs, reduced erosion, maintaining soil-quality, saving water, and securing yield stability were listed.

Few obstacles for the implementation of new cultivation methods were named. One respondent saw "legislative hurdles", another "lacking knowledge". Respondents pointed out that the economic success of new cultivation methods depends strongly on farm-specific advantages and disadvantages and could hardly be generalised. With regards to these few obstacles, respondents saw this measure on average as "not complicated".

Measures integrating several risks: Insurances and Reserve Funds

Respondents saw insurances against damages through climate change and the creation of reserve funds for future adaptation measures and damage reparation payments as effective over a narrow range of issues (see Tab. 4-2). Such measures were thought of as effective mainly to buffer yield losses through drought stress or extreme events. In comparison to the other sectors that were surveyed (particularly nature conservation), in agriculture respondents attributed a relatively high effectiveness to measures integrating several risks.

On average across federal states, respondents rated the degree of implementation of both measures as rather low, namely "currently considered" (see Fig. 4.2-7). In all federal states, insurances are already on the agenda, but reserve fund building is not. Brandenburg and Mecklenburg-Western Pomerania (hail insurance only) reported the highest degree of implementation ("partially implemented") for insurances. According to respondents, the creation of reserve funds is in the farthest stage of implementation in the states Brandenburg and Thuringia ("partially implemented"). The reasons to implement these measures were listed as previous flood experiences, general financial risks, and the general uncertainty of the future. Only Brandenburg's respondent listed climate change as one of the reasons to buy insurances and create reserve funds.

According to most respondents, there are financial obstacles in getting insurances and building reserve funds. They argue that capital resources of many agricultural enterprises were not big enough and that building public support of the insurance fees needs to be pursued more vigorously. As further obstacles, legislative hurdles and gaps in knowledge were listed. Respondents also mentioned that the responsibility for insurance against risk was not clearly divided between public and private bodies. One expert suggested pursuing federal or EU-wide solutions. Broad distribution of federal reserves and insurances would also spread the risk widely. With regard to these obstacles, respondents rated both measures as "complicated", while to this only four out of seven experts responded at all.

Further Measures

At the end of the survey, experts were asked for further measures that may be suitable to prevent risks of climate change or capitalize on opportunities. The respondents gratefully took up this opportunity and listed, among others, the following measures: higher drought resistance and robustness of crop plants e.g. through breeding and genetic engineering; targeted and decreased use of fertilisers and pesticides together with improvements in soil organic content; expansion of irrigation systems, as well as improved water holding capacity of the soils; targeted weather forecasts fro farmers by meteorological services; new crop rotation systems to minimise case specific, climate related risks, as well as increased cultivation of C_4-plants to increase biomass production.

Adaptation to Climate Change in Agricultural Departments

The experts from functional departments on agriculture in the federal states were also asked about activities of their administration to adapt the impacts of climate change. Respondents replied that there was indeed an ongoing discussion about the issue of adapting to climate change in their administration. However, from other responses we got the impression that this response related more to initiatives to reduce greenhouse gas emissions (mitigation).

Practical initiatives to adapt to the impacts of climate change were only reported from three federal states: In Mecklenburg-Western Pomerania the development of soil management techniques that prevent water and wind erosion through the LfA, the expansion of water-saving cultivation methods, and experimentation with the cultivation of thermophilic plants (soy); in Saxony among others, sparing soil management, experiments with crop rotation, and monitoring of pest occurrence; and in Brandenburg the encouragement of irrigation and drainage, and the programme to create cultural landscapes (Kulturlandschaffungsprogramm, KULAP).

Asked about the relevance of the issue of adaptation in comparison to other issues in their administration, two respondents answered "important" (Saxony and Brandenburg), two "slightly important", and two "unimportant". In none of the administrations the issue was rated as "very important". Adaptation to the impacts of climate change therefore seems to be of variable significance in the agricultural departments of the various federal states, but was never seen as being of high importance.

Adaptation in the Agricultural Sector: Summary and Conclusions

The cultivation of adapted varieties, and new, adapted cultivation techniques to conserve soils and save water are seen as broadly effective measures to mitigate potential risks and capitalize on potential benefits of climate change. Moreover, the cultivation of new crop types, and adapted irrigation systems were rated as effective in many ways. For each potential impact of climate change, respondent named two, for some potential impacts even more, effective adaptation measures.

Among the six measures about which was enquired, three were on average rated by respondents as only "currently considered": cultivation of new crop types, insurances against damages, and the creation of reserve funds. The three further measures – cultivation of adapted varieties, adapted irrigation systems, and new cultivation techniques – were rated on the qualitative scale on average two steps higher, namely as "partially implemented". However, the range of responses was wide, and there were large differences in the degree of implementation of measures between federal states. Some federal states seem to lag behind. Furthermore, we would like to stress that – except for one respondent – no expert rated even a single measure as already "implemented".

However, there were few obstacles, so that respondents rated the implementation of measures on average, and particularly in comparison to other sectors (particularly nature conservation) as little complicated. Of little complexity seemed especially the cultivation of new crop types and the implementation of new cultivation techniques – measures that were also seen as widely effective regarding various impacts of climate change. If the awareness of risks and opportunities of climate change can be raised in agriculture, there seem to be few difficulties in adapting to climate change.

Respondents named weather extremes, sometimes very specific events in the past, as triggering events for the implementation of measures that are also suitable to adapt to climate change. However, climate change is only named by Brandenburg, and to a lesser degree by Mecklenburg-Western Pomerania as one of the reasons for the implementation of measures. Currently a debate about climate change takes place only in few agricultural departments of federal states that were surveyed. We therefore conclude that impacts of climate change have not or only sparsely been considered in the planning of measures, and that agriculture in most federal states is not yet adapted to future impacts of climate change. The risks of the past (particularly weather extremes) have been considered, but not the anticipated changing conditions in eh future. Because extreme weather events are considered, there is an awareness of the demand for adaptation measures. The challenge is to expand this awareness to the opportunities and risks of other, more long-term climate impacts.

In general, the adaptive capacity of German agriculture should be high with regard to future impacts of climate change. In agriculture, highly effective but little complicated measures are available (mainly the cultivation of new crop types and the use of new cultivation techniques), which is a rare opportunity.

Federal states should use the opportunity to exchange their experience and knowledge, since the degree of implementation of adaptation measures and the state of present discussion on adaptation to climate change was very different between some federal states.

4.2.8 References

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4.3 Forestry

4.3.1 Summary: Vulnerability of the Forestry Sector

Climate change holds risks and opportunities for German forestry. Opportunities arise through increased yield potential and the possibility to introduce new tree species. Risks arise through partly profound potential impacts of climate change, and through the long time scale and complexity of implementing adaptation measures in the forestry sector. Threats to forestry can be listed on several levels:

Tree species: Among the main tree species, Norway spruce (*Picea abies*) is particularly impacted by climate change. Norway spruce prefers moist, cool stands and its resistance to heat and aridity is limited. Spruce is often already currently grown at the limit of its range of tolerance, because due to its high growth potential it is grown in many places outside its natural habitat. Furthermore, spruce is particularly susceptible to the indirect impacts of climate change, such as calamities (bark beetle, e.g. *Ips typographus* and *Pityogenes chalcographus,* Coleoptera: Scolytidae) and damages through extreme events (windbreak). The sensitivity of spruce to climate change is of particular economic importance, since spruce is the most frequently planted tree species in Germany. Beech trees (*Fagus sylvatica*) are also hygrophile and sensitive, but not to the extent of spruce. Only those stands where beech reaches its limit of aridity are threatened, and beech is usually grown at suitable sites. Oak (*Quercus* spec.), Scots pine (*Pinus sylvestris*) and non-native Douglas fir (*Pseudotsuga menziesii*) are relatively less sensitive. However, especially in pine monoculture, the risk of forest fires will increase considerably with climate change.

Forest ecosystems: Mixed forests are less sensitive than coniferous forests, since they can better adapt to climate change. High genetic diversity also decreases sensitivity.

Regions: Within Germany, those regions are particularly vulnerable that struggle with low water availability already today (parts of Eastern Germany), that expect particularly large temperature variation (South-western Germany), and that grow spruce outside its natural range of distribution (Southern and Western Germany). Less vulnerable are coastal areas (relatively small change in climate, low risk of drought), the alpine upland, and large parts of the lower mountain ranges.

To date, the forestry sector is adapted to the impacts of climate change only to a certain degree. On the one hand, the discussion about climate change is most intense compared to the other examined climate-sensitive sectors, but on the other hand, the full implementation of planned adaptation measures to climate change often takes several decades in the forestry sector. In some regions, measures still need to be planned. Consequently, we rate the vulnerability of the forestry sector to climate change without further measures as "moderate" (business-as-usual scenario, see chapter 2.8). Only the drought prone regions (Eastern Germany), as well as regions with strong temperature increase and a high proportion of out-of-natural-habitat spruce stands (lower regions in Western and Southern Germany) are rated as presently "highly vulnerable".

However, the forestry sector should have a high capacity to adapt to the impacts of climate change more than today, since a range of effective adaptation measures are available, even if these are often rated as "complicated". The shift to mixed forests and the maintenance of genetic diversity were seen as broadly effective in responding to a range of uncertain risks and opportunities of climate change, since these measures maintain or broaden the capability to adapt. The economic pressure that each forest owner has to bear will also be decisive for the adaptive capacity of the forest sector. In this regard, the adaptation of privately owned forests relies on special support. We expect that the vulnerability of the forestry sector to climate change can be rated as "low", if the suggested adaptation measures are implemented (improved-business scenario, see chapter 2.8).

4.3.2 Forestry and Climate

Forests are typical, multifunctional ecosystems. As providers of wood and fibre they offer us provisioning ecosystem services (see chapter 1.3). Locally, they protect from erosion, avalanches, immission and noise (protecting function), they have a positive impact on the water balance and the local climate (regulating ecosystem service), and provide opportunities for recreation (cultural ecosystem service). They are also important for biodiversity and nature conservation (Häusler & Scherer-Lorenzen, 2002). In Central Europe, forests are the ecosystems richest in species diversity. Some forms of forestry threaten biodiversity. Forestry poses a risk to 338 of the 711 threatened fern and angiosperm (flowering plant) species (Korneck & Sukkop, 1988) and to approximately 800 of the approximately 1700 threatened animal species (Bode, 1997). Finally, forests are important for climate regulation as potential sinks of carbon (see below).

Forestry is tightly linked to climate and weather conditions. Climatic conditions determine to a large part the range of suitable tree species and the yield potential of specific species. The course of weather conditions is decisive for variations in the occurrence of phenological phases such as bud break and blooming, and for biomass increment. Weather extremes, such as storms or extreme rainfall events, but also drought and heat waves, can permanently damage forests.

The principal interaction between climate and plant physiology, plant growth and plant development have already been described in the chapter on agriculture and are analogue for forestry (see chapter 4.2). In the following we will therefore only describe sets of factors or complex climate impacts on forests.

Yield Potential and Water Supply

In principle, similar to agriculture, climate change is expected to increase yield potential in forestry. This is on the one hand due to the "fertilising" effect of the increased CO_2-content of the air. CO_2 enhances photosynthetic activity and water use efficiency (Jarvis, 1998). On the other hand, rising temperatures increase photosynthetic rate and other metabolic processes until a certain temperature optimum. Furthermore, a temperature increase leads to a longer vegetation period and therefore to a longer growth phase. In experiments, a doubling of CO_2-content of the air led to a growth increase by 20% in trees on average (Norby et al., 1999). However, in case of a temperature increase of much more than approximately 2ºC negative effect will prevail in most native tree species (Hirschberg et al., 2003).

It strongly depends on water and nutrient supply if an increase in temperature and CO_2-content will actually increase yields in a specific location, with water supply probably being the future limiting factor (Flaig et al., 2003).

Water supply depends on the one hand on water availability, on the other on the demand of the forests. With increasing temperatures water demand increases owing to increased plant and soil evaporation (evapotranspiration).

On the assumption of a decrease of precipitation in future as a consequence of climate change, water supply would decrease as well. Furthermore, declining groundwater tables as a consequence of melioration measures and increased water extractions can decrease water supply. The impacts of decreased water supply are drought stress, impaired growth and drought damages. The susceptibility to drought stress varies with species. For example, while spruce and beech exhibit low drought resistance, pine is relatively robust concerning drought stress. According to an experts' survey, drought stress is the most relevant impact of climate change on forest growth (Spiecker et al., 2000).

Shifts in Species Distribution and Tree Species Composition

Climate is one of the main factors determining the composition of tree species in the potential natural vegetation, as well as the suitability of specific species for use in forestry. Long-term climate changes lead to changes in local conditions and therefore shift species distribution. Many forest ecosystems today are already under increased adaptation pressure, since forests need a long time to adapt to environmental changes. This pressure is stronger the more local ecological conditions will change in future (Borchert & Kölling, 2004). Tree species with a small range of tolerance are particularly sensitive (e.g. fir, *Abies alba*), as well as species that rely on cool and moist conditions (e.g. spruce).

Pests and Pathogens

Animal (insects) and non-animal pests (fungi) usually profit from rising temperatures. Pests and pathogens generally adapt rapidly to climate conditions, due to their short generation times and high mobility. The susceptibility of forests to pests, however, can be increased by prior climatic damages, such as drought or windbreak.

When temperatures are high and vegetation period is long, animal pests, such as e.g. the bark beetle, can produce several generations per year, leading to increased abundance over longer periods of time. Mild winters also increase their reproductive success. Moreover, insect pests can spread further North and higher in altitude. New invasive pest species are expected (Ulrich & Puhe, 1994). However, we would like to stress that different insect pest species can react very differently to climate change.

Risk of Forest Fires

The risk of forest fires is influenced by two sets of factors: people’s behaviour and climatic or weather conditions. A climate related risk of forest fires increases the probability of forest fires, however most fires are triggered by human activity (Badeck et al., 2004b). Generally, the risk of forest fires increases in dry, hot summers.

Impacts of Extreme Weather Events – Storm Damages

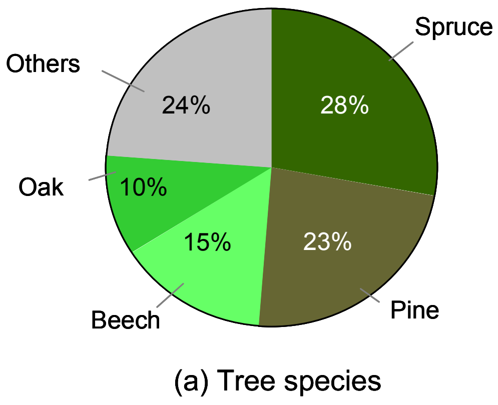
Among coniferous trees, spruce and Douglas fir are particularly sensitive to windbreak; among deciduous trees this is true particularly for beech, birch (*Betula pendula*) and poplar (*Populus* spec.). Mixed stands are thought to be less sensitive. Previously damaged trees are particularly at risk (Ulrich & Puhe, 1994). Storm damages increase the risk of insect calamities, particularly through the infestation with bark beetles.

4.3.3 Baseline Situation: Forestry in Germany

With a forest area of 11.1 million hectares (ha), one third of Germany is forested. Almost three-quarters of the forests (73%) are mixed stands. Norway spruce (*Picea abies*) is grown on a little more than a quarter (28%) of the forested land and is therefore the most common tree species in Germany. This is followed by pine (*Pinus sylvestris*) with 23%, beech (*Fagus Sylvatica*) with 15%, and common and sessile oak (*Quercus robur* and *Q. petraea*) with 10% (Fig. 4.3-1a; BMVEL, 2004). Forty-six percent of the forest is privately owned, 34% are owned by the federal states or the federal government, and 20% are owned by towns, communities and other corporate bodies (Fig. 4.3-1b). The forestry sector employs approximately 175,000 people and accounts for approximately 3% of gross national product (DFWR, 2001).

Recent Development

The percentage of deciduous trees, particularly of beech trees, has distinctly increased in the last 15 years, as a consequence of management measures (forest conversion programmes), while the percentage of coniferous trees decreased. Total forest area also increased slightly, on average by approximately 3500 ha per year.



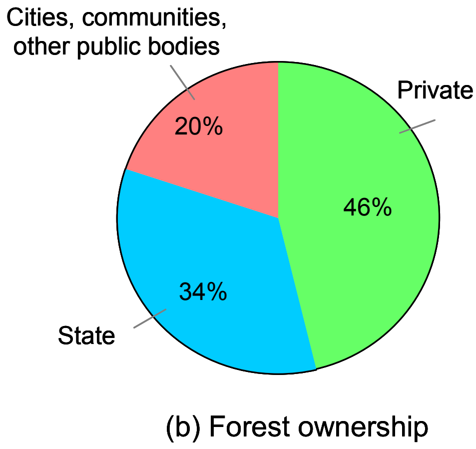


Fig. 4.3-1: Tree species (a) and forest ownership (b) in Germany (BMVEL, 2004; DFWR, 2001).

The stock of wood in German forests is high. With an average of 320 stored solid cubic meters of wood per hectare they are not only at their peak compared to historical records, but also obtain a leading position relative to European neighbouring countries. Wood increment is also relatively high: In the old federal states an annual increment of on average 12.6 stored solid cubic meters were observed during the period 1987 to 2002 (average across all tree species and age classes). This trend has been observed for many other European countries as well (Spiecker et al., 1996). On average, only two-thirds of this increment is harvested. Since less wood is used than annual growth adds, the stock of wood and age of the forests and trees increases. This bears advantages (older forests usually are more diverse, rich in structure and store more carbon) and risks: with increasing age the susceptibility of trees to environmental stress increases and the risk of depreciation of wood through calamities increases (BMVEL, 2004).

Novel Damages to Forests

Since the mid 1970s, novel damages to forests have been recorded on wide areas within the whole of Europe. When originally mostly fir and spruce were impacted, damages now occur increasingly also on deciduous trees, particularly beech. Interplay between various abiotic influences (pollution, nitrogen deposition, weather conditions) and biotic factors (calamities) is speculated to be the root cause of this. Among these factors, pollution is seen as the most important cause. Since the mid 1980s, the health status of German forests is regularly monitored in forest damage inventories, mainly focussing on the indicator "crown transparency".

In the year 2004, 72% of all trees exhibited distinct crown transparency or were rated as "in stage of alert". This was the highest level of recorded damage since the beginning of forest damage inventories. For the first time, the main reason for this high level of damage in 2004 is not thought to be pollution, but the weather conditions in the hot and dry "record summer" of 2003, and its side- and after-effects. These are direct damage through drought and radiation; damage through increased ozone content of the air, as a consequence of intensive solar radiation; and the spread of calamities as a consequence of the mild winter in 2003, as well as prior damages through direct weather impacts (BMVEL, 2004).

Current Impacts of Climate Change

An early sign of climate change may be the increase of wood increment described above. The main cause of this is thought to be nitrogen deposition from the atmosphere, but the increasing warming and the elongation of the vegetation period do indeed contribute to increased wood growth. The vegetation period of the main forest tree species in Europe and Germany has already been elongated by 10-11 days from the 1960s to the 1990s of the 20^{th} century (Menzel, 1997; Badeck et al., 2004a).

German forests are primarily at risk through drought stress. This is true particularly for the warm and dry areas in the Northeast and Southwest of Germany. Moreover, in the Southwest spruce as the main tree species is little resistant to aridity. In the North, especially in the Northeast, sandy soils with low water holding capacity increase the risk of drought stress. Furthermore, stands close to groundwater table (lowland riparian forest) are at risk through declining groundwater tables (Gerstengarbe et al., 2003).

The heat wave in the summer of 2003 shows how strongly yield potential can be threatened by drought stress. Drought and high temperatures led to a near total depletion of the water reserves in forest soils available to plants. In August/September, the water uptake of trees in many stands was strongly impaired. The consequent water deficiency had profound impacts in many forest areas. Premature shedding of leaves and needles, actinocutitis (sunburn) and a general decrease of vitality of the forest trees were observed. This led to a poor status of tree crowns in 2004, but also to e.g. decreased increment and resistance to pests (BMVEL, 2004). Damages through extreme weather conditions such as in the year 2003 can continue to have an effect over more than 10 years, and can lead to changes growth trends in the long term, beyond actual reduced growth rates (Anders et al., 2004).

In 2003, the connection between drought, heat and risk of pest infestation became also apparent. An explosive propagation of pests, particularly bark beetles and nun moths (*Lymantria monacha*, a leave-eating butterfly, especially on spruce and pine), was a consequence of high temperatures and decreased vitality of forests in 2003 (BMVEL, 2003).

In Germany in the year of the heat wave, the area of burnt forest was also by 25% larger than the average across 1991-2002, namely 1315 ha. In 1992 the largest area of burnt forest since 1990 was registered, with 4908 ha and an estimated damage of 12.8 million €. In this "record summer" the absolute maximum air temperature reached 39.1ºC, and the maximum of precipitation deficiency was in Northeast Germany, where stand conditions and plantation types (sandy soils, pine stands) in general cause maximum forest fire risk (Anders et al., 2004).

Almost every fire starts on the ground – it is therefore meaningful that since the last few decades undergrowth of grasses in forests is increasing and favouring two grass species that rank very highly on the scale of inflammabilty, namely wood small-reed (*Calamagrostis epigejos*) and wavy hair-grass (*Deschampsia flexuosa*). Furthermore, the grass layer contributes to increased evaporation and therefore to further desiccation. Reasons for increasing grass layer are thought to be on the one hand atmospheric nitrogen deposition and acidification, and on the other hand climate warming in combination with dryer summers. Therefore, dry summers increase the risk of forest fires not only in the year itself, but also in the following years (Anders et al., 2004).

Moreover, in recent decades, an increase in forest damages through storms was observed. Particularly in Southern Germany, the low-pressure systems "Vivian", "Wiebke" (1990) and "Lothar" (1999) caused disastrous damages.

The Forestry Sector and Climate Protection

Presently, German forests are a sink of carbon. Between 1987 and 2003, forests in Germany absorbed approximately 75 Mt CO_2, which corresponds to approximately 3% of Germany's CO_2-emissions during the same time (BMVEL, 2005). Therefore, the protection and maintenance of forests plays an important role in climate protection.

Further Influences on the Forestry Sector in Germany

In Germany, forests overwhelmingly are managed ecosystems. Management strategies (targeted tree species, rotation times, type of harvest) vitally determine the status of the forest and influence the processes within it. In their turn, management strategies depend strongly on the actual conditions of the wood market. Land use changes such as afforestation, and the building of roads and settlements are further direct influences. Besides these direct human influences, forests are indirectly impacted through anthropogenic pollution (sulphur compounds, nitrogen, ozone) and changes in the water balance (melioration). Further influences are biotic factors such as pest insects and fungi, and the invasion by neophytes. Many of these factors interact. Climate and weather extremes and the impacts of climate change act as additional stressors in concert with these factors and often enhance their impacts (e.g. risk of calamities).

4.3.4 Impacts of Climate Change – Trends and Projections

Yield Potential and Wood Increment

We expect that the influence of climate change on yield potential will increase in future. Of special importance are water supply and therefore precipitation and its seasonal patterns. Besides this, yield potential will continue to also depend strongly on the chosen management options (targeted tree species, type of management).

An experts' survey reached the conclusion, that under the assumption of a warming by 1-2ºC and an increase of precipitation by 0-20% in the next 60 years, productivity (annual increment) could be increased by 5-20%, depending on tree species and region (Spiecker et al., 2000). Scenarios of the study "Forests and Forestry in Germany Under Global Change" (Pretzsch et al., 2002) project an increase of wood production in Germany by 5% by the year 2030, using a relatively wet climate scenario calculated by HadCm2. On the other hand, the relative dry climate scenario calculated by ECHAM4 projected a decrease in wood production by 9% (Döbbeler & Spellmann, 2002).

Results from the ATEAM project (see chapter 2) show that Germany can expect a further increase in stocks of wood and also carbon stocks in the next 100 years under all scenarios (Fig. 4.3-2, Fig. 4.3-7 in the Annex). According to these scenarios, German forest would continue to be a sink of carbon in future. However, this goes along with an aging of the forest stands, lower increments (Fig. 4.3-3, Fig. 4.3-8 in the Annex), and a higher susceptibility to weather extremes and calamities. Reasons for this trend are not so much climate changes, but the present trend in management of low wood extraction. Accordingly, the results depend more upon different socio-economic conditions (SRES-Scenarios) than on different climate scenarios calculated by different climate models.

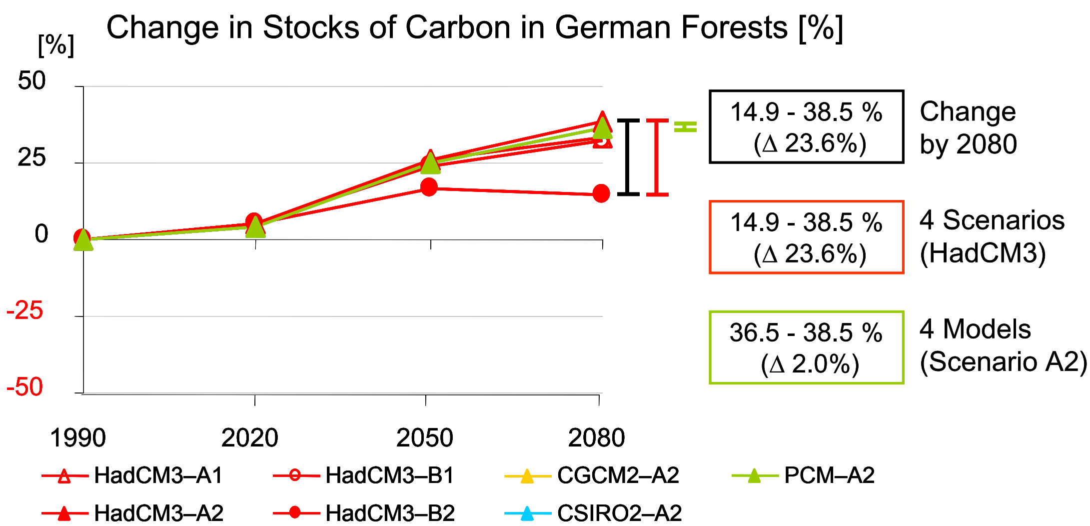


Fig. 4.3-2: Relative change (%) in stocks of carbon (above and belowground) of German forests up to 2080 relative to baseline (1990) for seven ATEAM scenarios.

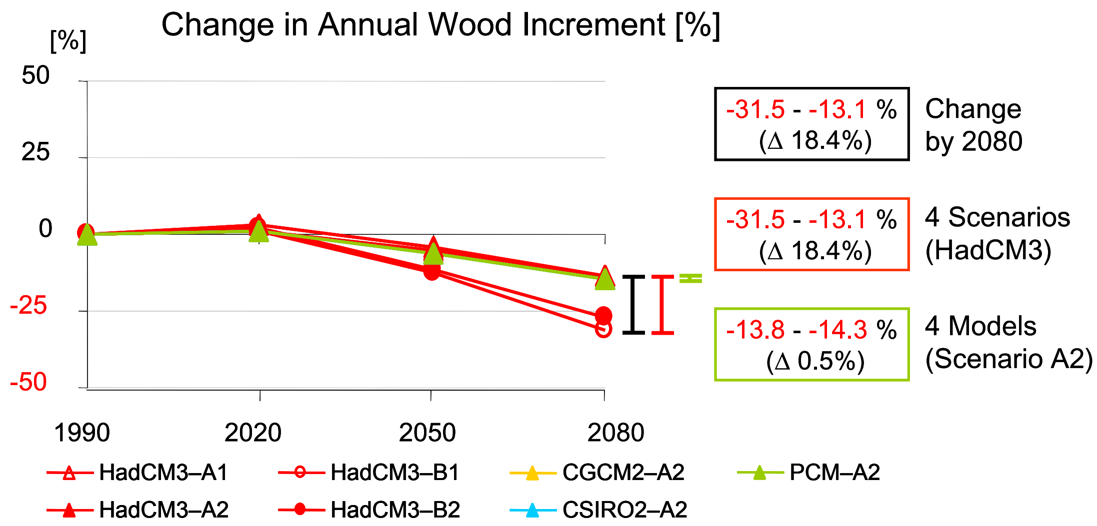


Fig. 4.3-3: Relative change (%) in annual wood increment in German forests up to 2080 relative to baseline (1990) for seven ATEAM scenarios.

Shifts in Species Distribution and Tree Species Composition

On the assumption of declining precipitation, beech will be penalised in many dry regions of Germany (among others in parts of Eastern Germany), since here it already reaches its limits of aridity under current conditions. Here, stand conditions will shift towards oak-hornbeam (*Carpinus betulus*)- and alternatively oak-pine-forests.

Spruce will also be particularly impacted. Spruce is adapted to moist and cool environments, and its natural area of distribution is limited to sub-alpine and high mountainous locations in high and low mountain ranges. Presently spruce is however grown in wide areas of Southern and Western Germany in different environments. Here climate impacts will likely lead to yield losses, due among other things to drought stress and high temperatures (Flaig et al., 2003).

On the other hand, changing environments may offer the opportunity to introduce new species and to diversify the range of suitable species. In the alpine region it is for example expected that the altitudinal limit of beech will incline and therefore the proportion of mixed forests in this regions may increase.

If Mediterranean species will be able to migrate north is still a matter of debate. One limiting factor could be the soil conditions (e.g. soil pH) (VWF, 1994).

Altogether, it can be expected that the rate of climate change will exceed the rate at which forests can adapt naturally. Therefore, adapted species and cultivars should be a target of facilitation.

Pests and Pathogens

The entire interrelations between climate change and pests and pathogens are not yet understood. However, it appears that particularly pests of spruce (e.g. bark beetle) will profit from climate change (Flaig et al., 2003).

Risk of Forest Fires

Model simulations of risk of forest fires for the federal states Baden-Württemberg and Brandenburg from 2000 to 2050 show a considerably increased risk for Brandenburg. Particularly the dry Southern part of this state is rated to be in the highest class of fire danger under the scenarios studied. In Baden-Württemberg, the risk of forest fires will increase only very moderately, owing to moister conditions and a different tree species composition. The actual area burnt will depend on developments in fire prevention. New technologies, such as video surveillance and the distribution on mobile phones have already markedly reduced the amount of area burnt in recent years.

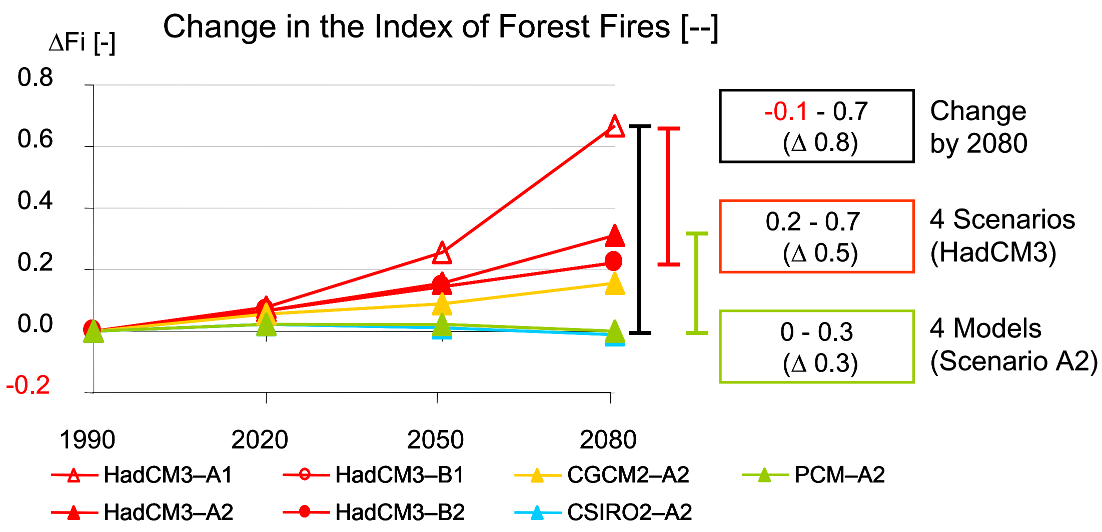


Fig. 4.3-4: Changes in the index of forest fires (Thonicke, 2002) in Germany up to 2080 compared to baseline (1990) for seven ATEAM scenarios. The index of forest fires is unitless.

In the ATEAM project an index of forest fires according to Thonicke was used (Thonicke, 2002), which considers climatic conditions as well as the moisture level of the upper soil layer. Results show a considerable increase in the risk of forest fires in Germany under almost all scenarios (Fig. 4.3-4). The index of forest fires inclines disproportionately with the assumed warming in each scenario. All regions of Germany show increased fires risk, with the exception of the Alps, the alpine upland, and the coastal regions. Arid coniferous forests on sandy soils in the North and Northeast of Germany that exhibited a relatively high risk already in 1990 are particularly impacted (see Fig. 4.3-9 in the Annex).

Impacts of Weather Extremes – Storm Damages

It is probable that the frequency and intensity of storms will increase in future (see chapter 3), however, we currently have no reliable projections of this. The susceptibility to storm damages could be increased also, owing to prior damages particularly under the assumption of drought stress.

4.3.5 Impacts of Climate Change – Assessment by Regional Experts

As described in chapter 2.6, we conducted experts' surveys in the various climate-sensitive sectors of Germany – including the forestry sector. The survey among regional experts of the forestry departments of 13 German federal states[15] included 13 potential elements and impacts of climate change, eleven risks and two opportunities. The results of the survey are depicted in Fig. 4.3-5.

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[15] In the federal states Hamburg, Bremen and Berlin no surveys were conducted for the forestry sector.

	Schleswig-Holstein	Mecklenburg-Western Pomerania	Lower Saxony	Brandenburg	Saxony-Anhalt	North Rhine-Westphalia	Hesse	Thuringia	Saxony	Rhineland-Palatinate	Saarland	Baden-Württemberg	Bavaria
longer periods of aridity	-2	-2	-3	-3	-3	-2	-3	-2	-3	-3	-3	-3	-3
more extreme periods of aridity	-1	-1	-3	-2	-2	-2	-1	-2	-2	-3	-2	-3	-2
more frequent extreme rainfall events	-1	0	-2	-2	-3	-2	-3	-2	-3	-2	0	-2	-3
increased precipitation	-2	0	99	0	-2	-2	-2	0	-1	-2	0	-2	-2
more frequent or more intense storms	-3	-3	-3	-1	-3	-3	-3	-2	-2	-3	-3	-3	-3
declining groundwater tables	-3	-3	-3	-3	-3	0	-1	-1	-3	-2	-1	-1	-1
dcreased species diversity of forests	-3	-1	-3	-1	-1	-1	-1	0	99	-1	0	-3	-2
invasion of new pest species	99	-2	-2	-2	-2	-2	-3	0	-1	-2	-1	-2	-3
increased susceptibility to common pests	-1	0	-3	-3	-2	-3	-3	-3	-2	-3	-2	-3	-3
increased risk of forest fires	-1	-3	-3	-3	-3	-1	-3	-1	-2	-2	0	0	-3
chnaged demand of other land users	-2	-1	-1	-1	-3	-1	0	-2	-1	-1	-1	-1	0
increased potential yield	2	0	1	0	1	2	3	2	0	2	3	1	2
wider range of suitable habitats	2	0	0	1	1	0	0	2	1	2	0	0	2

Fig. 4.3-5: Experts' rating of potential impacts of climate change in the forestry sector. Sample size: Telephone interviews in 13 federal states.

Experts rated most risks as "negative" or "very negative", and the opportunities as "positive" or "very positive". Only two impacts (reduced species diversity of forests and changed demands of other land users) are rated on average as "slightly negative". None of the risk or opportunities of climate change were rated as insignificant ("neither positive nor negative").

Risk Assessment

Three risks were on average across federal states rated as "very negative". These were *more frequent or more intense storms* and *longer periods of aridity* as direct climate impacts, and *increased susceptibility to usual pests* as indirect climate impact.

The greatest worry of experts was *more frequent or more intense storms*. All respondents rated this risk most frequently as "very negative". Two main reasons seem to be responsible for this: First, experts observed an increase in storm damages in recent decades. Second, respondents stressed that storm threaten forests immediately and directly, and can pose an existential risk to forest enterprises. Wood from storm-breaks enters the market unplanned and in large quantities, which leads to a strong decrease in prices. For example, in the months following the large storm events of the 1990s, wood prices sank by up to 50%. Today, many state forests have to be financially self-sustaining and therefore reach financial difficulties more easily. Small private forest owners are even more at risk, since they hardly own any financial reserves to cope with such events.

Longer periods of aridity also play an important role. All experts rate them as "negative" at minimum; the majority even rated longer periods of aridity as "very negative". In response to the open questions, a link to the dry summer of 2003 is made. This link and the strongly negative rating lead to the hypothesis that there is a connection between the freshness of recent events and the degree of negativity in their rating. Some experts identified the summer of 2003 as a reference value of sorts. An increasing frequency of hot summers is expected, therefore in its planning forestry should take the findings of the year 2003 into account.

Respondents thought of *increased susceptibility to usual pests* as a similarly existential threat to the forestry sector. The majority of experts rated this risk as "very negative". They identify the various pest species. Some stress the damages caused by pathogenic fungi, others focus on specific insect species. Mainly, respondents pointed to the extreme propagation of pest species. The species have been known for a long time, but so far have played only a marginal role. Respondents often named favourable weather conditions, such as e.g. mild winters, as the trigger of this extreme propagation.

The majority of the assessed risks were ranked on average over the 13 federal states as "negative". These risks were among others extreme periods of aridity, more frequent extreme rain events, and more precipitation as a direct impacts of climate change, as well as declining groundwater tables and invasion of new pest species as indirect impacts.

Some patterns appear when comparing the distribution of ratings across federal states. A distinct pattern appears when looking at the rating of the risk of *more frequent extreme rainfall events*. Extreme rainfall events increase the risk of floods. Many respondents seem to be influenced in their ratings by their experience in recent years. Here especially the extreme rainfall events in the year 2002 play an important role. Particularly the abutting states of Elbe and Danube rated the issue of more frequent extreme rainfall events as "very negative", since the floods particularly hit them. In this context, respondents named water retention in forests and the protection against soil erosion as special demands towards planning in forestry.

A geographical pattern also became very apparent in the ratings of the risk of *declining groundwater tables*. This risk was rated on average as "negative" for natural and planted forest stands. But there were distinct differences in the ratings from different federal states. All respondents from Northern and Eastern states rated this impact as "very negative", while experts from Southern and Western states mainly chose the category "slightly negative".

The ratings of the risk of *increasing precipitation* are also interesting. Again a geographical pattern appears. While Western and Southern federal states rated this risk mainly as "negative", Eastern and Northern states ranked an increase of precipitation mainly as insignificant.

There was a wide range of responses for the risks of *invasion of new pest species* and *forest fires*. However, no geographical pattern was found within these responses. Replies on these issues exhibit a high degree of uncertainty about the probability of occurrence and the severity of the threat. Furthermore, a causal connection between climate change and these issues is not seen as certain. For example, some respondents saw the increase of international trade as root cause of the threat of new pest species to forests. So-called "imported pests" are distributed through imported products and means of transport worldwide, and can also infest German forests.

Assessment of Opportunities

The *increased yield potential of forests* is seen as an opportunity. This issue was on average rated as "positive". Respondents from Eastern Germany saw this issue as less important than respondents from the West, some experts from Western Germany even rated this issue as "very positive". An increase in yield potential is mainly expected in the short-term, in the long-term climate change could even decrease yield potential. Moreover, experts stress that an increase in potential will not necessarily lead to an increase in actual yield. As a reason for this the relatively low demand for wood was named among other things.

Another opportunity of climate change lies in the widened range of locations suitable to forestry. Shifting climatic zones can offer the opportunity to newly use specific locations or to improve their usage. This issue is rated on average as "slightly positive". In four federal states respondents chose the rank "positive", in six states "neither positive nor negative" was chosen. Some experts described programmes that are specifically targeted at the afforestation of areas at the limit of suitable arable soil conditions. Such soils were previously used for agriculture, but are barely viable. The programmes support a shift of the usage of these soils to forestry with fast growing trees, which can later be used for the production of alternative, renewable energy resources. The impacts of climate change can play a role in the selection of locations for such a conversion of use.

Some respondents stressed the *importance of public interest* in the role of forests. The risks of climate change impacts on forestry could lead to increased public awareness of the issues dealt with in the forestry sector. Raised awareness is thought of as positive, it is believed to enliven the discussion on the societal role of forests and their functions, and could increase the appreciation of long-term planning in forestry. Respondents drew comparisons to the public debate about "waldsterben" (forest dieback). Some respondents also stressed the role of *forests as source of raw materials*. In the medium term, wood could be used as renewable energy source in biomass energy plants, especially with a sustained high supply of wood. This form of usage is open to low quality wood, which previously is rather seen as an unavoidable side-product of high-quality wood production. Therefore the focus of forestry enterprises could shift in the medium term, not only quality matters, but also the quantity of wood production gains in importance. This could lead to changed plantation and management methods, and might hold some negative consequences for the "forests as ecosystems".

4.3.6 Adaptation to the Impacts of Climate Change

Measures of forest conversion – increasing diversity: In the face of climate change impacts that hardly can be predicted for any specific forest stand, diverse forests with nature-oriented species compositions and wide genetic amplitude are the best precondition for adaptive and therefore henceforth stable forest ecosystems (BMVEL, 2004). Currently programmes of forest conversion towards suitable species and mixed forests are underway. This is welcomed as the right management direction, since out-of-natural-habitat tree species and monocultures often show a small range of tolerance with respect to long-tem changes and are more susceptible to stresses (pests, windbreak). However, potential impacts of climate change should be considered when selecting target species. In critical areas (sandy soils, current insufficient water supply) the plantation of drought-tolerant or frugal tree species should be encouraged. For example, the conversion of pure coniferous forest stands by introducing beech trees should not take place at locations that are already presently at the limit of beech distribution with regard to their moisture balance (BMVEL, 2004). On such locations, oak-hornbeam plantations are an example of a possible alternative. The conversion of out-of-habitat pure spruce stands is of special importance. At such unsuitable locations, spruce has proven to be particularly sensitive to the direct (water deficiency) and indirect (pest infestation) impacts of climate change (Feemers et al., 2003).

Increasing Genetic Diversity: Besides enhancing species diversity, increasing genetic diversity plays an important role. To guarantee the modification of physiological processes on the individual level, as well as to allow adaptation on the population level, genetic diversity should reflect an extent that corresponds to the specific location (Anders et al., 2004). Adaptation on the genetic level includes favouring trees from well-adapted, e.g. drought-tolerant populations.

Plantation of Non-Native Tree Species: It is currently a matter of controversial debate if non-native species that are well-adapted to the impacts of climate change (e.g. Douglas fir) should be increasingly used.

Management Strategies: Only about 70% of the annual increment is harvested in German forests. This goes along with an aging of the stands, a decrease in biomass increment, and a decrease in carbon absorption. Harvesting wood sustainably and in alignment with wood increment is therefore an important contribution to the protection of our forests. Rejuvenation of stands on the one hand leads to an increased adaptability of (young) individual trees, and on the other hand promotes natural selection toward climate-adapted populations. The Federal Government supports an increased demand for wood by 20% within the next 10 years with its "Charter for Wood" (BMVEL, 2005).

Increased Prevention of Forest Fires: Such measures include mainly improved forest fire early warning systems via video surveillance or satellite-based systems, a better integration of planning levels (forest owners, communities, regional authorities, forestry departments, fire brigades, road constructions), and improvements in technical infrastructure. Moreover, a conversion to mixed forests, which usually exhibit a moister forest internal climate, decreases the risk of forest fires (Badeck et al., 2004b).

Changes in Water Management Plans: This refers to measures that counteract an additional decrease in water supply, mainly through declining groundwater tables. Examples for this are the re-wetting of floodplain forests and the deactivation of melioration systems (draining systems).

Reducing Additional Threats: This mainly includes the further decrease of pollution, the maintenance of soil fertility (mainly protective lining of soils, minimising soil compaction), as well as avoidance of the disturbance of sensitive forest ecosystems, e.g. through decreased traffic.

Improved Risk Management: In general, consistent risk management of forestry enterprises should gain importance and be supported, e.g. through training courses. This includes the identification, prevention and defence against risks, as well as the management of damages.

4.3.7 Effectiveness, Degree of Implementation and Obstacles of Adaptation: Assessment of Regional Experts

The survey of regional experts from forestry departments of 13 German federal states[16] concerned not only the rating of potential climate impacts (section 4.3.5), but also adaptation measures that are suitable to adapt to climate change. The survey included five categories of measures. Respondents rated these measures with regard to their degree of implementation (see Fig. 4.3-6), as well as obstacles and complexity of implementation. Additionally we interviewed a scientific expert on the forestry sector, to assess the effectiveness of the measures regarding the avoidance of potential risks (see section 4.3.5) and the exploitation of potential opportunities of climate change (see Tab. 4-3).

[16] In the federal states Hamburg, Bremen and Berlin no surveys were conducted for the forestry sector.

Tab. 4-3: Rating of the degree of effectiveness of adaptation measures to mitigate risks and capitalize on opportunities of climate change in the forestry sector.

Adaptation measures	Risks											Opportunities	
	Longer periods of aridity	More extreme periods of aridity	More frequent extreme rainfall events	Increased precipitation	More frequent or more intense storms	Declining groundwater tables	Decreased species diversity	New pests	Increased susceptibility to pests	Increased risk of forest fires	Conflicts with other land users	Increased potential yield	Wider range of suitable habitats (climatic regions)
Plantation of drought-resistant species	X	X				X	X						X
Conversion to mixed forests	X	X	X	X	X	X	X	X	X	X			
Maintaining genetic diversity		X	X			X	X	X	X			X	X
Prevention of forest fires	X	X								X			
Changes in Water Management Plans	X	X		X		X				X	X		

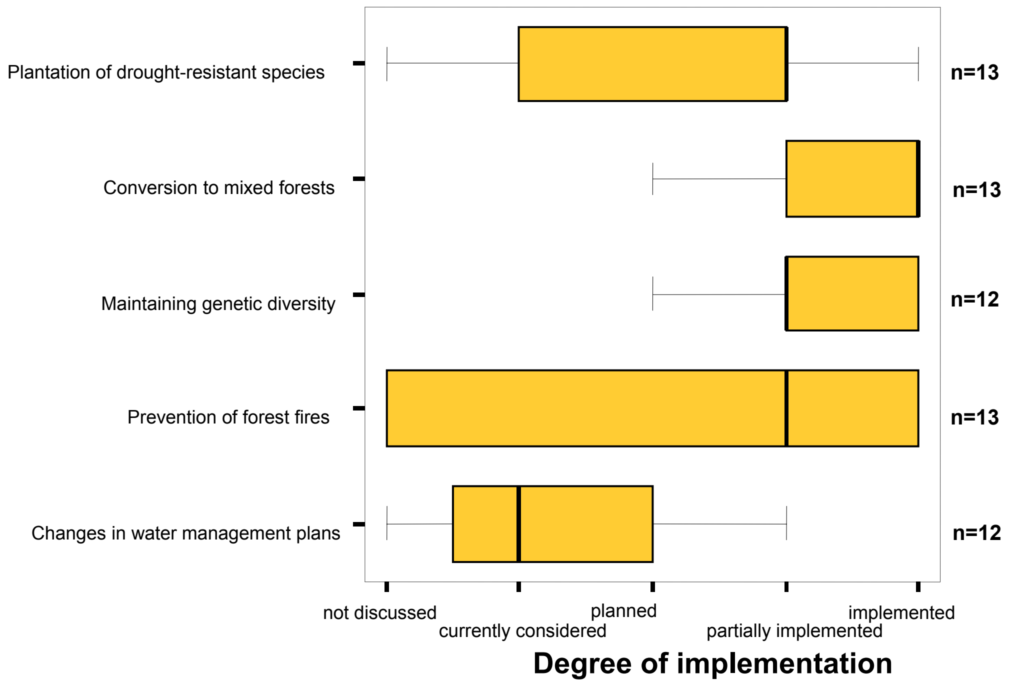

Fig. 4.3-6: Assessment of the degree of implementation of measures that are suitable to adapt to climate change in the forestry sector. Sample size: 13 telephone interviews in all 13 federal states[17]. n.d. = no data.

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[17] Illustration of the frequency distribution of ratings by various federal states as box-plot: Each box represents the central 50% of the distribution and therefore illustrates

Motivation of Previous Measures by Climate Change

Adaptation activities in the forestry sector of German federal states can be divided into *two groups of measures*. On the one hand, there are activities that, according to respondents, were started as direct responses to projections or experiences of climate change. This applies particularly to measures that were planned or implemented in recent years. On the other hand, experts describe activities that have been practice since a longer time. Their implementation was not motivated by climate change, however, these measures are still suitable to adapt to climate change. For example, in some Western states conversion programmes towards mixed forests have been going on since over 20 years. Other issues motivated these programmes, but nevertheless they decrease the sensitivity to climate impacts.

Plantation of Drought-tolerant or Frugal Species

The first category of measures comprises the increased *plantation of drought-tolerant or frugal species* (e.g. oak, hornbeam, and basswood (*Tilia* spec.) in Brandenburg, alternatively pine and Douglas fir in Bavaria). These plantations may be effective measures against the risks of longer or more extreme periods of drought, declining groundwater tables, and of reduced species diversity, and may be suitable for a wider range of locations that are open to forestry use (see Tab. 4-3).

According to respondents, such measures are on average already "partially implemented" (see Fig. 4.3-6). In eight out of 13 federal states the plantation of drought-tolerant or frugal species was rated as already "partially implemented" or "implemented". In the remaining five states, such measures are not yet planned, but currently debated at best.

Many respondents state that assumptions about forest growth from the past do not anymore match current observations. This is attributed not only to climate change. Therefore a revision of stand monitoring is planned. The results of this new monitoring point to adapted suggestions concerning the planting of trees, which could stress the cultivation of drought-tolerant species. However, the introduction of such species can vary strongly with region. It was considered more important to align new plantations with average conditions at a specific, local stand.

Such respondents that document the degree of implementation of the plantation of drought-tolerant or frugal species as low, particularly identify the uncertainty of future periods of drought as an important obstacle. These respondents rather planted mixed stands, to be able to react flexibly to the uncertain impacts of climate change. With regards to these obstacles, the plantation of drought-tolerant or frugal species is rated on average as a "complicated" measure.

Conversion or Rejuvenation to Mixed Forests

A second category of adaptation measures is concerned with the *conversion or rejuvenation of forests to mixed forests*. We use the term mixed forest in a wider sense, referring to a high diversity of tree species, as well as to a high structural diversity of the forest (age, size etc.). The conversion to mixed forests, as well as the maintenance of genetic diversity is of very broad effectiveness in relation to other measures (see Tab. 4-3). It is therefore a highly advisable strategy with regard to enhanced adaptability to various, uncertain risks of climate change. Experts from forestry departments rank the conversion to mixed forests as an important measure.

On average, respondents rated the degree of implementation of the conversion to mixed forests with "implemented" as higher than that of any other measure (see Fig.

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the values between the lower and the upper quartile. The more to the left the box is shown, the more negative a specific impact of climate change is rated. The thick vertical line represents the median value. The whiskers to the left and right of the box illustrate the range of responses. The n-values give the number of valid answers each box-plot is based on.

4.3-6). In almost all federal states, the conversion of forests to mixed forests is already being "implemented" or is "partially implemented". Due to long conversion times, the conversion of forests will only be completed in a few decades. However, the political decision for the principle conversion of forests has already been made in most federal states. The time of the first implementation of such measures was much earlier in Western than in Eastern states. Therefore, the conversion of forests is rated as further advanced in Western states.

The majority of respondents does not name adaptation to climate change as the main reason to convert the forests. This is much more a host of measures that were designed to tackle a range of challenges. Two reasons that were identified most frequently are the diffusion of risks and the orientation to potential natural vegetation. The diffusion of risks through mixed forests is seen as insurance in the face of various risks that are difficult to calculate. Climate change is only one of a range of risks. Forests are meant to gain general stability in comparison to classic monocultures. Hedging economic risks also plays an important role.

Responses regarding the complexity and the obstacles of forest conversions are contradicting. Some experts classify the introduction of mixed forests as "complicated" and reduce their expected profits accordingly. Others stress the profitability of mixed forests. All respondents stress that the conversion of the entire state forests is a process of multiple decades. Short-term risks will not be mitigated by such measures.

Increasing and Maintaining Genetic Diversity

A third category of measures we enquired about is the *increase and maintenance of genetic diversity*. Under this category we summarise any practical measure that conserves genetic diversity. Examples for this are using seedlings from different origins, monitoring and conserving specific sub-species, and the creation of genetic databases. As mentioned before, the conservation of genetic diversity is of broad effectiveness (see Tab. 4-3), just as the conversion to mixed forests, and therefore also is an advisable strategy to enhance broad adaptive capacity of the forestry sector.

On average, this measure was rated as already "partially implemented" (see Fig. 4.3-6). The vast majority of respondents reported on initiatives to maintain genetic diversity. Only few respondents reported this measure as already "implemented". A Germany-wide programme for the conservation of forest gene resources from the 1980s is named as the initial spark for such measures. This programme created the first forest gene banks.

The widening of the ecological amplitude of specific species is seen as the main objective of this adaptation measure. Species shall become increasingly robust to environmental influences. Another reason to implement such measures concern the protection of nature (e.g. the conservation of specific sub-species).

Respondents identified as the largest obstacles the limited financial and organisational resources of the federal states. Many experts also desired better coordination and networking between federal states. On average, however, the increase and maintenance of genetic diversity was rated only as "slightly complicated".

Prevention of Forest Fires

This category refers to any measures to prevent forest fires, for example the further development of technologies for early warning systems and fire fighting, plans of alarm, measures in forest management, and public education. The measures should on the one hand prevent the occurrence of fires, and on the other hand reduce the extent of damages through fires. In this context, the prevention of forest fires is also an effective measure with regard to longer or more extreme periods of aridity (see Tab. 4-3).

On average across the 13 federal states, prevention of forest fires was rated as already "partially implemented" – however, there were very large differences between specific federal states (see Fig. 4.3-6). In nine out of 13 states, this measure was rated as already "implemented", some even since some time. Most states stress that preventive measures are already established. Forest fires have been seen as an important risk for a log time, and the technical measures in place are rated as sufficient. Adaptation therefore currently concerns only the improvement of systems that are already in place. Some experts use the period of extreme drought of 2003 as a reference value, i.e. they expect an increasing frequency of similar events in future. The planning of adaptation measures is adapted accordingly.

An important trend in recent years took place in technological development. The surveillance of forests by video- and infrared-techniques, as well as the increasing distribution of mobile phones facilitates detection of and warning about fires already in the early stage. Eastern German states are more active with regard to early warning technologies. This may be due to a relatively wide distribution of coniferous monocultures, which are particularly susceptible to fire. Measures to detect and fight forest fires were dominant. Only one respondent explicitly named forest management measures as means of preventing fires. The other respondents did not go into such special prevention strategies, apart from the general benefits of introducing mixed forests.

The average and the majority of respondents rated prevention of forest fires as "complicated". Many experts saw the coordination with other actors of forest fire fighting as a key issue (e.g. community administration, local fire fighters, technical relief organisation). In this regard, the clarification of responsibilities and the creation and updating of plans of action play an important role. In general, it is seen as inadequate to finance such measures from the budget of the forestry department alone, since the protection against fire lies in the interest of other actors as well. Therefore some experts stress the public good such adaptation measures contribute to and the need for support from states and communities.

Water Supply and Management

As a last category of measures to adapt to climate change, we asked about activities with regard to *water supply and management*, in order to prevent future water shortages in the forests. Systematic management of surface and groundwater is seen as an effective response to potential climate impacts such as longer and more extreme periods of aridity, increased precipitation, declining groundwater tables, increased risk of forest fires, and the possibly exacerbated conflicts of usage within the forestry sector, as well as with actors in other sectors (e.g. agriculture, producing industry, local waterworks) (see Tab. 4-3). Concepts for systematic water resource management have the primary goal to prevent, mitigate or even avoid conflicts between different groups of interest.

Eight out of 13 respondents reported that such measures are currently considered or being planned. On average, concepts of water management were rated as "currently considered" (see Fig. 4.3-6). Obviously, this measure is not as far along towards implementation compared to other measures. The complexity of the measure does, however, not seem to lie beyond that of other measures. Concepts of water management were seen as "complicated" by the majority of respondents. Some experts remarked that water management could become a "politically sensitive topic" more quickly than other measures. From the viewpoint of forestry departments alone, water management concepts seem only of limited complexity. However, the diverging interests of other users, such as agriculture and waterworks, increase the complexity of the issue in a political sense.

Further Measures

Respondents did not name any qualitatively new measures when asked for further measures within the forestry sector that would be suitable to adapt to risk of climate change and capitalize on its potential opportunities. We see this as evidence, that the categories of measures surveyed here were relatively comprehensive.

Adaptation to Climate Change in Forestry Departments

All experts involved in the survey were from forestry departments of federal states. The results of the survey show that within the forestry departments of the 13 surveyed federal states there is an ongoing debate on the impacts of climate change. Eight out of 13 respondents rated the degree of relevance of the subject of *adaptation to climate change in their departments* in comparison to other topics as "important". None of the departments sees the topic as "unimportant". In the forest departments of the North-western federal states North Rhine-Westphalia, Saarland, and Schleswig-Holstein adaptation to climate change was rated as "slightly important", in Baden-Württemberg and Saxony as "very important". The adaptation to climate change therefore has a relatively high relevance in the forestry departments of most federal states, especially in comparison to the other climate-sensitive sectors that were surveyed here.

In comparison, other topics are even more relevant than adaptation to climate change. For forestry departments especially the topics reform of the administration and development of wood prices are of utmost importance. All respondents rated these issues uniformly as very important. It seems that day-to-day management issues push aside long-term strategic decisions.

When asked what triggers the *debate about adaptation to climate change* in the forestry departments, the majority of respondents pointed to experiences with extreme weather events. Especially storm events were listed. In this respect, the years 1990 and 1994 are mentioned in particular. In these years extraordinarily high storm damages were recorded. Further triggers of damages are extreme weather conditions. Respondents named especially strong pest infestations, caused by extreme summers or mild winters.

Some experts stressed the need *to integrate their activities in the larger political activities* of the state government. The objective here is a general, sector-encroaching adaptation. The same respondents who stress this integration of their activities related more often than others to studies that assess the impacts of climate change on a regional scale. They deduct demands on the planning of forest management from the results of such regional studies. Specific forestry studies are another basic resource for planning in forestry. These studies directly relate to the activities within the forestry sector and are mostly based on retrospective, empirical data. All in all, seven of the 13 state representatives related their answers explicitly to results of scientific studies – in comparison to other surveyed sectors (particularly the transport sector etc.) this is evidence of a high degree of knowledge concerning climate change.

Adaptation in the Forestry Sector: Summary and Conclusions

The conversion to mixed forests, and the maintenance of genetic diversity were seen as most broadly effective measures to mitigate potential risks and capitalize on potential benefits of climate change in comparison to other adaptation measures. Therefore these measures are particularly advisable strategies to promote broad adaptive capacity to various, uncertain risks and opportunities of climate change. We also wish to stress that there does not seem to be single potential impact of climate change on forestry that could not be met at least with one suitable adaptation measure. Most measures that are suitable to adapt to climate change in Germany are however, not yet fully, but "only" partially implemented. Solely the implementation of improved water management concepts is currently only in an early stage. The implementation of most measures was rated as "complicated", indicating that full implementation will not be achieved without difficulties, and that special support may be necessary.

Potential impacts of climate change have already been accounted for in the planning of some measures. Relative to other sectors that were surveyed (particularly the transport sector), there seems to be an intensive debate on climate change and its impacts on the forestry sector. In this sense, the forestry sector can serve as a role model for other sectors. However, also for the forestry sector we doubt that the currently implemented and planned measures will be sufficient to confront the impacts of climate change; the debate about climate change in the forestry department is in its early stage, for many forest owners this debate seems not yet to have begun. This means: the forestry sector is probably not adapted to climate change in most federal states.

However, in general the forestry sector should have a high capacity to adapt in future to impacts of climate change; a range of effective adaptation options is available, many of which are already being implemented. Moreover, the central actors in the forestry sector – forestry departments of the federal states – have a high level of knowledge concerning potential impacts of climate change and rank adaptation to climate change highly on their agenda. Decisive elements in the adaptive capacity of the forestry sector are the development of the economic context (wood market), the economic pressure on individual forest owners, the opportunity to coordinate decisions, and the perception of risks and opportunities of climate change and the consequent willingness to adapt. In this regard, private forestry may be particularly vulnerable. But economic pressure also grows on forests owned by states or corporate bodies.

4.3.8 References

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4.3.9 Annex

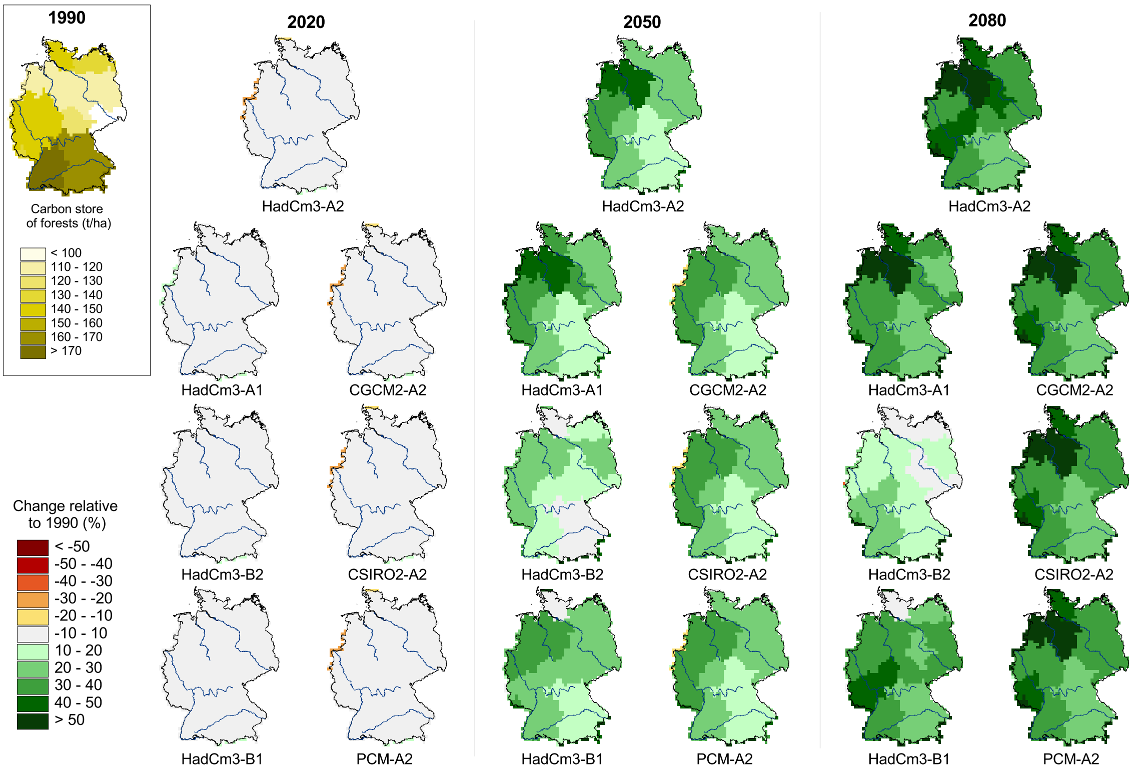

Fig. 4.3-7: Regional relative changes in the carbon store of forests (above- and belowground; %) across Germany up to 2080 compared to 1990 for seven ATEAM scenarios.

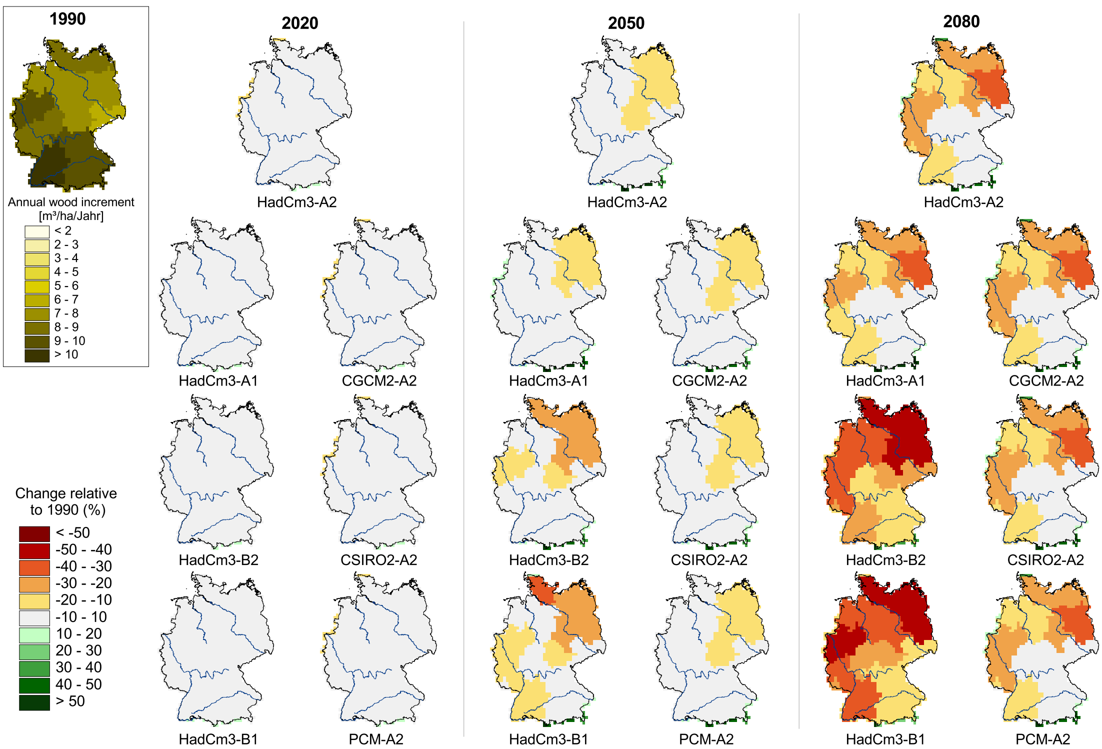

Fig. 4.3-8: Regional relative changes in annual wood increment (%) across Germany up to 2080 compared to 1990 for seven ATEAM scenarios.

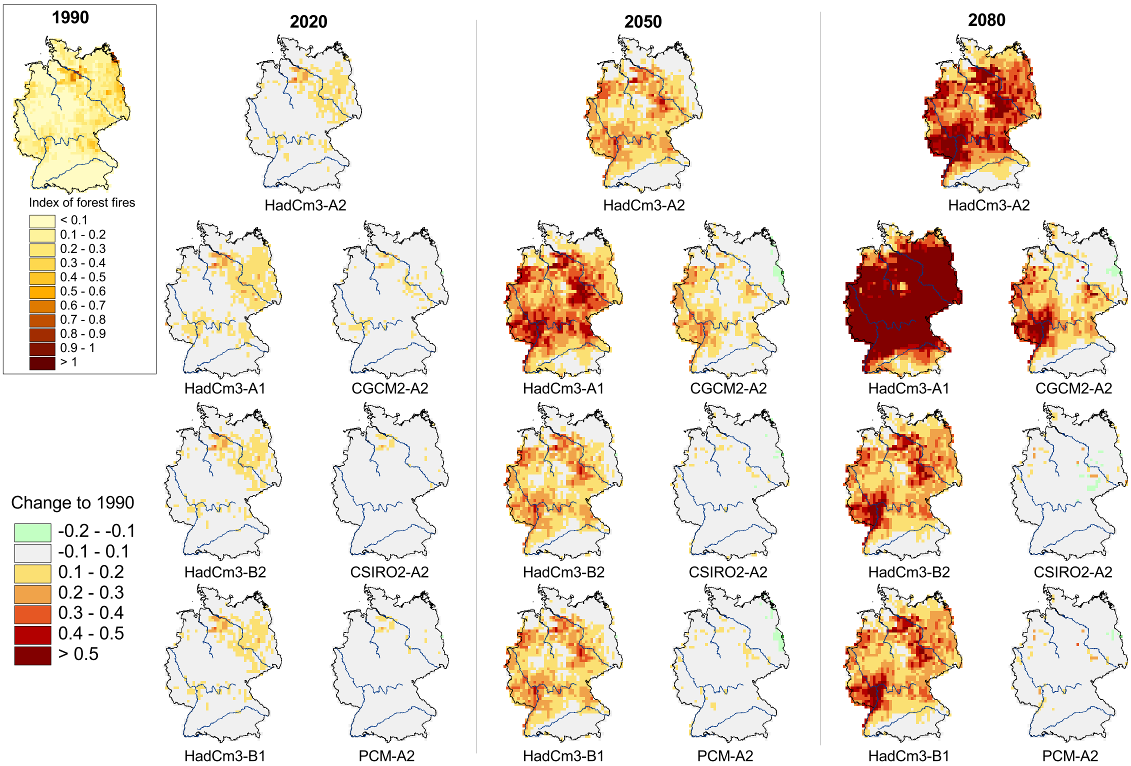

Fig. 4.3-9: Regional changes in the index of forest fires across Germany up to 2080 compared to 1990 for seven ATEAM scenarios. The index is unit-less (see text for further explanation).

4.4 Biodiversity and Nature Conservation

4.4.1 Summary: Vulnerability of the Nature Conservation Sector

Shifts in species distribution to the North and to higher altitudes, as well as changes in plant phenology and animal behaviour are considerable impacts of climate change on the nature conservation sector that have been observed already and are expected to continue.

Shifts in potential species distribution lead to migration of such species with migration potential (animals often migrate actively, plants mostly through seed dispersal). In the long term, species that are of limited migration potential, as well as species whose migration is hindered by geographical obstacles (mountains, water bodies) or lacking connection between habitats are threatened by extinction. Particularly impacted are rare species (species on the Red List), species with a narrow ecological range of tolerance, as well as cold- and moisture-loving (hygrophile) species.

Shifts in potential species distribution have a profound influence on the number of species and the species composition of communities and habitats. In the long term, the composition of existing communities will change, and new communities may form. "Azonal biotopes" on special locations are particularly impacted, such as wetlands, but also montane shrubs, and vegetation communities on rock or stone.

Regionally, the Alpine area is particularly impacted, because of its abundance of endemic plants and animals, many azonal biotopes and unique climatic locations.

In the medium to long term, changes in species composition and communities in Germany cannot be avoided. Adaptation measures should primarily seek to maintain and promote natural adaptive potential. This includes measures to enable migration (e.g. connecting habitats) and flexible concepts of protection. Wetlands require special protection (e.g. through alterations in water management).

As part of the European coordination of nature conservation efforts (e.g. NATURA 2000) and additional national initiatives, many of these adaptation measures have already been introduced and some have already been fully implemented. However, only in a few cases this is in direct response to climate change. Therefore, monitoring of climate change impacts on biodiversity and climate change related trends should receive more attention in nature conservation in future.

There are a number of further factors that impact biodiversity and nature conservation negatively at present and in future, namely land use changes, such as e.g. disturbance, fragmentation and destruction of habitats through development, transport, agriculture and forestry, as well as replacement of native species by invasive species, some of which profit from climate change.

The assessment of the vulnerability of the nature conservation sector is difficult, because it depends to a large extent on the objectives of the protection of biodiversity. Vulnerability with and without further adaptation needs to be rated as "high" if the conservation of present level species richness is the goal. Even if changing species compositions are accepted, vulnerability without further adaptation will still be "moderate" to "high" (business-as-usual scenario, see chapter 2.8). The processes brought about by anthropogenic climate change will most probably exceed the adaptation potential of many biological systems and will therefore threaten the diversity and stability of species, habitats and ecosystems in general. A reduction of vulnerability to "moderate" levels should be possible if adaptation options are implemented through nature conservation management – this will in any case require special public and governmental support (improved-business scenario, see chapter 2.8).

4.4.2 Biodiversity and Climate

Biodiversity refers to the diversity of living organisms of any origin. It includes the diversity within species (genetic diversity), between species (species diversity) and the diversity of ecosystems (Convention on Biological Diversity, 1992).

Biodiversity is not an ecosystem service in the purest sense (see chapter 1.3), but is the basis of many other ecosystem services (Millennium Ecosystem Assessment, 2005). Biodiversity describes the elements of a landscape, its species, communities and ecosystems and determines many supporting and regulating services, such as e.g. the maintenance and functioning the oxygen, nitrogen and carbon cycles, soil formation, pollination, and the regulation and filtering of surface waters. Furthermore, biodiversity determines many provisioning ecosystem services, such as the production of food, raw materials, water and genetic resources for pharmaceutical and medical uses. Finally, biodiversity is the basis of cultural ecosystem services, such as the recreational value of a landscape or the cultural identity of a region (SCBD, 2003). Besides this significance for ecosystem services, biodiversity contains a cultural and societal value *per se*, which is expressed in the need to protect and conserve biological diversity. The protection and conservation of biodiversity is manifested as important goal in the Federal Nature Conservation Act (BnatSchG §2).

Climate determines in interaction with many other factors, such as soil type, hydrology, landscape structure, and anthropogenic interference biodiversity on all levels (genes, species, ecosystems). In the course of evolution, genotypes adapted to a specific climate of one species have developed. This genetic diversity contributes to ecosystem stability and flexibility, and ensures a selection of well-adapted varieties in agriculture and forestry.

On species level, climate directly influences physiology and metabolism. Photosynthesis and other metabolic processes in plants are strongly influenced by radiation, temperature and water availability. Moreover, the CO_2-content of the atmosphere plays an important role (see chapter 4.2). Animals are mainly influenced by the temperature regime (optimal temperature, resistance to cold and frost). Here, temperature mainly influences metabolic physiology (e.g. frequency of breath) (Leuschner & Schipka, 2004). Climate and weather conditions also directly determine the temporal occurrence of different processes of life and characteristic phases in the annual and lifetime cycles of a species. In plants these include the various phonological phases (bud break, flowering, maturation of fruits etc.), in animals the phenomena of reproduction, individual development, periods of activity and rest, as well as migratory behaviour.

Climate influences biodiversity indirectly, through the amount and type of available food, soil conditions and other features of the habitat. These parameters have a strong influence on the number of individuals (abundance) of plant and animal species.

Regarding the amount of these interdependencies, climate is a decisive factor for the potential distribution of a specific species. The area of climatic conditions under which a species can potentially occur (e.g. minimum and maximum temperature) is called “climatic envelope”, and will primarily earmark a species’ distribution.

Climatic suitability for specific species directly influences the composition of species communities. Moreover, climate influences the conditions for symbiosis and competition within and between different communities. In addition to that, climate influences ecosystems directly and indirectly, e.g. through changing the water and nutrient balance, or through impacts of extreme events.

Further Factors

In Germany, the type of land use and the intensity of use play an important role for biodiversity. Habitat disturbance, fragmentation and destruction, e.g. through agriculture, forestry, development and transport, are seen as the main threats to species in Germany. Pollution from agriculture and industry is another important stressor.

The increases distribution of non-native, invasive species is another influence of biodiversity in Germany. Such species can be brought to Germany e.g. through the transport of goods or people, and may expand rapidly replacing native species, owing, among other things, to the lack of competitors. Invasive species are often thermophilic, and may be better adapted to global warming than native species.

Biodiversity and Climate Protection

Through the type of land cover in a region, biodiversity influences various climatic factors, such as e.g. the energy and water balance or gas flux to the atmosphere, leading to an influence on the local, regional and global climate (SCBD, 2003). The carbon balance of the terrestrial biosphere is of particular importance (see chapter 3.3), since the biosphere can contribute to a decrease in the CO_2-concentration of the atmosphere by a net uptake of carbon, for example through forests and moors.

Measures to increase the net carbon uptake of the biosphere, such as afforestation as considered in the Kyoto protocol, can contribute to climate protection. On the other hand, such measures can conflict with the protection of biodiversity, for example when species are planted out of their natural habitat (Herold et al. 2001).

4.4.3 Baseline situation: Biodiversity and Nature Conservation in Germany

So far, 28,000 plant and fungi species have been found in Germany, among which are 3,242 flowering plants. Insects are, with 33,305 species, the largest group among the approximately 48,000 animal species occurring in Germany. There are 706 species of vertebrates in Germany, the species richest among which are teleost fishes and birds. With 91 species, mammals are only a small group among vertebrates (Völkl, 2004).

The population of many of these species are currently under threat. Among monitored plants, 28.7% are threatened and 3.7% have already gone extinct. Among animals, e.g. 71% of amphibian and reptile species, 37% of bird species, and 38% of mammal species are threatened. Six percent of bird species and 13% of mammals have already gone extinct (BFN, 2004). Among the approximately 500 types pf biotopes over two thirds (69%) are ranked as threatened.

On the other hand, for some species, especially birds, but also some bat species, a positive population development is observed (e.g. Montagu’s harrier (*Circus pygargus*), quail (*Coturnix coturnix*), Alpine swift (*Apus melba*)). These are the effects of current protection schemes, such as the Guidelines for Fauna and Flora Habitats (Fauna-Flora-Habitat-Richtlinie, FFH), which was implemented in 1992, and measures for extensification of agriculture. The coherent network of NATURA 2000 includes the areas registered under FFH and guidelines for bird protection, which cover approximately 13% of German land area (BFN, 2005).

Changes in species composition, which are linked to climate change, have already been observed in Germany and Central Europe. Thermophilic animal and plant species, mostly sub-Mediterranean, Mediterranean, Atlantic, but also sub-tropical and tropical species immigrate or expand their limits of distribution towards North and East. Today, the scarlet darter (the dragonfly *Crocothemis erythraea*), which was first sighted in Germany in 1918, is found in the Upper Rhine Valley, in North Rhine-Westphalia, Northern Hesse, Northern Bavaria and Saxony. Also the redistribution of the praying mantis (Mantidae) in Southern Germany is thought to be linked to climate change. On average, a study of 99 species (birds, butterflies, Alpine plants) showed a shift in species distribution per decade of 6.1 km North or 6.1 m up in altitude respectively (BFN, 2004).

Warmer spring temperatures and longer summers have lengthened the vegetation period of many tree species from Central Europe by on average 10 days since the 1950s (Menzel, 1997). Milder winters are one of the main factors explaining why many birds have given up (black redstart (*Phoenicurus ochrurus*), firecrest (*Regulus ignicapilla*), goldfinch (*Carduelis carduelis*)) or altered (earlier arrival, later migration) their migratory behaviour (BFN, 2004).

4.4.4 Impacts of Climate Change – Trends and Projections

Species Level

Various scenarios project a further Northward shift of climate zones by the year 2100 by 200 to 1200 km (BFN, 2004) and by several hundred meters up in altitude (Hughes, 2000). This surpasses the maximum speed of migration (approximately 20 to 200 km per century) of many species. Moreover, migration is hindered by the lack of suitable habitats.

Furthermore, continued changes in phenology in the form of elongated vegetation periods are expected (SCBD, 2003). This can lead to an increase of yields for plants, but goes along with a higher susceptibility to late frost and infestation with pests (see chapter 4.2).

In general, further threats to species and extinctions due to climate change are expected in Southern and Central Europe. Model simulations by Bakkenes et al. (2002) and Thomas et al. (2004) project an extinction of 10-30% of present species owing to climate change in Central Europe. In Germany between 5-30% of the present animal and plant species could be affected (Leuschner & Schipka, 2004).

The "worst case" scenario HadCM3 A1f (highest greenhouse gas concentration) of the scenarios from the project ATEAM (see chapter 2) shows a possible loss of species in Germany by the year 2080 ranging from 25% (North-western Germany) to over 50% (Southern and Eastern Germany) per grid cell (average loss per grid cell of 10′ x 10′ in %, under the assumption of no migration) (Schröter et al., 2004, Schröter et al. 2005).

When taking into account potentially new species, which immigrate from the South leads to a different picture (net balance of emigrating or lost species versus immigrating species): The number of species per grid cell of herbaceous plants in Germany decreases by 4-14% by 2080, depending on the emission scenario (Fig. 4.4-2 in the Annex). Especially strong declines of up to –36% are found in the Alpine region and in South-western Germany.

Trees show little sensitivity up to the year 2050, but then exhibit a distinct increase in tree species diversity up to the year 2080 under all scenarios except A1, particularly in Northern Germany (Fig. 4.4-3 in the Annex). Under the A1-scenario parts of Eastern Germany and Western Germany show a decline in tree species richness.

Amphibians and reptiles exhibit an increase in species richness per grid cell until 2050 by approximately 10%, followed by a decline to previous levels by 2080 (Fig. 4.4-4 in the Annex). The reason for this is that under a moderate increase in temperature current and new species from the South could co-exist. If temperature rises further, conditions for current species deteriorate rapidly.

Birds do not exhibit any considerable changes under this statistical analysis (Fig. 4.4-5 in the Annex). However, we have to expect that changes in landscapes affecting resting and nesting places will nevertheless have a negative impact on populations. This could however not be simulated by the underlying modelling method (at the resolution of the analysis, land use change effects were confounded with climate effects).

Species Communities and Ecosystems

Species and ecosystems that have a narrow tolerance of temperatures and very specific demands on habitats are particularly threatened (SCBD, 2003). This could be especially true for ecosystems with a high proportion of species on the red list, which often occur at small, climatically extraordinary locations (Leuschner & Schipka, 2004). Also ecosystems including long-lived plants (e.g. forests) are particularly endangered. Owing to their relatively long reaction times they are fairly well buffered against short-term changes, but of limited adaptive potential in the long-term. Sensible phenological phases of such plants, such as e.g. the maturation of seeds, are particularly threatened (SCBD, 2003).

Many climate change impact studies show that climate change can affect specific species within a community very differently. For example, the distribution of species within the same community can change in diverging ways. This can lead to the decoupling of food webs and the break-up of symbiotic relations between species. It must therefore be expected, that old communities will be dissolved and new connections between species in different "climatic envelopes" will develop.

Location with microclimatic-hydrologic extraordinary conditions, such as e.g. wetlands or montane brush, rock and stone vegetations, could offer a short-term buffer against changing climatic conditions (Leuschner & Schipka, 2004). At the same time, such ecosystems are particularly endangered in the medium- and long-term, since their species are usually tightly linked to the micro-climatic-hydrologic extraordinary conditions and will not be able to migrate elsewhere if these locations are not part of a wider network (Wittig & Nawrath, 2000).

In the medium- to long-term, wetlands and moors are also particularly impacted through decreasing summer precipitation and changes in flooding patterns. This endangers not only the moisture dependant plant communities of wetlands, but also the species rich bird communities, such as inhabit for example large floodplain areas in Eastern Germany. Wittig and Nawrath (2004) rate plant communities at moist locations (lean marshes, *Carex* spec. communities, wet meadows and forests, moors) as particularly threatened by climate change. Rising sea levels and increased storm activity endanger freshwater marshes are at the coasts (SCBD, 2003).

Ecosystems of the Alps are also particularly impacted. In the Alps, relief, soil and climate vary greatly and on a small scale, supporting a mosaic of highly diverse habitats and biotopes. The Alps are home to approximately 30,000 animal and 13,000 plant species, approximately 39% of the European angiosperm flora. About 15% of the 2,500 plants growing above the tree line are endemic (Grabherr, 1998). Alpine plants are particularly sensitive to climate change, owing to their narrow ecological tolerance and the lack of migration options (alternative habitats are lacking). Additionally, species migrating from lower areas will increase the pressure. Such species may increase species diversity of Alpine regions in the short-term, but will lead to extinctions of endemic species in the long-term (EEA, 2004).

Other negative impacts on ecosystems and biological diversity will be the increased expansion of pests through milder winters, more frequent forest fires (due to increased temperatures and aridity in summer), as well as extreme rainfall events, floods and droughts.

4.4.5 Impacts of Climate Change – Assessment by Regional Experts

As described in chapter 2.6, we conducted expert surveys in various climate-sensitive sectors, including the nature conservation sector. Sector-specific assessments of potential elements and impacts of climate change are available for different environmental zones (see chapter 2.6) from the following four federal states: Schleswig-Holstein, Hamburg, Brandenburg, and Saxony. Assessments of the particularly vulnerable Alpine region are not available. Positive ratings are regarded as acknowledgments of opportunities, negative ratings as acknowledgments of risks. Due to the low rate of return of the questionnaires, we did not graphically illustrate the results of the survey. The assessment, which is discussed in the following, must be seen as very preliminary due to various reasons. Only very few questionnaires were returned from the federal states, only one expert per federal state was approached, and few respondents base their assessment on studies of past and future climate development and its impacts.

General Assessment of Climate Change

Respondents rated the significance of climate change for biodiversity on average across all environmental zones and federal states in recent times (1990 to today) as "neither positive nor negative". The ratings are almost identical for the different environmental zones and federal states. In the short (today to 2010) and medium term (2010 to 2020), climate changes was on average judged to be "slightly negative", in specific environmental zones and federal states also as "slightly positive" or "negative". Only two ratings are available for the long term (2020 to 2050), but both are "negative". With a good deal of caution we conclude that generally increasingly negative impacts are anticipated in the nature conservation sector.

Risk Assessment

On average, respondents rated various potential *elements of climate change* as "slightly negative" or more negative already in the short term. These include a decrease in annual precipitation[18], stronger variations in precipitation, more frequent extreme rainfall events, as well as heat waves and hot days. In the medium- and long-term, these ratings become increasingly negative. Increasing average annual and summer temperatures, which were rated as neutral in the short term, are also rated as "negative" in the medium term. The decrease in the annual precipitation sum is seen as the most severe risk.

Among the four surveyed *potential impacts of climate change* on biodiversity, only the changes in landscape balance (including declining groundwater tables) were rated as a risk. The other impacts (see Opportunity Assessment) were rated as rather positive. This positive assessment is probably mainly a function of the small sample size.

Opportunity Assessment

Some *elements of climate change* – increasing winter temperatures, less frost days and the increase in the annual precipitation sum – were on average rated as "slightly positive" or neutral to "slightly positive" in the short term. The medium- and long-term these elements were rated as increasingly positive.

The majority of *potential impacts of climate change* on biodiversity are on average rated as "slightly positive" in the short-, medium-, and long-term. This applies to possible changes of species and ecosystem diversity owing to shifting species distributions further North or up in altitude, changes in phenology of plants (bud break, flowering etc.), and in the behaviour of animals (nesting time, bird migration etc.). The strongest positive ratings were given to changes in plant phenology.

Further Impacts

We also asked for further possible impacts of climate change on biodiversity and nature conservation. Respondents listed the emigration and disappearance of species that are adapted to cool and moist conditions, the changes or the disappearance of cool and moist ecosystems with long development times, as well as the immigration and expansion of thermophilic or heat-tolerant, drought-tolerant, nitrophile species and generalists.

4.4.6 Adaptation to the Impacts of Climate Change

The environment responds dynamically to changes in conditions. Management measures to protect and conserve biodiversity under changing climatic conditions will be especially successful if they facilitate and support this dynamic. Of special importance is the maintenance and *improvement of migration options for species*. These include measures to connect biotopes on local, regional, national and trans-national scales. This task has been adopted in the new version of the Federal Nature Conservation Act, which states that the federal states should dedicate at least 10% of their land area to the connection of biotopes (BnatSchG §3).

We have to rethink the concepts of protection in nature conservation, which is mainly concerned with small nature reserves. Due to climate change, targeted species in

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[18] According to the present state of knowledge increases and decreases in annual precipitation are possible, depending on the region. Therefore, both developments were offered to the respondents for rating.

many European regions will emigrate from nature reserves (Araújo et al., 2004). *Flexible reserve borders*, which shift with species distribution offer a solution. Species with future suitable habitats that, due to a climate change induced shifts further North or up, do not overlap with current suitable habitats or species that are faced with obstacles for migration, such as e.g. natural barriers (Alps, North sea, Baltic sea) deserve special attention. In these cases, planned species introductions are an option to think about.

Concepts for water balance management are suitable to maintain or revive natural water logging, in order to protect wetlands, which are particularly threatened by climate change (see above). These include concepts to revive water logging and dams that are adapted to the needs of nature conservation.

In general, nature conservation strategies should be complemented by concepts that target the *protection of processes within natural systems*. The European cultural landscape is strongly influenced by human life style and management. Therefore characteristic dynamic changes within natural ecosystems over time and space are often hindered or forestalled. However, to adapt to climate change, such dynamics are very important. Besides migration they include also e.g. succession, rejuvenation or fires.

4.4.7 Effectiveness, Degree of Implementation and Obstacles of Adaptation: Assessment of Regional Experts

We have responses from the expert survey (method described in chapter 2.6) on measures that are suitable for climate change adaptation from the following six federal states: Schleswig-Holstein, Hamburg, Brandenburg, Saarland, Hesse, Thuringia, and Saxony. The following results of the survey must be seen as very preliminary assessment of the measures that are suitable to adapt the German nature conservation sector to climate change, since only one expert per federal state was approached and the return of the questionnaires from the federal states was scarce.

In the survey, different dimensions of the adaptation measures were evaluated; the effectiveness of the measure to mitigate the potential impacts introduced in section 4.4.5 (see Tab. 4-4), and the present degree of implementation of the adaptation measure (see Fig. 4.4-1). Given that respondents rated potential impacts rather positive, with the exception of changes in landscape balance, Tab. 4-4 shows mainly how respondents rated the effectiveness of measures to capitalize on opportunities of climate change.

Tab. 4-4: Rating of the degree of effectiveness of adaptation measures to mitigate risks and capitalize on opportunities of climate change in the nature conservation sector. The number of respondents that rated a particular measure of mitigation resp. exploitation as effective is shown. Sample size: 6 questionnaires from the federal states Schleswig-Holstein, Hamburg, Brandenburg, Hesse, Thuringia, and Saxony.

	Impacts			
Measures	Changes is species and ecosystem diversity and composition due to shifts in species distribution to the North and to higher altitudes	Changes in plant phenology (bud break, flowering, etc.)	Changes in animal behaviour (breeding times, mirgration of birds, etc.)	Changes in landscape balance (e.g. declining groundwater tables)
Improvement of migration options for species	5	-	2	1
Flexible reserve borders	1	-	1	1
Protection of processes within natural systems	3	-	1	3
Concepts for water balance management	3	-	-	4
Measures integrating several risks Insurance against climate change damages	-	1	-	1
Creation of reserve funds for furture adapatation measures and damage resparation payments	-	1	-	1
Weitere genannte Maßnahmen: *Defizitausgleich Schutzgebiete*	1	-	1	1
nachhaltige Landnutzung	1	-	-	-
Pflegemaßnahmen	1	-	-	1
Waldumbau	1	-	-	1
extensive Landwirtschaft	1	-	-	1

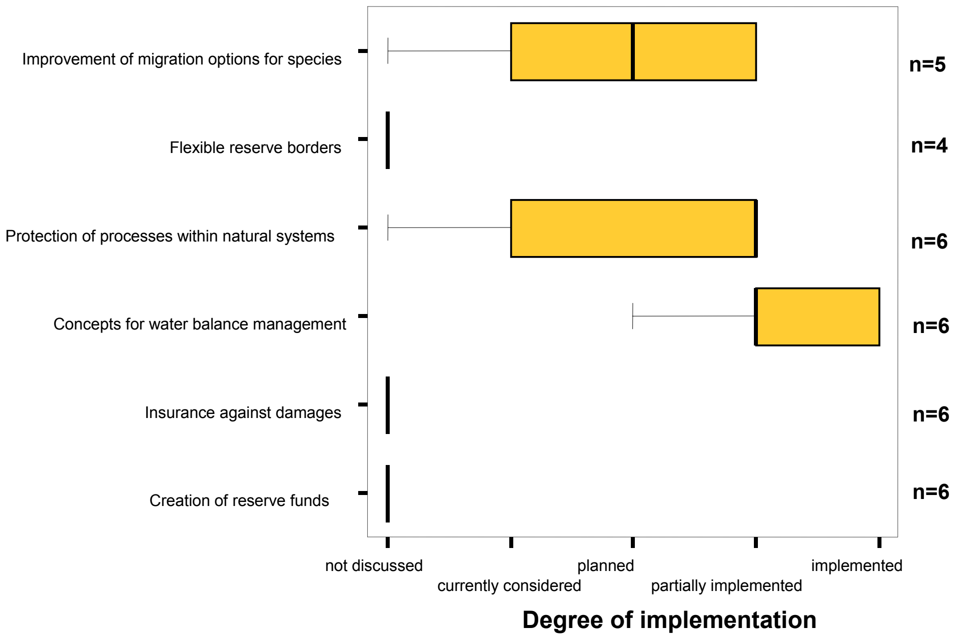

Fig. 4.4-1: Assessment of the degree of implementation of measures that are suitable to adapt to climate change in the nature conservation sector. Sample size: 6 questionnaires from the federal states Schleswig-Holstein, Hamburg, Brandenburg, Saarland, Thuringia, and Saxony. The n-values give the number of questionnaires each box-plot is based on.[19]

Improvement of Migration Options for Species

Nearly all experts thought that the improvement of migration options for species is an effective measure to respond to changes in species and ecosystem diversity and composition due to shifts in distribution Northward and to higher altitudes (see Tab. 4-4). Fewer respondents also saw an effectiveness of this measure to react to potential changes in the behaviour of animals and in landscape balance.

Respondents rated this measure on average across the six surveyed federal states as "planned" (see Fig. 4.4-1). However, there were distinct differences between federal states. The highest rating ("partially implemented") was reported from Brandenburg, and Schleswig-Holstein. None of the respondents gave climate change as a reason to implement this measure, but among other things the realisation of legal guidelines, general nature conservation goals, state-wide planning of biotope and network planning, as well as the conservation of populations were listed.

Two respondents named organisational hurdles as obstacles, one financial hurdles, another lack of knowledge. Moreover, other priorities and lacking capacities were listed as detrimental for implementation. With regard to these obstacles, respondents rated the improvement of migration options on average as "complicated".

Flexible Reserve Borders

According to the survey, flexible reserve borders are a measure of little effectiveness to respond to the impacts of climate change (see Tab. 4-4). Accordingly, this measure was rated as "not discussed" in four of six federal states (the other two respondents could not answer make a statement on this; see Fig. 4.4-1). According to respondents, the main reasons to not implement this measure are legal obstacles; currently it is legally binding to fix reserve borders. Flexible reserve borders would violate the law. One respondent also names organisational obstacles and lacking knowledge. With regard to these hurdles, two experts rate the implementation of flexible reserve borders as "very complicated", the other respondents did not give any assessment.

The Concept of Process Protection

Half of the respondents rated the concept of protecting processes within ecosystems as an effective measure to respond to potential changes in species and ecosystem diversity and to potential changes in landscape balance (see Tab. 4-4). On average, this measure is rated as already "partially implemented", however there are very strong differences between federal states (see Fig. 4.4-1). The highest ratings ("Partially implemented") are reported from Brandenburg, Schleswig-Holstein, Saarland and Saxony. As reasons to implement the concept of process protection, respondents identified primarily the objective to make room for natural development. Only one respondent gave climate change as a motive.

Obstacles for implementation were seen in financial restrictions (3 respondents), legislative conditions (2 respondents) and lacking knowledge (1 respondent).

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[19] Illustration of the frequency distribution of ratings by various federal states as box-plot: Each box represents the central 50% of the distribution and therefore illustrates the values between the lower and the upper quartile. The more to the left the box is shown, the more negative a specific impact of climate change is rated. The thick vertical line represents the median value. The whiskers to the left and right of the box illustrate the range of responses. The n-values give the number of valid answers each box-plot is based on.

Furthermore, resistance from inhabitants, for example against the introduction of management measures, were named. Consequently the implementation of the concept of process protection was rated as "complicated".

Concepts for Water Balance Management

Similar to concepts of process protection, half of the respondents think of concepts for water balance management as effective to deal with possible shifts in species and ecosystem diversity and potential changes in landscape balance (see Tab. 4-4). On average across federal states, water management concepts were rated as already "partially implemented" (see Fig. 4.4-1). Two respondents – from Hamburg and Saarland – even rated these concepts as already "implemented". Therefore water management concepts show the highest degree of implementation compared to other measures used in the nature conservation sector in Germany. Respondents mainly gave general protection goals as reasons to implement water management concepts. According to the respondents, the impacts of climate change were not among the reasons to implement these measures in any federal state.

Half of the respondents saw financial and organisational obstacles to implement these measures, a third additionally named legislative hurdles. Furthermore, other conflicting uses e.g. for agriculture were seen as hurdles. With regard to these obstacles, an implementation of concepts for water balance management was on average rated as "very complicated", while one respondent rated it as only "slightly complicated".

Measures integrating several risks: Insurances and Reserve Funds

Respondents thought of measures integrating several risks, such as insurances and the creation of reserve funds, which were also surveyed in the other climate-sensitive sectors (e.g. forestry, agriculture), in general as little suited to deal with potential impacts of climate change in the nature conservation sector (see Tab. 4-4). Only one respondent rated the insurance against damages from climate change and the creation of reserve funds to prepare for future adaptation measures and damage reparation payments as effective with regard to potential changes in phenology of plants and in landscape balance. Nearly all respondents rated both measures as "not discussed" (one expert did not respond), which is probably explained by the fact that losses of biodiversity through climate change (e.g. species' extinctions) can only be counteracted financially to a very limited degree. Furthermore, there are no experiences in the nature conservation sector with insurances or reserve funds. It is therefore not surprising that most experts did not give any responses concerning complexity or obstacles to implement these measures.

Further Measures

Moreover, experts were asked for further measures that may be suitable to prevent risks of climate change or capitalize on opportunities in their federal states. Respondents listed the following measures: balancing deficits of nature reserves (e.g. landscapes with strongly heterogeneous relief and microclimatic diversity to maintain ecological niches), NATURA 2000, Life Projects, federal nature protection projects, conversion of pine to deciduous forests, sustainable and nature-oriented land use (e.g. reduced usage of pesticides and fertilisers), extensification of agriculture, measures of renaturalisation and nature-oriented management, nature conservation oriented land use and contracted nature conservation.

Adaptation to Climate Change in Nature Conservation Departments

Only three respondents from the nature conservation departments of federal states reported that there is a debate about the adaptation to climate change within their administration. However, no practical programmes aimed at tackling the impacts of climate change in the nature conservation sectors were named. Nevertheless, we got the impression that Saxony has already very intensively discussed the impacts of climate change on biodiversity and nature conservation, and that here there is collaboration between different functional departments in the context of Saxony's Integrated Climate Protection Concept. Accordingly, asked about the current relevance of climate adaptation in their administration in relation to other topics, only the expert from Saxony responded with "important", three other experts with "slightly important", and two with "unimportant". Two federal states' experts did not respond to this question. In none of the administrations this topic is rated as "very important". Consequently, the adaptation to climate change is currently of little significance in the nature conservation departments in most federal states.

Adaptation in the Nature Conservation Sector: Summary and Conclusions

Most respondents saw the surveyed adaptation measures as effective to deal with potential changes in species and ecosystem diversity, as well as changes in landscape balance – with the exception of insurances and reserve funds. Few respondents saw possibilities to respond to changes in the behaviour of animals. Nearly no respondent identified an effective measure to confront changes in plant phenology.

The implementation of measures that are (also) suitable to adapt to climate change is a particular challenge. All measures were rated as "complicated" or "very complicated", so that their full implementation – which has so far only been achieved for the concepts of water balance management and in few federal states – will probably not be easy and needs special support. Moreover, it is questionable whether the existing and planned measures will suffice to confront the anticipated changes in biodiversity and nature conservation due to climate change; since, according to respondents, climate change was nearly never among the reasons to implement measures. A debate about the adaptation to climate change is currently held in only very few nature conservation departments. We therefore conclude that the impacts of climate change were not or only very little regarded in the recent planning of measures, and that the nature conservation sector in most federal states is not yet adapted to climate change.

In general, the nature conservation sector in Germany should have a certain potential to adapt to the impacts of climate change. There is a range of effective measures, some of which have already been implemented for other reasons than climate change. However, the implementation of these measures is mostly rated as complicated. Flexible reserve management has so far not been discussed mainly due to legal obstacles. This is a particular challenge – not only for the legislator, but also for society and its understanding of nature conservation and nature reserves. Federal states should use the opportunity to exchange their experience and knowledge, since the degree of implementation of adaptation measures and the state of present discussion on adaptation to climate change was very different between federal states.

The adaptive capacity of nature conservation in the Alpine region, with its large occurrence of endemic plants and animals, many azonal ecosystems and extraordinary climatic locations, is small. In this region, climate change will cause the disappearance of habitats, without alternatives for the impacted animals and plants.

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4.4.9 Annex

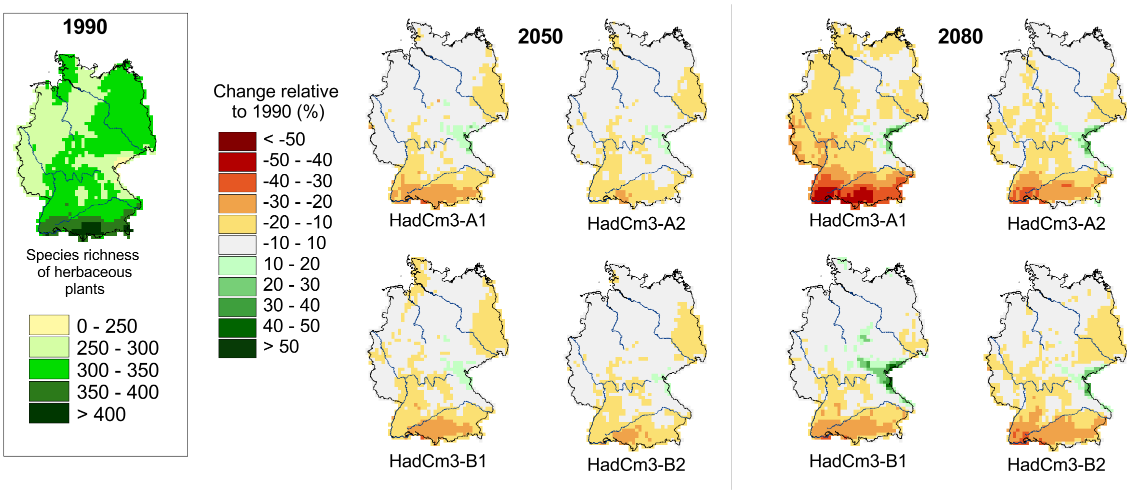


Fig. 4.4-2: Regional relative change in herbaceous plant species per grid cell across Germany up to 2080 compared to 1990. The analysis is based on 1350 selected herbaceous plant species that occur in Europe. In contrast to other ATEAM results, only scenarios based on the climate model HadCM3 are available.

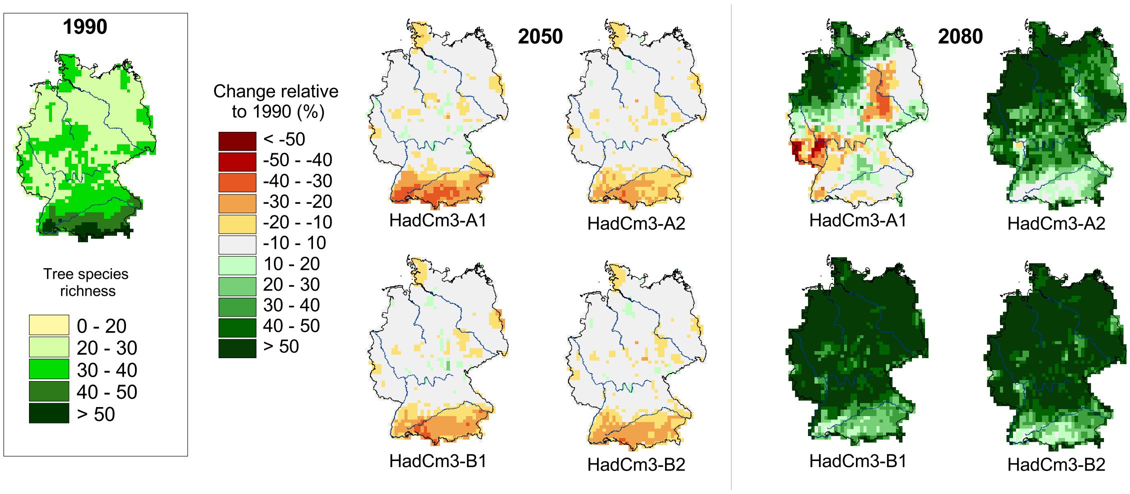


Fig. 4.4-3: Regional relative change in tree species per grid cell across Germany up to 2080 compared to 1990. The analysis is based on 125 selected tree species that occur in Europe. In contrast to other ATEAM results, only scenarios based on the climate model HadCM3 are available.

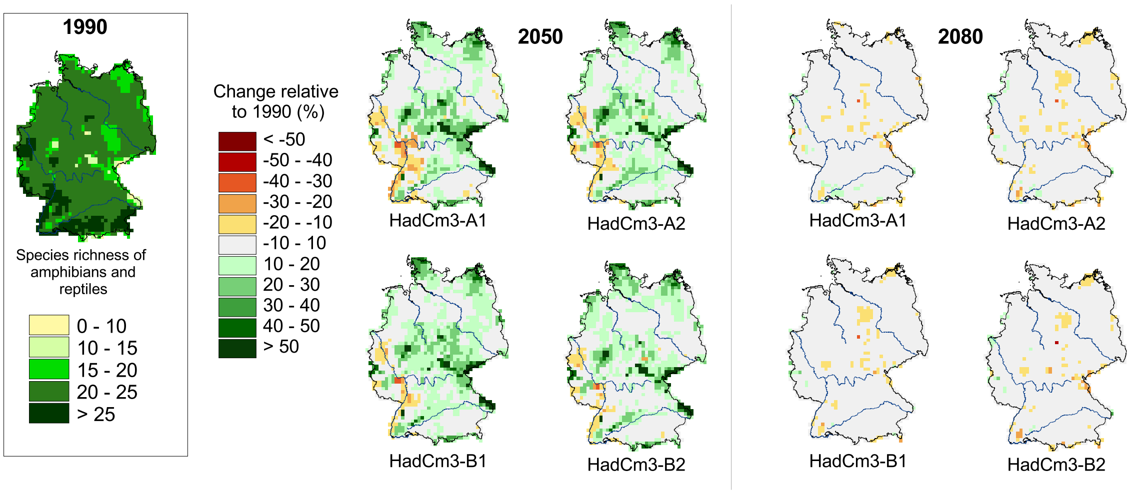


Fig. 4.4-4: Regional relative change in amphibian and reptile species per grid cell across Germany up to 2080 compared to 1990. The analysis is based on 108 selected amphibian and reptile species that occur in Europe. In contrast to other ATEAM results, only scenarios based on the climate model HadCM3 are available.

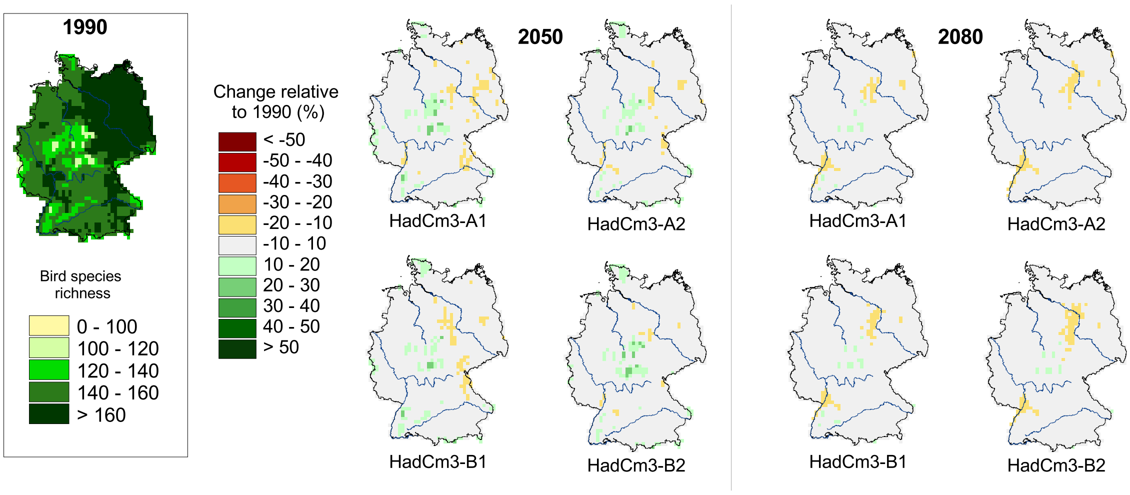


Fig. 4.4-5: Regional relative change in bird species per grid cell across Germany up to 2080 compared to 1990. The analysis is based on 383 selected bird species that occur in Europe. In contrast to other ATEAM results, only scenarios based on the climate model HadCM3 are available.

4.5 Health

4.5.1 Summary: Vulnerability in the Health Sector

Potential impacts of climate change on the health sector in Germany can be direct or indirect:

Heat stress on the human body that can lead to death is the most important direct impact. Particularly the cardiovascular system is strained. For example, the heat wave of 2003 presumably caused approximately 7,000 deaths in Germany.

Changes in the distribution, population and infectious potential of disease vectors such as blood-sucking insects, ticks and rodents are indirect impacts of climate change. Increasing temperatures improve the conditions for distribution and infection, so that an increasing danger is assumed, even though the causal interactions between vector-borne diseases and climate change are not yet fully understood. Particularly lyme disease (borreliosis), which is transmitted by ticks, is a distinct and increasing threat to public health. There is also the potential danger of a re-occurrence of malaria infections.

Negative changes in environmental conditions, such as the quality of water, air and food are further indirect potential impacts of climate change.

People whose health is already stressed are especially vulnerable to impacts of climate change. This is particularly the case for elderly and infirm people. Children can also be particularly susceptible. Furthermore, social factors, such as lacking access to information and material resources or lacking connection to a social network can increase the vulnerability of a person to the negative impacts of climate change on health.

Regionally, the upper Rhine rift and congested urban areas, especially in climatically unfavourable locations (closed valleys) are particularly hit by the direct impacts of climate change.

The necessity of adaptation (prevention and aftercare) to climate-induced health problems is often not yet fully recognised, in spite of the existence of a well-developed health care system in Germany. In 2005, the German Meteorological Service (Deutscher Wetterdienst) introduced a heat-warning system as a first measure of adaptation. Measures to redesign city and building architecture (fresh air ventilation, insulation, cooling systems) so far were mainly only discussed and are far from being implemented.

For vector-borne diseases there is also a lack of education and prevention measures, as well as a lack of information on the interrelation with climate change. Moreover, there is only a limited range of adaptation measures to deal with vector-borne diseases. For some, vaccination is not available, and therapies are often of long duration and not always successful (e.g. borreliosis).

In general, there is still great uncertainty in the specific impacts of climate change on health, particularly concerning indirect impacts.

The German health care system is so far little adapted to climate change, so that without further measures, Germany is regionally "highly", nationwide "moderately" vulnerable in the context of heat impacts. In the context of vector-borne diseases there is great uncertainty about climate impacts, however, given the potentially high risks and the lacking adaptation measures we rate the health sector as "highly vulnerable" regarding this threat (business-as-usual scenario, see chapter 2.8). In future, the public health sector should be able to adapt to climate change, since there are various potentially effective adaptation measures, particularly in the form of education and warning, which also do not seem to be very complicated. On the other hand, in the field of vector-borne diseases, education and warning seem to be almost the only effective measures. In the health sector, special support is needed to switch from reactive to a proactive planning of adaptation measures, which also takes into account scenarios of future climate change, in addition to weather events and climate trends of the past. We expect a reduction of the vulnerability in the health sector to "low" if the identified adaptation measures are implemented (improved-business scenario, see chapter 2.8).

4.5.2 Health and Climate

Climate influences the human body directly and indirectly (McMichael et al., 1997). Immediate consequences of climate and weather conditions, particularly of thermal extremes on the human body, are considered direct impacts. For example, with increasing heat- or cold stress, the demands on the cardiovascular system and breathing increase (Koppe et al., 2003). Changing distribution, population of infectious potential of disease vectors, such as mosquitoes, ticks or rodents are indirect impacts of climate change. Furthermore, climate influences human health through changing environmental conditions, such as e.g. the supply of clean water, the conditions for food production, and the danger of extreme weather events (Jendritzky et al., 2004).

Direct Impacts

The human body is in permanent contention with the thermal conditions of its environment. Particularly old and weakened people are at risk, if regionally or seasonally extreme temperatures occur (Parry, 2000).

Besides exceeding a certain threshold of heat stress, duration, rate of change and point of time within the season (time of acclimatisation) play a role in determining heat stress (Koppe et al., 2004). Comparative studies of Lisbon, Madrid and Baden-Württemberg show that mortality increases significantly on days with strong or extreme heat stress. Differences in mortality under otherwise constant conditions are determined by socioeconomic factors, among other things. High air temperatures in congested urban areas causes additional heath threats due to air pollution.

It is controversial, whether higher winter temperatures could decrease winter mortality caused by hypothermia, as well as respiratory and cardiovascular diseases (WHO, 2003). Generally infectious diseases (e.g. influenza) mostly cause the increased mortality in winter relative to summer, with thermal conditions having only an indirect influence as opposed to heat stress. Winter mortality is also strongly coupled to socioeconomic factors such as heating, insulation of the flat (Parry, 2004).

Indirect Impacts of Climate Change: Vector-borne Diseases

Many animal pathogens, such as viruses and bacteria are transmitted to humans by vectors. Such vectors can be certain insects (mosquitoes, ticks), but also higher species (birds, mammals). Decisive factors in the biology of the vectors and the pathogens are, among other things, the climatic and microclimatic environmental conditions. The anticipated climate change will change the distribution and transmission dynamics of vectors, which will influence the diseases they transmit (WHO, 2003).

Indirect Impacts of Climate Change: Deterioration of Environmental Conditions

Health impacts through deteriorated environmental conditions are another potential indirect impact of climate change. This includes the distribution of allergens in the air, degradation of the quality and quantity of water and food, as well as the degradation of ecosystems, which humans need for their recreation (McMichael et al., 2003).

The concentration of air-borne allergens, such as pollen depends strongly on season. Climate change could cause a shift and elongation of the relevant seasons, and therefore cause an increased health threat. Furthermore, the burden of air pollution in congested urban centres with pollutants such as nitrous oxides (NO_x), ozone (O_3) and dust (PM: particulate matter) depends on the climate. For example, with increasing temperatures and increased radiation, secondary pollutants such as ozone develop in higher quantities. The specific impacts of climate on health through its influences on air quality are however as yet unclear (Parry, 2000).

Future water shortages can decrease the availability of clean drinking water and impair wastewater treatment. This could increase the occurrence of diseases. Increased “algal blooms” of Cyanobacteria in rivers, lakes and the North and Baltic sea is a further possible indirect impact. Some “algal blooms” excrete toxic substances. This causes water pollution that renders it unsuitable for drinking water production and recreation. Contamination of the body with such polluted water can cause skin rashes, coryza, and gastrointestinal and pulmonary diseases.

The quality of food can be impacted, e.g. through increased infestation with Salmonella as a consequence of higher temperatures. However, professional storage and distribution of the food can prevent this.

Finally, the increasing frequency of extreme weather events and their impacts, such as flood or storm, are another health hazard. Such extreme events can on the one hand cause direct physical injuries, and on the other hand have strong impacts on human mental health, through stress, anxiety states, and depression. These health hazards impact particularly coastal inhabitants, through the projected rise in sea level and the increased probability of storms (WHO, 2003).

In general, knowledge on health impacts through a deterioration of environmental conditions due to climate change is still sparse and largely relies on experts’ assumptions. More detailed studies of this issue are not yet available.

4.5.3 Baseline Situation: Health and Climate in Germany

The Health Care System in Germany

The vulnerability of Germans to the Impacts of climate change on health is to a large extent dependent on the future state of the health care system. In a global comparison, the German health care system currently has a very high standard. A tightly woven net of physicians and medical clinics guarantee area-wide basic to maximum care in Germany. A worldwide unique network of more than 1000 rehabilitation clinics ensures aftercare following acute care. This well-developed infrastructure is presently mostly capable to counteract negative health impacts of the climate. However, health care is deteriorating due to the need to save money, and there seem to be large deficits in the context of health problems due to climate *change*. Additionally, there is a general need for a stronger orientation toward precaution in the German health care system.

Bioclimate in Germany

There are large regional differences in Germany, especially with regard to the thermal stress on human health (Fig. 4.5-1). While there is very little heat stress in the Alps, the lower mountain regions, and at the coast, there is strong heat stress on health particularly in summer, especially in the upper Rhine rift, but also in parts of Southern and Eastern Germany. In congested urban centres (particularly in closed valleys) with increased temperatures relative to their surrounding areas, strong heat stress is also to be expected. Here hot days are often accompanied by additional unfavourable conditions (mugginess, ozone stress), and the temperatures are often even a few degrees higher than in surrounding areas. Particularly at night a cooling-down is lacking, which would be important for periodic recovery.

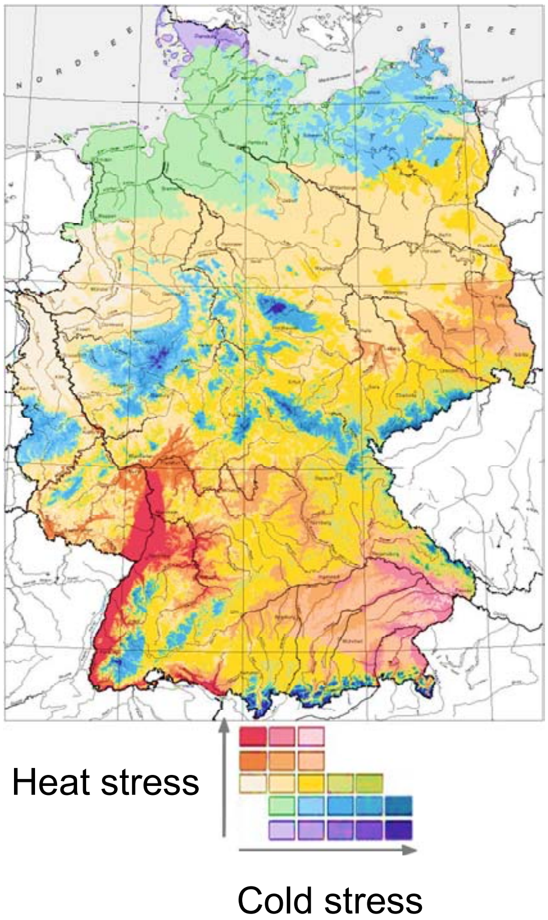


Fig. 4.5-1: German bioclimate during 1970-2000 (Jendritzky et al., 2003).

Heat wave 2003

The heat wave of the summer of 2003 has demonstrated the direct impacts of heat on human health in Germany and its regional distribution. Koppe and Jendritzky (2004) showed that the heat wave caused an extraordinarily increased mortality of 900 to 1300 additional deaths in Baden-Württemberg in August 2003 alone (see Fig. 4.5-2). This corresponds to an increase of approximately 16-24%. There are no exact results for the whole of Germany. However, extrapolations yield a minimum of 7,000 additional deaths (Jendritzky, 2004). Mostly elderly people were affected. Koppe et al. (2003) suspect that mortality in the summer of 2003 would have been even higher if the air in Germany had not been so dry.

Besides the direct impacts of the heat wave on health in 2003, there were regional shortages of drinking water. Moreover, toxic algal blooms occurred in the North and Baltic sea, causing the closing down of many beaches.

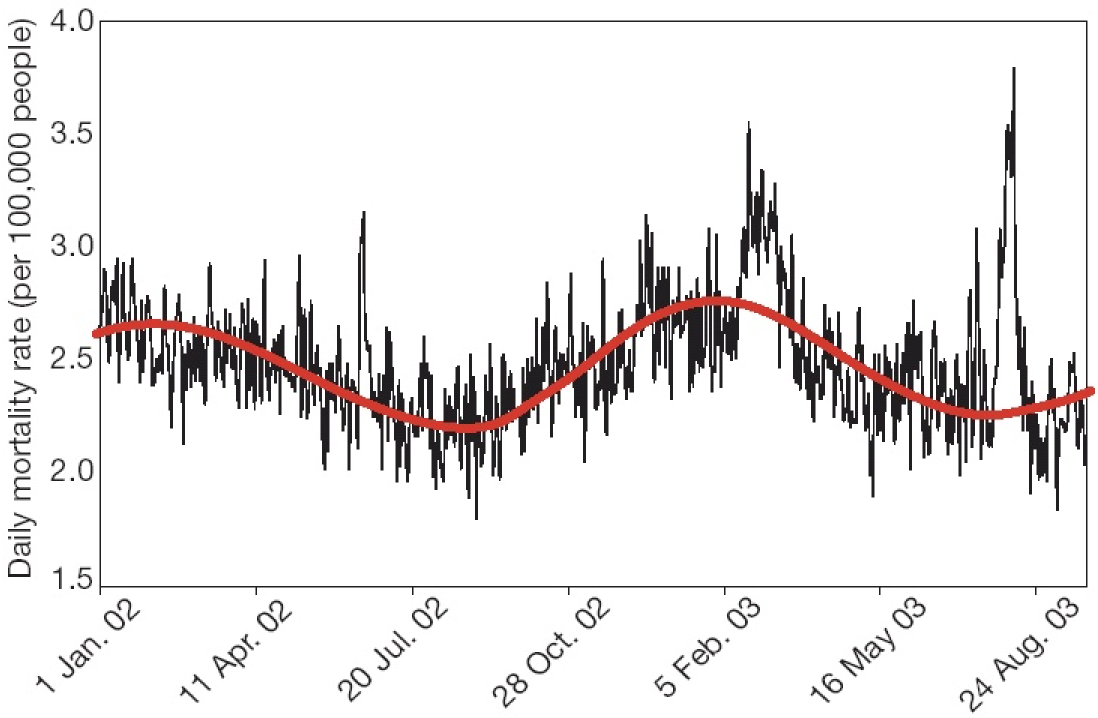


Fig. 4.5-2: Impact of the heat wave 2003 on mortality in Baden-Württemberg (Koppe & Jendritzky, 2004). There is a distinct peak in August 2003 (black line), which deviates distinctly from the oscillating trend (red line).

Indirect Impacts

Among the vector-borne diseases, the danger through diseases transmitted by ticks, mainly *Ixodes ricinus*, is most pressing. Due to the epidemiological significance of these diseases (tick-borne encephalitis (russian spring summer encephalitis or "Frühsommer-Meningo-Enzephalitis" (FSME), Lyme-borreliosis) the most and the latest studies are found on this subject area. Some studies from Sweden and Czechia indicate an expansion of the distribution toward North and to higher altitudes. However, it is not yet established how the distribution of (infested) ticks is actually affected and enhanced by climate change (Maier et al., 2003).

Further important disease vectors in Germany are mosquitoes (Culicidae), sand flies (phlebotoms), black flies (Simuliidae), midges (Ceratopogonidae), fleas (Siphonaptera), bugs (Heteroptera), human lice (Phthiraptera), flies (Diptera) and mites (Acari) (Maier et al., 2003). Rodents and other mammals (foxes, stray dogs) can also carry pathogens and can contaminate human food and surroundings, leading to infections.

In principle, climate change also causes the risk of malaria infections in Germany. Besides the occurrence of the mosquito *Anopheles* (presently mainly in the upper Rhine area), heat is a decisive factor in the infestation of the pathogen within the *Anopheles* mosquito. The risk increases significantly if the day and night temperatures do not fall below 18ºC for two weeks. However, an epidemic spread is not expected (Ärzte Zeitung, 06.10.2004).

Climate change influences the occurrence and distribution of most of disease vectors listed here, which can lead to health hazards. Abundant data corroborate the dependence of disease vectors on climate, particularly on temperature, and that for example they can react rapidly to temperature changes. Moreover, there generally is a positive correlation between the rate of development of the pathogens in the vector and increasing temperature, up to a certain temperature threshold that cannot be exceeded. Analysis of the present situation reveals that many non-native, thermophilic disease vectors have already entered Germany. However, other factors, such as e.g. international animal trade, as well as increased transport of goods and people also lead to an increased risk of importing disease vectors.

4.5.4 Impact of Climate Change – Results from the Literature

Direct Impacts

The year 2003 was an extraordinary year, however, it was shown that the probability of occurrence of such an extreme year was already considerable increased within the recent decades (Schönwiese et al., 2003). Some scientist see the year 2003 as representative of climatic conditions, which will be more frequent in the next 100 years, because of the further increasing temperatures and the accompanying increased frequency of extreme temperature events (Beniston, 2004). Therefore, heat and heat wave related health problems will become more frequent in future, and finding a solution to these will become one of the essential tasks of the health care system (Koppe et al., 2003). Germany is especially vulnerable to the impact of climate change on health, because of the continuous enlargement of the most susceptible demographic group, the elderly.

Indirect Impacts

The health risk due to vector-borne diseases will increase in Germany in future. The specific contribution of climate change to this process can presently not be definitely clarified (Maier et al., 2003).

4.5.5 Impacts of Climate Change – Assessment by Regional Experts

As described in chapter 2.6, we conducted expert surveys with representatives from the relevant functional departments in various climate-sensitive sectors in Germany, including the health sector. Sector-specific assessments of direct and indirect impacts of climate change are available for different environmental zones (see chapter 2.6) from the following six federal states: Hamburg, Berlin, Mecklenburg-Western Pomerania, Thuringia, Hesse, and Baden-Württemberg. Negative ratings are regarded as acknowledgments of risks, positive ratings as acknowledgments of opportunities. The results of the survey are depicted in Fig. 4.5-3. The assessment, which is discussed in the following, must be seen as preliminary, since only one expert per federal state was approached and the return of the questionnaires from the 16 federal states was scarce. On the other hand, almost half of the respondents base their assessment on studies of past and future climate development and its impacts on their federal state.

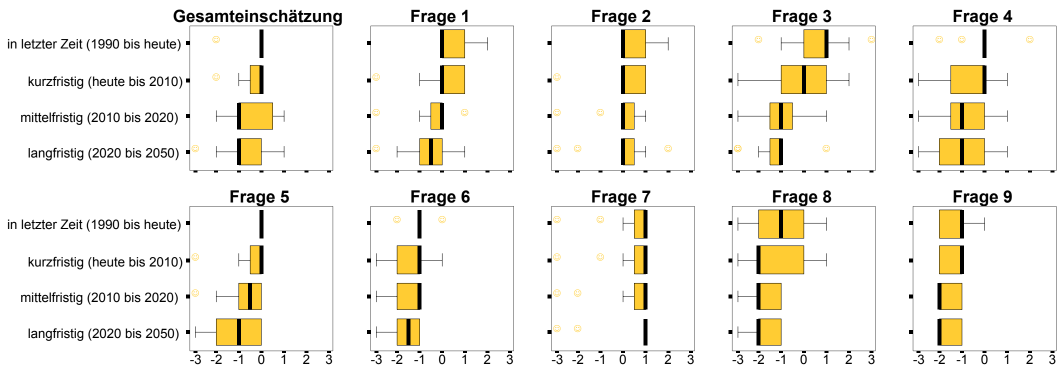
General Assessment of Climate Change

On average over environmental zones and federal states, respondents rated the significance of climate change for the health sector in recent time (1990 to today) and in the short-term (today to 2010) as "neither positive nor negative", while the expert from Berlin gave the rating "negative" for both these time periods. In the medium- (2010 to 2020) to long-term (2020 to 2050) the ratings on average turn to "slightly negative", but the differences between ratings for different environmental zones and federal states increase further. In the long-term, the ratings ranged from "very negative" (upper Rhine rift in Baden-Württemberg) to "slightly positive (all environmental zones in Thuringia).

Risk Assessment

Respondents rated the *direct impacts of climate change* of more hot days and heat waves on average as most negative, with large differences in specific ratings. Already for the past, more heat days and heat waves were rated on average as "slightly negative" in Berlin even as "very negative". For the future, they are on average rated as "negative", in Berlin and in the upper Rhine rift of Baden-Württemberg even as "very negative". Respondents saw increased inter-annual variations in precipitation and more frequent extreme rainfall events as "slightly negative" to "negative" developments. Rising average annual temperature, rising summer temperatures and an increase, alternatively decrease in annual precipitation sums[20] was on average rated as neutral in the short-term, but rather negative in the medium- and long-term. However, again the range of responses was partly very wide.

Experts' ratings of climate change and some of its particular elements

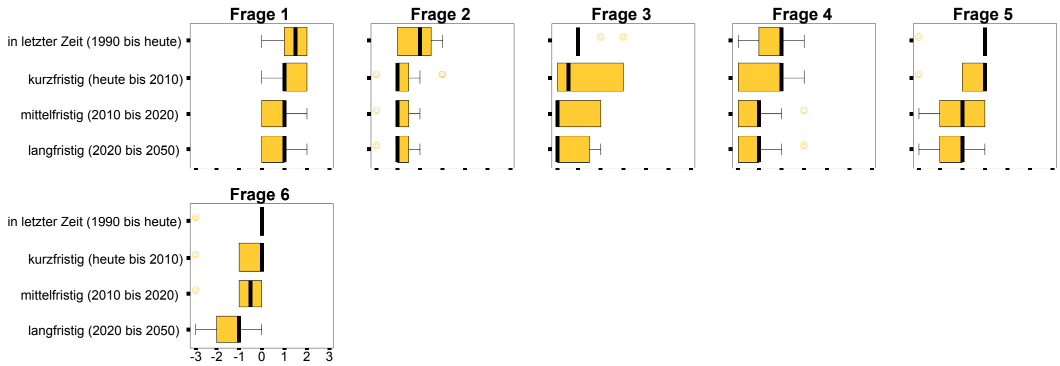


In your opinion, how positive/negative for your sector is/are ... ...

Question 1: … increasing mean annual temperature?
Question 2: … increasing winter temperatures?
Question 3: … increasing summer temperatures?
Question 4: … an increase in the annual sum of precipitation?
Question 5: … a decrease in the annual sum of precipitation?
Question 6: … stronger inter-annual variations in precipitation?
Question 7: … less frost days?
Question 8: … more hot days and heat waves?
Question 9: … more extreme rainfall events?

[20] According to the present state of knowledge increases and decreases in annual precipitation are possible, depending on the region. Therefore, both developments were offered to the respondents for rating.

Experts' ratings of climate change and its potential impacts



In your opinion, how positive/negative for your sector is/are ...

Question 1: … fewer problems with frost (frostbite, deaths through cold)?

Question 2: … increased problems with heat (circulation problems, impacts on brain vessels and the respiratory system, death through heat)?

Question 3: … deaths and injuries through extreme events (storm, flood)?

Question 4: … distribution of ticks?

Question 5: … distribution of Anopheles-mosquitoes (malaria)?

Question 6: … diseases caused by problems with water quality (surface water and drinking water)?

Response scale

-3 = Very negative
-2 = Negative
-1 = Slightly negative
0 = Neither positive nor negative
1 = Slightly positive
2 = Positive
3 = Very positive

Gesamteinschätzung = Overall rating
Frage 1, 2… = Question 1, 2…

In letzter Zeit (1990 bis heute) = In recent times (1990 to today)
Kurzfristig (heute bis 2010) = Short-term (today to 2010)
Mittelfristig (2010 bis 2020) = Medium-term (2010 to 2020)
Langfristig (2020 bis 2050) = Long-term (2020 to 2050)

Illustration of the frequency distribution of ratings for environmental zones and federal states as box-plot: Each box represents the central 50% of the distribution and therefore illustrates the values between the lower and the upper quartile. The more to the left the box is shown, the more negative a specific impact of climate change is rated. The thick vertical line represents the median value. The whiskers to the left and right of the box illustrate the range of responses. Yellow boxes mark outliers and extreme values, which stand out from the upper or lower quartile by 1.5 to 3 times the box length.

Sample size: 6 questionnaires from the federal states Hamburg, Berlin, Mecklenburg-Western Pomerania, Thuringia, Hesse, and Baden-Württemberg.

Fig. 4.5-3: Experts' rating of potential impacts of climate change in the forestry sector.

The six surveyed *indirect potential impacts of climate change* on the health sector were mostly rated as risks. The on average biggest risks that were seen by respondents are deaths and injuries through extreme events (storm, flood), but there were marked differences between environmental zones and federal states. Increased problems with heat (circulation problems, impacts on brain vessels and the respiratory system, death through heat) were rated more homogeneously as "negative". Respondents saw the distribution of ticks as only "slightly negative" in the short-term, and "negative" in the medium – and long-term. The distribution of Anopheles-mosquitoes and diseases caused by problems with water quality (surface water and drinking water) were on average seen as less severe problems.

Opportunity Assessment

Among the potential *direct impacts of climate change* less frost days were on average rates as a "slightly positive" opportunity. Rising winter temperatures were on average rated neutrally, but there is a trend to see this development as another opportunity. However, one respondent saw both impacts as "very negative". Fewer problems with frost (frostbite, deaths through cold) were the only potential *indirect impact of climate change* that was understood as an opportunity.

Further Impacts

We also enquired about further possible impacts of climate change on the health sector. Respondents listed diseases associated with disease vectors, algal toxins, the import of new diseases through worldwide ecological changes, the long-term exacerbation of ozone and smog related problems, and health impacts of skin and eyes due to changes in solar radiation.

4.5.6 Adaptation to the Impacts of Climate Change

In contrast to the United Kingdom, Portugal, Canada and the United States of America, in Germany there currently exists neither an assessment of the role of climate and climate change in the public health sector, nor any precautious planning (Koppe et al., 2003).

Germany is relatively under-prepared with regard to heat-related health impacts, since such problems appeared massively and widely in the history of Germany for the first time in the year 2003. There is a lack of medical knowledge, education and prevention measures and early-warning systems (Jendritzky 2005, personal communication). As one response, a number of federal states have produced a "catalogue of precautions against heat". The German Meteorological Service (Deutscher Wetterdienst, DWD) gives heat warnings since the summer of 2005. In Hesse, an early warning-system based on information from the DWD was already installed in 2004. Moreover, the Working Group of the Scientific Medical Societies (Arbeitsgruppe der Wissenschaftlichen Medizinischen Fachgesellschaften, AWMF) installed an experts' commission for the planning of prevention measures (Wichert, 2004).

Studies rate the situation of medical entomology, which is responsible for the assessment of the risk of and precaution against disease-vectors and the pathogens they transmit, as problematic and deteriorating in recent decades. A national reference laboratory for diseases transmitted by ticks does exist, however, skilled professionals for the practical and scientific work in this field are lacking almost everywhere (Maier et al., 2003). For example, as a consequence, the dark figure of infections with borreliosis is high, since this disease is often not identified and treated as such.

The recommended adaptation measures given in the health sector are:

- Increased education of the public and the specialised medical and nursing staff about health risks and preventive measures,
- The introduction of early-warning systems including locally adjusted intervention measures, which announce temporally and spatially specific warnings and recommend behavioural guidelines,
- Increased medical research in this field, as well as intense monitoring of climate-related diseases (existing monitoring network, such as e.g. the one in place at the Robert-Koch-Institute, can be used here),
- Expansion of medical prevention and care,
- Implementation of technical protection measures (insulation, air conditioning, etc.),
- Reference to climate–induced health problems in public health care programmes, so that suitable vaccinations and reductions of pathogens can be put in place.

Another set of adaptation measures concerns the sector of climate-oriented urban planning and adapted architecture. In future, sufficient ventilation and "islands" of cooler temperatures will be important particularly in congested urban areas. Buildings need to be equipped with sufficient insulation and cooling options. With regard to climate protection, the use of alternative energy sources should be favoured in this field (e.g. through solar cooling).

4.5.7 Effectiveness, Degree of Implementation and Obstacles of Adaptation: Assessment of Regional Experts

We have responses from the survey (method described in chapter 2.6) with experts particularly from health departments and ministries from the following seven federal states: Hamburg, Berlin, Mecklenburg-Western Pomerania, Thuringia, Hesse, Saarland, and Baden-Württemberg. The following results of the survey must be seen as preliminary assessment of the measures that are suitable to adapt the German health sector to climate change, since only one expert per federal state was approached and the return of the questionnaires from the federal states was scarce.

In the survey, different dimensions of the adaptation measures were evaluated; the effectiveness of the measures to mitigate the potential impacts and capitalize on potential opportunities of climate change introduced in section 4.5.5 (see Tab. 4-5), and the present degree of implementation of the adaptation measures (see Fig. 4.5-4).

Heat Waves: Education, Warning Systems, Emergency Planning, Insulation and Cooling of Buildings

Nearly all respondents saw education and improved warning systems as an effective measure to adapt to heat waves (see Tab. 4-5). Only half of the respondents thought that improved emergency planning would be effective, and surprisingly few saw improved insulation and cooling of buildings for specific groups of people (elderly and infirm) as an effective measure.

Tab. 4-5: Rating of the degree of effectiveness of adaptation measures to mitigate risks and capitalize on opportunities of climate change in the health sector. The number of respondents that rated a particular measure of mitigation resp. exploitation as effective is shown. Sample size: 6 questionnaires from the federal states Berlin, Hamburg, Thuringia, Hesse, Baden-Württemberg, and Mecklenburg-Western Pomerania.

	Impacts					
Measures	Fewer problems with frost (frostbite, deaths through cold)	Increased problems with heat (circulation problems, impacts on brain vessels and the respiratory system, death through heat)	Deaths and injuries through extreme events (storm, flood)	Distribution of ticks	distribution of Anopheles-mosquitoes (malaria)	Diseases caused by problems with water quality (surface water and drinking water)
Heat waves						
Education	1	5	1	5	4	1
Improved warning systems	-	4	1	2	3	1
Improved emergency planning	-	2	1	-	-	3
Improved insulation and cooling of buildings for specific groups of people	1	2	-	-	-	-
Extreme events						
Education	1	1	3	2	2	2
Improved warning systems	1	1	4	-	-	2
Improved emergency planning	-	1	4	-	1	2
Vector-borne diseases						
Education	-	-	-	5	3	1
Improved warning systems	-	-	-	2	3	-
Campaigns of vaccination	-	-	-	1	1	-
Measures integrating several risks						
Insurance against damages through climate change	-	1	1	-	-	1
Creation of reserve funds for future adaptation measures and damage reparation payments	-	-	1	-	-	1

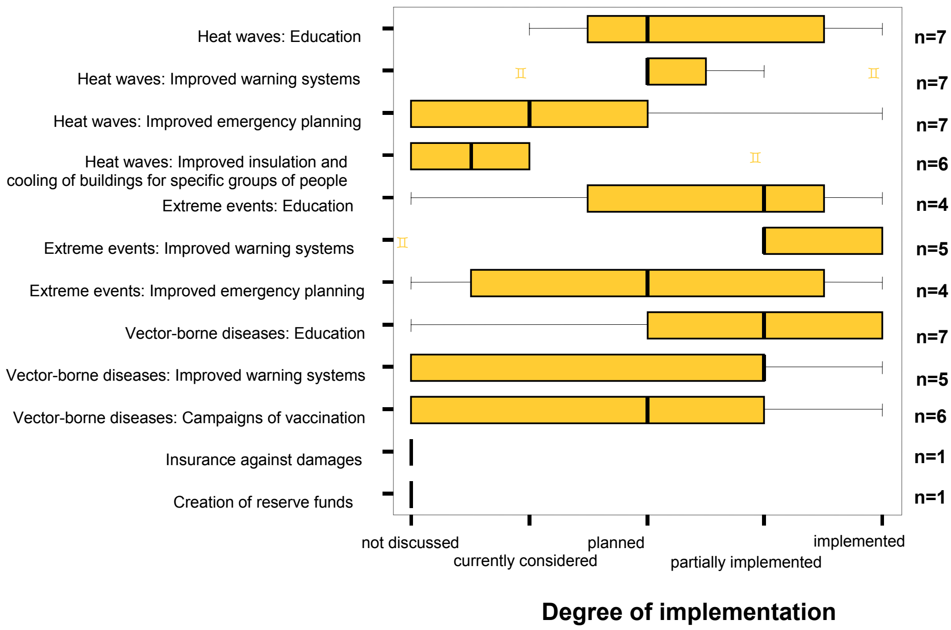


Fig. 4.5-4: Assessment of the degree of implementation of measures that are suitable to adapt to climate change in the health sector. Sample size: 7 questionnaires from the federal states Hamburg, Berlin, Mecklenburg-Western Pomerania, Thuringia, Hesse, Saarland, and Baden-Württemberg. The n-values give the number of questionnaires each box-plot is based on. For further explanation of the graphic illustration see Fig. 4.5-3.

Respondents rated the degree of implementation for adaptation measures to heat waves overall as lower than that for adaptation measures to extreme events (e.g. floods) and vector-borne diseases (see Fig. 4.5-4). There are large differences between federal states, particularly with regard to education, warning systems, and emergency planning. Highest degrees of implementation (already "implemented") are reported from Hesse and Thuringia for education, from Hesse for improved warning systems, and from Baden-Württemberg for improved emergency planning. Most respondents name the experiences during the heat summer of 2003 as the reason for implementing these measures, as well as the initiative of a consortium of the higher state authorities on health, which was put into place upon suggestion of the DWD. Only the expert from Hamburg named climate change as an additional reason, but exclusively for the implementation of education regarding heat waves.

The lowest degree of implementation of measures that are suitable to adapt to heat waves is found for the insulation and cooling of buildings for specific groups of people. In all federal states, this measure is either "not discussed" or "currently considered". Only the expert from Thuringia reported this measure as already "partially implemented". As reasons for this the respondent named modernisation and energy saving plans, but not the intention to adapt to heat waves.

About half of the respondents saw organisational hurdles as obstacles for the implementation of the four measures to adapt to heat waves. For the implementation of education, warning systems, and emergency planning, one or two respondents named financial hurdles, while nearly all respondents saw financial hurdles for the improved insulation and cooling of buildings. As an additional obstacle, respondents reported that the precaution against heat waves was not yet an issue within political and public awareness outside of Southern Germany, which was particularly impacted by the 2003 heat wave. With regard to these obstacles, respondents rated the education about heat waves and improved warning systems on average as "slightly complicated", improved emergency planning as "complicated", and the insulation and cooling of buildings for specific groups of people even as "very complicated".

Extreme Events: Education, Warning Systems and Emergency Planning

Most respondents thought of specific education, warning systems and emergency planning as effective to avoid injuries and fatalities through extreme events (see Tab. 4-5). Education and improved warning systems were on average across federal states rated as already "partially implemented", while improved emergency planning was on average described as "planned" (Fig. 4.5-4). However, this is based on ratings from only four and five federal states, respectively. Nevertheless, the differences in the responses from these few states were extraordinarily high: the ratings ranges across the whole spectrum from "not discussed" to "implemented". The highest degree of implementation for all preventive measures against extreme events was reported from Hamburg, and regarding warning systems also from Berlin.

The main reasons that were given for the implementation of these measures were flood experiences and flood protection. None of the respondents named climate change as an additional reason for implementation of these measures. Only one expert responded about obstacles to implement the preventive measures[21]. This respondent named mainly organisational obstacles for all three measures. Only two experts rated the complexity of the measures, and responded "slightly complicated" to "complicated".

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[21] The targeted experts from health departments and ministries usually do not have access to the background knowledge necessary to evaluate concrete obstacles of implementation, since the implementation of measures against extreme events falls under the responsibility of the Ministry of the Interior.

Vector-Borne Diseases: Education, Warning Systems, and Campaigns of Vaccination

In all federal states, education of the public is seen as the most effective means to prevent a further spreading of ticks in the context of climate change (see Tab. 4-5). Most respondents thought of education and improved warning systems as effective to prevent the potential increased spread of malaria. Only one respondent thought of campaigns of vaccination as an effective measure to mitigate these two risks.

Respondents rated the education about vector-borne diseases and the related warning systems as on average already "partially implemented", and the respective vaccinations as "planned" – but there were marked differences between federal states (see Fig. 4.5-4). In Berlin, Thuringia and Hesse, education on risks through vector-borne diseases was rated as already "implemented". In Hamburg, the highest degree of implementation is reported for warning systems, in Thuringia for vaccinations. The following reasons were listed for implementing these three measures: prevention, legally compulsory registration in accordance with the law on protection against infections, and observations of tick-borne encephalitis and lyme disease. The respondent from Hamburg stressed the increased risk of Hamburg as a seaport to import mosquitoes, rodents and flees. According to respondents, climate change did not play a role in implementing the adaptation measures.

Respondents did hardly report on obstacles and complexity of the measures. A few respondents named financial and organisational hurdles, as well as lacking knowledge (lacking information about incidence and prevalence). The implementation of education and warning systems was rated on average as "slightly complicated", the implementation of campaigns of vaccination as "complicated".

Measures against water-borne diseases

Respondents thought of improved warning systems and emergency planning as effective measures to prevent diseases related to possibly enhanced problems with water quality due to climate change. Two out of six respondents further thought of education as effective (see Tab. 4-5). To avoid excessive length of the surveys, we did not ask about degree of implementation, obstacles and complexity of these measures.

Measures integrating several risks: Insurances and Reserve Funds

Only one respondent thought of insurance against damages through climate change and creation of reserve funds for future adaptation measures and damage reparation payments as effective to respond to potential impacts of climate change (see Tab. 4-5). Although we asked about the general effectiveness of these measures, representatives of health departments and ministries seem to have related this inquiry only to their specific administration. Therefore, the impression of limited effectiveness of insurance and financial reserve instruments seems justified, since these administrations mainly deal with the prevention of disease and death, rather than the financial impacts. It is further understandable that only one respondent reported on the degree of implementation of these measures in his federal state, and rated them as "not discussed" in his administration (see Fig. 4.5-4). The degree of implementation of insurance and reserve measures is much higher on citizen level, regarding citizens' life insurances, occupational disablement insurances, accident insurances, health insurances and financial reserves in case of illness.

Further Measures

Moreover, experts were asked for further measures in the health sector that may be suitable to prevent risks of climate change or capitalize on opportunities in their federal states. Respondents listed the following measures: reduction in urban heat islands through climate-suitable urban planning, climate–suitable architecture (design of buildings), education about solar radiation and skin diseases, research on changes in flora and fauna through spreading of toxic or allergenic species, as well as disease vectors, and long-term monitoring of health effects.

Adaptation to Climate Change in Health Departments and Ministries

Only three respondents from the health departments and ministries of federal states reported that there is a debate about the adaptation to climate change within their administration. In these three federal states – Hesse, Baden-Württemberg and Hamburg – there are practical programmes for the adaptation to climate change, which mainly relate to the implementation of warning systems. Hesse also collaborates with the project InKlim (integrated Climate Protection Program, InKlim 2012), and Hamburg collaborates with the Department of Hazard Protection. Asked about the current relevance of climate adaptation in their administration in relation to other topics, two respondents replied "important" (Baden-Württemberg and Berlin), one replied "slightly important", and three replied "unimportant". In none of the administrations the topic was rated as "very important". In the health departments and ministries, adaptation to climate change impacts currently seems to play a varying role, which is never very large and mostly focused on the risk of heat waves.

Adaptation in the Health Sector: Summary and Conclusions

Many respondents thought of education (and also improved warning systems) as broadly effective regarding adaptation to the potential impacts of climate change[22]. Many experts list several effective adaptation strategies for each potential impact of climate change. Moreover, these measures do not seem to be very complicated. There may have been few responses on the complexity of the implementation of adaptation measures, but many were rated as only "slightly complicated".

Such measures are, however, not yet fully implemented in the surveyed federal states. This is particularly the case concerning preventive measures against heat waves, and within this category particularly regarding insulation and cooling of buildings for specific groups of people. Even if few respondents regard this measure as effective, it is still highly necessary: Elderly and infirm people need suitable rooms where they can stay after a heat wave warning has been issued. Most respondents rate education and warning systems as effective.

The health sector shows the highest variability in the degree of implementation of adaptation measures, relative to the other climate-sensitive sectors. For nearly all measures, at least one federal state reports "full implementation". At the same time, nearly all measures are also "not discussed" in at least one federal state. Therefore we strongly recommend transfer of knowledge between federal states on sufficient means and ways to implement adaptation measures.

It is doubtful whether the currently available and planned measures within the German health sector will suffice to adequately respond to anticipated climate change impacts. According to respondents, climate change nearly never among the reasons to implement adaptation measures. A debate about adaptation to climate change is currently taking place only in few federal states (mainly concerning the implementation of heat warning systems). Many unanswered questions in the surveys are further evidence that climate change has rarely been discussed in the health sector. We therefore conclude that the impacts of climate change were not (or only very slightly) considered in present planning, and that the health sector is not yet adapted to climate change n many federal states. Consequently it is time to act. Adaptation needs to be seen as long-term process; due to the inherent uncertainty in concrete future impacts of climate change, alterations in adaptation strategies will become necessary as our scientific knowledge base improves continuously.

Damaging events in the past are often listed as reasons for implementing measures that are also suitable to adapt to climate change. Federal states that have already been hit in the past by heat waves, extreme events or increased occurrence of vector-

[22] We cannot draw conclusions on the measures integrating several risks, such as insurances and the creation of financial reserves, since there were only very few responses regarding these measures.

borne diseases, report distinctly higher degrees of implementation of adaptation measures, than federal states that so far have hardly been impacted. The pattern to implement preventive measures only when a particular risk has already caused damages can also be observed in other climate-sensitive sectors (e.g. agriculture). However, the health sector is concerned with risks of losses of human lives, losses that cannot be compensated after the event, as opposed to losses in the agricultural or forestry sectors. Therefore, in the health sector it is particularly important to move from reactive to proactive planning of adaptation measures, and to take into account scenarios of climate change in addition to climate trends of the past. When climate changes, past trends are poor indicators of future events.

The German health sector is not yet adapted to climate change. However, adaptation should well be possible in future, since effective adaptation measures are available for the various potential impacts of climate change. These are mainly education and warning systems, which also do not seem to be particularly complicated to implement.

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4.6 Tourism

4.6.1 Summary: Vulnerability of the Tourism Sector

The impacts of climate change on the tourism sector depend strongly on the form of tourism. City and cultural tourism are hardly impacted by climate change – unless the destination experiences an extreme event, such as heat wave or flooding and is not adapted to this.

Climate change will impact directly mainly on winter tourism. In the last 50 years we have already observed a marked decrease in snow safety in the lower Alpine altitudes and the German lower mountain ranges.

For the future we expect that winter sport will only be possible in the Alps above approximately 1500 m and in the lower mountain ranges above 800-1000 m. Artificial snow to increase snow safety and elongate the season will only be an appropriate adaptation measure in the short- to medium-term, since rising temperatures will render artificial snow making impossible at lower altitudes.

Owing to this trend, we anticipate a concentration of ski-tourism in higher altitudes of the Central Alps. German winter tourism will therefore rely importantly on alternative activities (hiking, cultural travels, wellness).

Typical forms of summer tourism, particularly beach holidays, are also impacted by climate change. Here a rather positive development in Germany is expected. Higher temperatures and lower precipitation in summer increase the attractiveness of German beach and bathing destinations and can elongate the bathing season significantly. With regard to classic destinations such as the Mediterranean losing attractiveness due to summer temperatures of partly beyond 40ºC, summer tourism could shift from southern regions to Germany. Even for summer tourism, adaptation measures are necessary, to increase the number of weather-independent attractions in potential summer holiday destinations.

Independent of climate change, tourism is prone to large variability and changes, which depend on socio-economic conditions, changes in age structure, changes in life style, and the fear of wars and terror.

In relation to these factors, the impacts of climate change on tourism have so far been rarely considered (except for winter tourism). Consequently, few adaptation measures have been discussed. In general, the offer of new activities is thought to play an important role.

The tourism sector is so far not adapted to climate change, resulting in "high" vulnerability of winter tourism, and "moderate" vulnerability to climate change impacts for the remaining tourism sector in Germany without further adaptation (business-as-usual scenario, see chapter 2.8). However, the tourism sector should be able to adapt in future. Losses in winter tourism could possibly be balanced by gains in summer. A range of effective adaptation options is available, some of which are already being implemented for reasons other than climate change. If this adaptive capacity is used, we expect a reduction to "low" vulnerability of the tourism sector to climate change (improved-business scenario, see chapter 2.8).

4.6.2 Tourism and Climate

As voluntary activities, tourism and the selection of tourism destinations are very sensitive to changes in basic conditions, among which are weather and climate.

Tourism depends on climate and weather conditions directly as well as indirectly, since climate and weather influence various ecosystem services that are essential to tourism (see chapter 1.3). For example, landscape structure, and particularly the existence and quality of bathing waters, but also the general impression of "intact nature" play a big role.

On the other hand, tourism itself can put significant pressure on various ecosystem services. In Germany, this concerns mainly the demand of land area and the conflict between intensive use of sensitive ecosystem (water bodies, Alps, etc.) and nature conservation interests.

Suitable climate and weather conditions are important basic conditions for holiday trips. By comparison, business and private trips are less dependent on climate and weather. Among holiday trips, particularly winter sport and some forms of summer holidays, such as bathing, farm, and activity holidays depend on suitable climate and weather conditions. Of less dependence are city, round, and event trips.

Twenty-two percent of all German holiday trips have climate- and weather-related motives. For day trips this proportion is even higher, namely 56% (Feige et al., 1999).

Tourism has a strong international dimension and reacts to any change in the competitive outcome between different tourism destinations. Therefore, tourism in Germany is also impacted by impacts of global change in other regions of the globe (Parry, 2000).

Naturally, to understand the vulnerability of the tourism sector, it is not sufficient to consider climate change only. Besides climate change, other national and global processes and events influence tourism. In recent years, losses in the tourism industry have been brought about among other things by the fear of terrorism since September 11th 2001, the war against Iraq, as well as the fear of diseases (e.g. severe acute respiratory syndrome, SARS) and natural hazards (e.g. the tsunami in South-East Asia in December 2004). Besides this, economic (dollar rate, oil price, economic power) and demographic development (aging) plays an important role.

Tourism and Climate Protection

Tourism is not only impacted by climate change, but is one of the causes of climate change, mainly through tourism related transport and traffic. Altogether, approximately 15.8 million tons of greenhouse gases were emitted through private overnight trips within Germany in 1999 (calculated as CO_2-equivalents). This corresponds to 1.6% of total German greenhouse gas emissions per year. Moreover, tourism by Germans in other countries caused as much as approximately 59 million tons of greenhouse gases per year during the 1990s (Schmied et al., 2001).

4.6.3 Baseline Situation: Tourism in Germany

Tourism contributes approximately 8% to the German gross national product (DWI, 2001), and is one of the most important economic sectors. Over 106 million guests from within and outside Germany come for on average ca. 3 overnight stays per year, hosted by over 50,000 commercial accommodations in Germany (Deutsche Zentrale für Tourismus, 2004a).

The number of overnight stays in Germany strongly depends on season and destination. Most overnight stays occur in summer. Among destinations, Bavaria, Baden-Württemberg, and North Rhine-Westphalia host most overnight stays (Federal Statistical Office, 2005).

Within Germany, holiday trips have the highest market share of 47%. Business trips are the second biggest market share with 41%. The rest is comprised of private trips of varying motives (e.g. visiting relatives). Among holiday trips, city trips are most frequent, followed by bathing and farm holidays (Fig. 4.6-1).

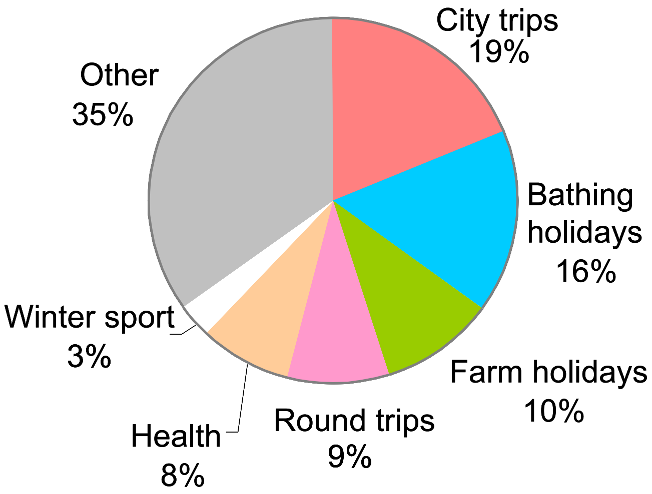

Fig. 4.6-1: Holiday trips by Germans, by market shares (IPK, 2004a).

Seventy-two percent of all trips, and about 60% of the holiday trips by Germans go to destinations within Germany. In spite of this high proportion of tourism within Germany, Germany also spends the worldwide highest amount on holiday trips abroad, namely 60 million US$ (World Tourism Organisation, 2005).

In the recent ten years, German tourism exhibited only weak trends. Such were the trend toward trips within Germany, the increasing usage of air-travel due to decreasing airfares, the increase of trips for older target groups (city trips, round trips), the trend toward spontaneous trips without prior reservation (accompanied by a stronger orientation on weather forecasts), and the increase in camping holidays (Deutsche Zentrale für Tourismus, 2004b).

4.6.4 Impacts of Climate Change – Results from the Literature

Winter Tourism and Winter Sport

Even though winter tourism accounts only fro 3% of all holiday trips with overnight stay in Germany (IPK, 2004a), it is locally of high importance (Alps, lower mountain ranges). Furthermore, additional guests on day trips can yield a similar gross turnover as overnight guests (Harrer & Bengsch, 2003).

Most winter sports, such as alpine skiing, snowboarding, cross-country skiing, tobogganing, snow shoeing etc. depend on snow and are therefore highly sensitive to changes in snow conditions. This large sensitivity becomes apparent already with natural climate variability, and has caused significant socio-economic losses in the alpine tourism sector in the snow-poor winters at the end of the 1980s. Winters with too much snow can also impact tourism negatively (Bürki, 2000).

Winter Sport in the Alps

Studies on the impacts of climate change on Alpine winter sport are mostly available for the Austrian and Swiss Alps. The results can largely be transferred to Germany. Simulations of snow safety in Switzerland indicate that with an increase in mean annual temperature by 2ºC by the year 2050, only ski resorts above approximately 1500m would have sufficient snow (Abegg, 1996). With a warming by 3ºC, this limit would rise to 1800m. As a consequence, the proportion of ski resorts with sufficient snow would be reduced from 85% to 63% (with 2ºC warming), or to 44% (with 3ºC warming) (Bürki et al., 2003). A study carried out by Graz University (Austria) shows that by the year 2050 about half of Austrian ski resorts will have to deal with severe snow deficiency (Steininger & Weck-Hannemann, 2002).

As a consequence of decreasing snow safety at lower altitudes, tourism can be expected to shift to higher altitudes. This increases the pressure on sensitive ecosystems in the high Alps. Moreover, also the high Alpine resorts will be impacted directly by climate change, particularly through increased risk to the technical infrastructure (ski lifts) as a consequence of melting glaciers and permafrost soils.

Among other things, the increased number of visitors to snow-safe areas in combination with worse snow conditions in other regions (small corridors of artificial snow) can cause a severe decline in safety on the ski pistes. For example, during the snow-poor December of 2004, accidents on the ski pistes more than doubled in comparison to the same month during years with sufficient snow (Tagesspiegel, 19.01.2005).

Emigration of winter tourists to other countries must be expected, since the German Alps comprise few ski resorts above 2000m. This is a trend that can be observed in smaller ski resorts at lower altitudes already today, owing to aging infrastructure and lacking alternative recreational offers (apres-ski, wellness, etc.) (Bürki, 2000).

Winter Sport in Lower Mountain Ranges

Ski resorts in German lower mountain ranges are particularly impacted by climate change, owing to their low elevation. A study for the Fichtelgebirge showed that snow safety has considerably declined since 1960 (Seifert, 2004). Between 1972 and 2002, the number of days with snowfall decreased significantly at 13 of 14 studied stations. Under the assumption of a temperature increase of 0.4ºC per decade in this region, only one out of six ski resorts would have sufficient snow by 2060 (Fig. 4.6-2). Already by 2025, the conditions for winter sport in the Fichtelgebirge will deteriorate considerably, which applies to the "natural" snow conditions, as well as to the potential for artificial snow making. Under these circumstances, the existence of a profitable ski industry seems highly unlikely (Seifert, 2004).

A detailed study is also available fro Baden-Württemberg (Deutsche Sporthochschule Köln, 2004). This study reaches the conclusion that climate change threatens the profitable operation of many of the 319 ski lifts of Baden-Württemberg, as well as the maintenance of cross-country skiing.

Since 1950, the duration of snow cover at altitudes below 300m in Bavaria and Baden-Württemberg has decreased by 30-40%. At intermediate altitudes (300-800m) the decrease was 10-20%. However, at higher altitudes above 800m, only small decreases and partially even increases are observed, due to increased precipitation and sufficiently low temperatures for snow (Günther, 2004).

Scenarios for the next two decades show that natural snow cover above a depth of 10 cm will only persist for longer than four weeks in the higher altitudes of Baden-Württemberg. On average, below an altitude of 750 to 850 m above sea level, there will likely not persist a snow cover of a minimum of 10cm depth for more than 14 days by the year 2012. The potential to make artificial snow will also be impacted by climate change. By 2025, only the high altitudes (Feldberg) will be suitable for technical snowmaking.

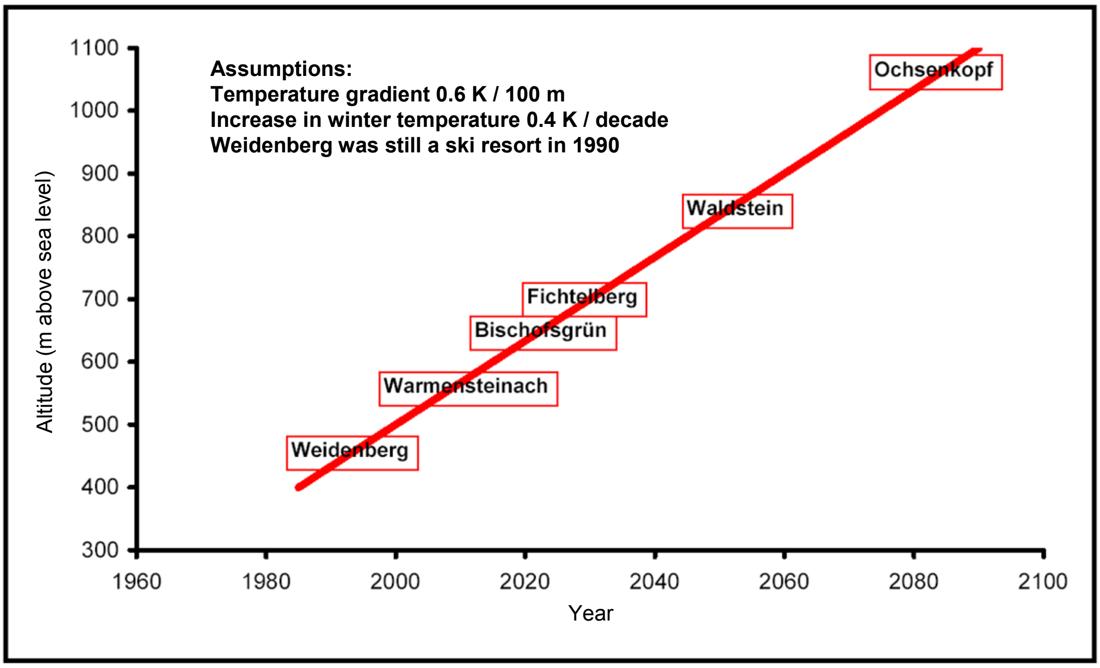

Fig. 4.6-2: Lower altitudinal limit (m above sea level) for winter sport in the Fichtelgebirge (Foken, 2003).

Summer and City Tourism

Summer tourism is largely influenced by three factors: air temperature, water temperature, and duration of sunshine (Parry, 2000). However, in contrast to winter tourism, the climatic prerequisites of summer tourism are less well-defined and specific dependencies are hardly studied. Furthermore, climatic demands and dependency of the various forms of summer tourism, such as bathing, activity, and farm holidays, vary.

The impacts of climate change on German summer tourism can only be understood within the European context. Still many Germans spend their summer holidays in the Mediterranean region. In total, the stream of tourists from Central and Northern to Southern Europe is the most important touristic movement worldwide and comprises of approximately 116 million arrivals, contributing 41% to inner-European tourism. These destinations could lose attractiveness especially during the main season, since the strongest future temperature increases are expected particularly for Southern Europe, with maximum temperatures of partly above 40ºC. Additionally this region may well experience considerable water shortages (Schröter et al. 2005). However, in low season (spring, autumn) Southern Europe remains an attractive destination (World Tourism Organization, 2003).

In Germany, rising temperatures and decreasing precipitation will rather favour summer tourism and lengthen the summer season. For example, results from a study for Baden-Württemberg show a marked elongation of the bathing season by 17 days into spring, and by 39 days into autumn by 2050 (Wolf, 2005).

As a consequence of such "favourable" climate conditions, summer tourism may well shift inland, or to Northern and Eastern Europe, along with an increased attractiveness of German destinations also for foreign guests.

However, even in Germany summer temperatures could, at least in specific years, rise into areas that are disadvantageous fro specific forms of tourism (e.g. indoor events). This has been observed especially during the hot summer of 2003. For example, considerably fewer visitors to museums and amusement parks were counted in Baden-Württemberg, while public pools and beer-gardens etc. profited (IHK Baden-Württemberg, 2004).

Besides the positive developments in climatic conditions (Feige et al., 1999), summer tourism at the coast could experience some negative impacts, such as rising sea levels, seaside erosion of the wadden sea (e.g. on the island Sylt), extreme events (storms, storm surges, etc.), and negative influences on ecosystems (Sterr, 1996).

The most important risks for city tourism, which mostly occurs in the summer months, are extreme events such as floods, extreme weather conditions such as heat waves, or the increased probability of occurrence of diseases previously unknown to Germany (e.g. malaria) due to climate change (see chapter 4.5). If the cities are not adapted to such events and fatalities occur, the mass media coverage will rapidly decrease the number of tourists (see e.g. tsunami in Southeast Asia in December 2004). Furthermore, it has to be considered that tourists are not familiar with local conditions and existing risks and adaptation measures (e.g. routines for evacuation in flood areas) and are therefore particularly vulnerable – especially if they are elderly, which is often the case for city tourists.

4.6.5 Impacts of Climate Change – Assessment by Regional Experts

As described in chapter 2.6, we conducted expert surveys with representatives from the relevant functional departments in various climate-sensitive sectors in Germany, including the tourism sector. Sector-specific assessments of direct and indirect impacts of climate change are available for different environmental zones (see chapter 2.6) from the following five federal states: Schleswig-Holstein, Lower Saxony, Mecklenburg-Western Pomerania, Berlin, and Saarland. We did not get responses from southern federal states with a high proportion of winter tourism. Negative ratings are regarded as acknowledgments of risks, positive ratings as acknowledgments of opportunities. Due to the low rate of return of the questionnaires, we did not graphically illustrate the results of the survey. The assessment, which is discussed in the following, must be seen as very preliminary due to various reasons. Only very few questionnaires were returned from the federal states, only one expert per federal state was approached, and few respondents base their assessment on studies of past and future climate development and its impacts.

General Assessment of Climate Change

On average over environmental zones and federal states, respondents rated the significance of climate change for the tourism sector in recent time (1990 to today) and in the short-term (today to 2010) as "neither positive nor negative", with large variability in the short-term ratings of environmental zones and federal states, ranging from "negative" to "slightly positive". In the medium-term (2010 to 2020) variability between ratings continues to be high, but the average value shifts toward "slightly negative". Only two ratings are available for the long-term (2020 to 2050), one of which is "neither positive nor negative", the other "negative". Moreover, only two to three respondents rated elements and impacts of climate change in the long-term, so that we will not discuss the long-term assessment in the following.

Risk Assessment

Among *potential elements of climate change*, respondents on average rated stronger inter-annual variations in precipitation and fewer frost days as most negative. These elements were already rated as "slightly negative" in the recent past. Respondents saw increasing winter temperatures, increasing annual precipitation sums[23], and increased frequency of extreme rainfall events as slightly less negative.

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[23] According to the present state of knowledge increases and decreases in annual precipitation are possible, depending on the region. Therefore, both developments were offered to the respondents for rating.

It is interesting to look at the respondents' assessment of increasing average annual temperatures and increasing summer temperatures. For the recent past and the short-term future, there is a tendency to see these trends as positive. In the medium-term, the trends are seen as negative.

All seven surveyed potential *impacts of climate change* on winter tourism were seen as risks. On average the rising snow line, shorter winter season, and the migration of tourists to snow safe regions (high Alps) are seen as only "slightly negative", and larger variations within the winter season as "slightly negative" to "negative". However, these average values are the result of neutral ratings for environmental zones in which winter sport almost played no role even in the past (e.g. North Western lowlands), and "negative" to "very negative" ratings for today's winter sport resorts (e.g. Central lower mountain ranges and Harz).

Opportunity Assessment

Among potential *elements of climate change*, respondents saw more hot days and a possible decline of annual precipitation sums as opportunities rather than risks, while these trends were partly also rated as "slightly negative" for tourism.

The potential *impacts of climate change* on summer tourism were nearly universally seen as positive. The biggest opportunity on average was seen in increasing tourism within Germany (and more visitors from outside Germany), due to higher temperatures and more frequent extreme events in Southern Europe and other destinations abroad. The impacts on activity holidays (sport, hiking) were also at least rated as "slightly positive' in future. There were very strong variations between the ratings from different federal states and environmental zones of the possible increase of bathing tourism (ranging from "negative" to "very positive").

Further Impacts

We also enquired about further possible impacts of climate change on the tourism sector. The respondents did not list any further impacts. The respondent from Berlin stressed that climate and weather hardly play a role fro city tourism, and would impact only few marginal segments (e.g. water tourism). Only extreme climate conditions would impact city tourism.

4.6.6 Adaptation to the Impacts of Climate Change

General Adaptation

Climate change is only one of the drivers that will influence tourism in the future. Other drivers, such as changes in recreational behaviour, demographic changes and economic factors have a much stronger influence on tourism in Germany. Therefore, specific adaptation measures need to be in accordance with each other.

In this context, more flexibility and a further diversification of the tourism offers in Germany is needed. Among these are increased possibilities for year-around weather-independent activities (indoor-events, hot springs, exhibitions, etc.), but also enhancing the attractiveness of tourist destinations through stressing regional specificities (cultural history, culinary specialities), and the improvement of educational and cultural tourism offers (e.g. presentations and concerts).

Various studies on tourism and climate change conclude that the main reason for the weak implementation of adaptation measures in the tourism industry is the lacking debate about climate change. Other issues (economic development, competition, etc.) often seem more important and a relative short-term perspective is adopted in discussions and operations (Bürki, 2000; Feige et al., 1999).

Adaptation of Winter Tourism

Artificial snowmaking is seen as one of the main strategies to avoid insufficient snow for winter sport. In principle, artificial snowmaking can balance the lack of snow due to decreased snowfall, increase snow safety and lengthen the season. However, snowmaking potential is also impacted by climate change. Cost-effective snowmaking can only be done at temperatures below –4ºC. In the course of climate warming, snowmaking in Germany ski resorts will only be possible in the short- and medium-term and only at higher altitudes. Moreover, due to high costs of investments, snowmaking facilities are only profitable on strongly frequented pistes with high lift capacities (Lutz, 2000). Both conditions are usually not given in German ski resorts. Additionally, snowmaking has negative environmental impacts due to high water (ca. 1000-4000m^3/ha) and energy use (ca. 25,000 kWh/ha), as well as a shortening of the vegetation period (Hahn, 2004). Therefore, the implementation of new snowmaking facilities should be carefully considered due to economic and environmental reasons.

Other adaptation measures are shifting the tourism activities from snow-dependent sports to offers like guided hikes, wellness, and culture. Such strategies are recommended especially for lower mountain ranges, which have suffered from insecure snow conditions already for some time.

Adaptation of Summer Tourism

We do not give specific strategies for adaptation for summer tourism, because the impacts on summer tourism were complex and less predictable. However, again the principle of diversification would increase flexibility in the face of changes.

4.6.7 Effectiveness, Degree of Implementation and Obstacles of Adaptation: Assessment of Regional Experts

We have responses from the survey (method described in chapter 2.6) with experts from the following seven federal states: Berlin, Baden-Württemberg, Hamburg, Mecklenburg-Western Pomerania, Lower Saxony, Schleswig-Holstein, and Saarland. The following results of the survey must be seen as preliminary assessment of the measures that are suitable to adapt the German tourism sector to climate change, since only one expert per federal state was approached and the return of the questionnaires from the federal states was scarce.

In the survey, different dimensions of the adaptation measures were evaluated; the effectiveness of the measures to mitigate the potential impacts and capitalize on potential opportunities of climate change introduced in section 4.6.5 (see Tab. 4-6; here we have responses from only four experts), and the present degree of implementation of the adaptation measures (see Fig. 4.6-3).

Winter Tourism: Measures to Lengthen the Season and Alternative Offers

Respondents thought of measures to lengthen the season and alternative offers in winter tourism as broadly effective regarding potential impacts of climate change (see Tab. 4-6). These measures were rated as effective especially with regard to a shorter winter season and the impacts on activity holidays.

On average across federal states, these measures were rated as already "partially implemented" (see Fig. 4.6-3). However, there were large differences between federal states, particularly for the measures to lengthen the season. Here the degree of implementation ranged from "not discussed" to "implemented". This is mainly due to the fact that Berlin, Hamburg and Mecklenburg-Western Pomerania do not host winter sport tourism and therefore do not have to discuss such measures, while the other federal states rated them as already "partially implemented" or "implemented". The motivation to lengthen the winter season and to diversify the tourism offer was so far primarily to enhance tourism and create jobs. Only the expert from Baden-Württemberg named climate change as one of the reasons to implement measures to lengthen the season and create alternative tourism offers.

Tab. 4-6: Rating of the degree of effectiveness of adaptation measures to mitigate risks and capitalize on opportunities of climate change in the tourism sector. The number of respondents that rated a particular measure of mitigation resp. exploitation as effective is shown. Sample size: 4 questionnaires from the federal states Baden-Württemberg, Saarland, Schleswig-Holstein, and Lower Saxony.

	Impacts						
Measures	Rising snow line	Shorter winter season	Larger variations in winter season	Migration of tourists to snow safe regions (high Alps)	More days with "bathing weather"	Impacts on acitivity holidays (sport, hiking)	Increasing tourism within Germany (and more visitors from outside
Winter tourism Measures to lengthen the season	2	3	2	2	1	3	1
Alternative offers	1	3	2	-	1	3	1
Summer tourism							
Increasing regional attractiveness	-	1	-	-	2	3	2
Measures integrating several risks Insurance against damages through climate change	-	-	-	-	-	-	-
Creation of reserve funds for future adaptation measures and reparation payments	-	-	-	-	-	-	-

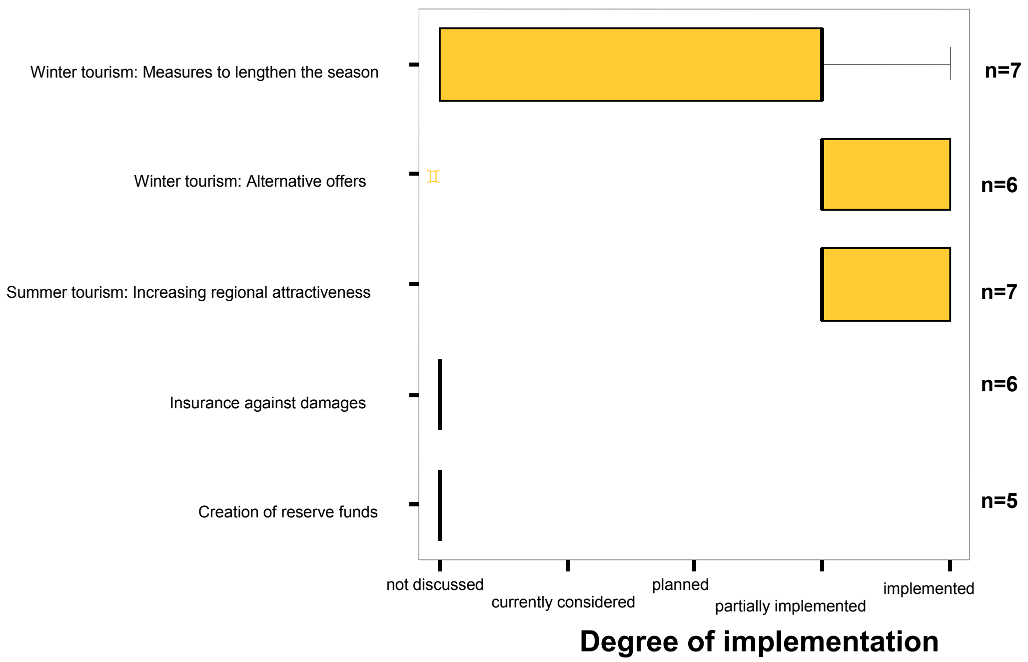

Fig. 4.6-3: Assessment of the degree of implementation of measures that are suitable to adapt to climate change in the tourism sector. Sample size: 7 questionnaires from the federal states Berlin, Baden-Württemberg, Hamburg, Mecklenburg-Western Pomerania, Lower Saxony, Saarland, and Schleswig-Holstein[24].

[24] Illustration of the frequency distribution of ratings by various federal states as box-plot: Each box represents the central 50% of the distribution and therefore illustrates the values between the lower and the upper quartile. The more to the left the box is shown, the more negative a specific impact of climate change is rated. The thick

Respondents named primarily financial and partly organisational hurdles as obstacles for the implementation of adaptation measures. One respondent identified climatic and environmental obstacles, e.g. for the use of snowmaking equipment. With regard to these obstacles, respondents rated both measures to lengthen the season and the creation of alternative attractions on average as "complicated".

Summer Tourism: Increasing Regional Attractiveness

Respondents thought increasing the regional attractiveness in summer tourism would be an effective measure to adapt to possible impacts of climate change, such as more days with suitable weather for bathing, and impacts on activity and inland tourism (see Tab. 4-6).

On average across the seven responsive federal states, this measure was rated as already "partially implemented", with only very small differences between federal states (see Fig. 4.6-3). As reasons for the implementation of this measure, respondents listed among other things the general promotion of tourism and the job market, and the constant task to renew tourist offers and develop the industry (also for city tourism). None of the respondents named climate change as one of the reasons to implement this measure. In this content one respondent stressed that it was the "tough competition" rather than climate change, which was the main problem in the tourism industry.

According to most respondents, the implementation of measures to increase the regional attractiveness for summer tourism was hindered mainly by financial and partly by organisational obstacles. With regard to these obstacles, the measures were rated as "complicated".

Measures Integrating Several Risks: Insurances and Reserve Funds

Most respondents related the question regarding insurances against damages through climate change and the creation of reserve funds for future adaptation measures and reparation payments to their specific administration, and not to the federal state (including the tourism industry) as a whole. Therefore respondents saw these measures as ineffective to respond to impacts of climate change (see Tab. 4-6), and the degree of implementation of these measures was uniformly rated as "not discussed" (see Fig. 4.6-3). Insurances and the creation of reserve funds are usually not an option for state agencies. Higher effectiveness and degree of implementation would result, if we had surveyed the existence of insurances and reserve funds in tourism enterprises.

Further Measures

Moreover, experts were asked for further measures in the tourism sector that may be suitable to prevent risks of climate change or capitalize on opportunities. Respondents listed the following measures: quality assurance (e.g. in maritime, youth and children tourism), promoting environmentally friendly activities (e.g. bicycle, horseback riding and water tourism), as well as encouraging tourists to use public transport.

Adaptation to Climate Change in Tourism Departments

Respondents from the tourism departments of the federal states were furthermore asked about the activities in their administrations to adapt to the impacts of climate change. Three out of seven experts replied that there was a debate about adaptation to climate change in their administrations. However, their further responses gave the impression that they were actually relating to initiatives to reduce greenhouse gas emissions (mitigation). Practical measures to adapt *to the impacts* of climate change were reported only from Baden-Württemberg. Asked about the current relevance of

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vertical line represents the median value. The whiskers to the left and right of the box illustrate the range of responses. The n-values give the number of valid answers each box-plot is based on.

climate adaptation in their administration in relation to other topics, three respondents replied "important" (Baden-Württemberg, Mecklenburg-Western Pomerania, and Schleswig-Holstein), while again adaptation was probably understood mainly to mean mitigation. In none of the administrations the topic was rated as "very important". Therefore, in the tourism departments of federal states, adaptation to climate change impacts currently seems to be of minor significance.

Adaptation in the Tourism Sector: Summary and Conclusions

From responses of seven tourism experts from seven federal states on measures that are suitable to adapt to the impacts of climate change, we conclude the following[25]: Respondents saw as effective measures to mitigate potential risk and capitalize on opportunities the lengthening of the season and the creation of alternative attractions in winter tourism, and the enhancement of regional attractiveness in summer tourism. There was not a single climate change impact for which not least one respondent named an effective adaptation measure.

The measures were on average rated as already "partially implemented". However, responses from the important winter sport destinations Bavaria and Saxony are lacking, so that it is unclear whether this apparent high degree of implementation applies for the whole of Germany, Furthermore, it is unclear if the existing and planned measures will suffice to respond adequately to the risks and opportunities of anticipated climate change, since according to respondents only in one federal state (Baden-Württemberg) climate change was among the reasons to implement adaptation measures. So far, a debate about adaptation to climate change takes place in only few of the tourism departments of federal states. We therefore conclude that the impacts of climate change were not or only very slightly considered in planning adaptation measures, and that the tourism sector within most federal states is not yet adapted to climate change. On the other hand, the main actors in the tourism industry are not the surveyed tourism departments, but the tourism enterprises. Nevertheless, it seems that hardly any enterprises have adapted to climate change in Germany, with the possible exception of the TUI AG.

In general, the tourism sector in Germany should have the capacity to adapt to the impacts of climate change in future. Losses in winter tourism could possibly be balanced by gains in summer. A range of effective adaptation options is available, some of which are already being implemented for reasons other than climate change. The adaptation through state tourism departments was mostly rated as "complicated", with regard to primarily financial and partly organisational obstacles.

[25] We cannot draw conclusions on the measures integrating several risks, such as insurances and the creation of financial reserves, since there were only very few responses regarding these measures.

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4.7 Transport

4.7.1 Summary: Vulnerability of the Transport Sector

The transport sector will probably profit from climate change *in winter*, since a decrease of frost and ice days will lead to a decline in restrictions to all transport means (roads, rail traffic, navigation, air traffic). *In summer*, heat days can cause problems in road traffic (increased risk of accidents, damages to infrastructure).

A specific risk to all transport means in all seasons is posed by an increased frequency of extreme events due to climate change, such as storms, hail, and floods. These events can lead to fatalities, the short-term breakdown of traffic (sometimes accompanied by considerable economic losses due to losses in production), and can cause damages to infrastructure (e.g. as with the Elbe flood 2002).

In addition to these direct impacts of climate change, navigation is impacted by variations in water levels primarily on large, unregulated rivers (Elbe, Weser, Rhine). Stronger disruptions due to high as well as low water are to be expected.

A range of primarily technological adaptation options is available to the transport sector. These include the use of new materials, the construction of protective infrastructure, and relocation of transport routes.

In general, potential impacts of climate change on the transport sector and necessary adaptation measures are hardly discussed within science and in practice. This is a considerable deficit, due to the national economic significance of the transport sector, and the potential negative impacts of climate change this sector.

The transport sector in Germany is currently not adapted to climate change, resulting in a present "moderate" vulnerability to the impacts of climate change, particularly extreme events (business-as-usual scenario, see chapter 2.8).

In general, the transport sector should be able to adapt to the impacts of climate change in future, since a range of effective adaptation measures is available. On the other hand, adaptation will probably be very complicated, because one cannot rely on present knowledge or on existing adaptation measures. Therefore, the adaptation of the transport sector needs special support, particularly with regard to education about risks and opportunities, which will arise through climate change. If the available adaptation measures are implemented, a reduction to "low" vulnerability of the transport sector can be expected (improved-business scenario, see chapter 2.8).

4.7.2 Transport and Climate

Transport of people and goods is a prerequisite for the high standard of living of modern societies. Problems with the transport of raw materials, the shipping of products or commuter traffic have far-reaching consequences for economy and society (Parry, 2000). There are specific interactions with the tourism sector, which was also analysed as part of this study (see chapter 4.6), as tourism relies heavily on transport.

Climate, weather conditions and weather are important factors in transport, since they influence safety, efficiency (i.e. cost-effectiveness), and punctuality of transport. Climate and weather influence both transport means and transport infrastructure for all means of transport (roads, rail traffic, navigation, air traffic). However, different transport means are impacted differently by climate change.

Road Traffic

In winter, snowfall, ice, fog and hail impede road traffic. This leads to slow speeds of traffic, traffic jams, and an increase in the risk of accidents. Moreover, frost causes damages to roads and bridges.

Strong rainfall events lead to floods and the erosion of slopes, which disrupt traffic in the short-term and can also lead to permanent damages of transport infrastructure. Other extreme events, such as storm and hail, also cause great damages, primarily to vehicles.

Heat waves in summer impair the concentration of drivers and can lead to an increase in the risk of accidents. According to a study of the Federal Office for Road Traffic (Bundesanstalt für Straßenwesen), the number of accidents increases by 13% outside cities, and by 22% inside cities when the temperature inside vehicles is above 32ºC (Arminger et al., 1995). Extreme temperatures of above 37ºC even increased the number of accidents by 33%. Moreover, high temperatures cause damages to road paving (e.g. lane grooves).

Rail Traffic

Rail traffic is less dependent on weather than road traffic. In winter, mainly icing of the power supply can impact rail traffic. In summer, particularly weather extremes are important. These include damages to overhead contact lines (catenaries) through storms, the uprooting of trees through storms, undercutting of railroad tracks through heavy rainfalls and floods, as well as track damages through extreme heat.

Air Traffic

Weather influences efficiency and safety of air traffic. Air transport is sensitive primarily to thunderstorms, strong winds, mist, fog, rain, snow and ice on the ground and in the air. Winter weather conditions on airports are a frequent cause of delays and potential hazards (Hauf et al., 2004). All larger airports in Germany respond to these dangers with a complex system of winter maintenance procedures.

Navigation

Navigation is also negatively impacted by frost and ice in winter. Icing over of surface waters impairs navigation and cause the need to use icebreakers. In cold winters, navigation may also be shut down completely.

Of even more importance is the influence of climate on the water levels of rivers. At high water, navigation often has to be restricted, since rapid velocities of river flows endanger the ships, or because already flooded areas cannot tolerate the waves caused by navigation. During arid periods, water level can sink below a critical level, so that the discharge of cargo ships is no longer warranted. Particularly free flowing rivers (e.g. Elbe, Rhine, Weser) are impacted by climate–induced fluctuations of water levels. In regulated rivers, water level fluctuations can to some extent be buffered by damming. Finally, seaports and navigation of coastal waters can be impacted by sea level rise.

4.7.3 Baseline Situation: Transport in Germany

In Germany, passenger traffic is dominated by motorised individual transport. Passenger cars are used by 79.1% of all people in traffic (see Fig. 4.7-1a). With 45 million vehicles, the degree of motorisation is very high (Federal Statistical Office, 2005). This diminishes public transport on roads and rails, which only contributes 8% to passenger traffic. However, air traffic is of increasing significance. The number of air passengers increases continuously, which can be attributed among other things to the increasing existence of cheap airlines. Nevertheless, air traffic currently contributes only 4.6% to total passenger traffic.

Also in the transport of goods, road traffic dominates (see Fig. 4.7-1b). Rail traffic has lost market shares in recent years and now only contributes 15% to total transport of goods. Through-traffic plays a major role in transport of goods. Germany is known as the main mediator of through-traffic in Europe.

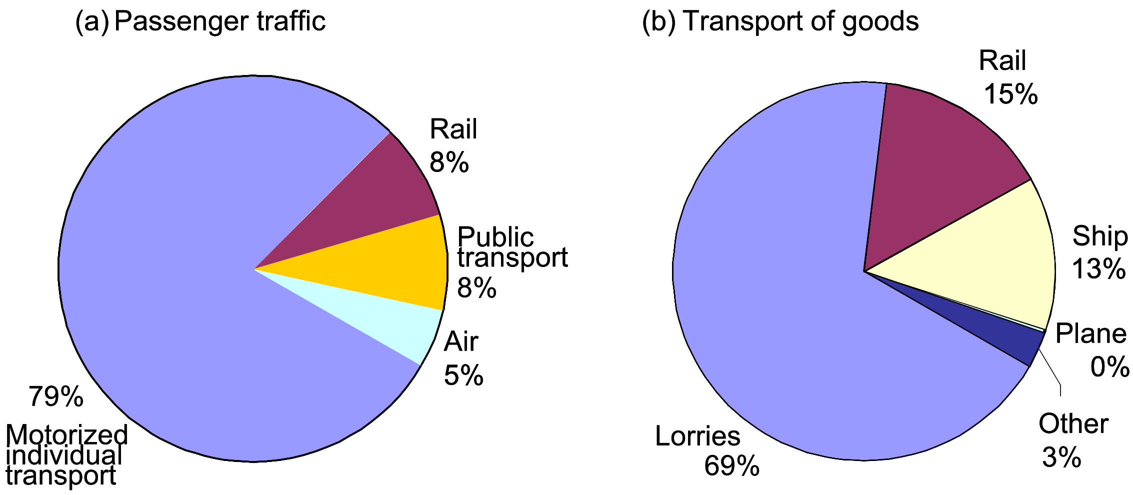

Fig. 4.7-1: Overview of the contributions of different transport means to (a) passenger traffic, and (b) transport of goods in Germany (Federal Government, 2000).

The transport sector is an important contributor to the greenhouse effect. In Germany in the year 2000, approximately 22% of total emissions stemmed from transport (UBA, 2001). To this amount of carbon dioxide, the contribution of passenger cars was highest with 59%, followed by lorries with 25%, and air traffic with 8%.

Transport and Climate

There are no concrete studies or monitoring programmes on the impacts of climate change on the transport sector in Germany so far. Therefore this impact only becomes apparent with recent extreme events, such as e.g. the heat summer of 2003. During this event, low waters caused limitations in navigation, up to the stranding of ships (e.g. on the Elbe). It is unclear whether there we additional fatalities in road traffic caused by the heat, and if so how many.

4.7.4 Impacts of Climate Change – Results from the Literature

The future impacts of climate change on the transport sector in Germany have also not been studied yet. Scenarios and projections are limited to the development of transport and its impacts on climate protection. In their projection of autumn 2000, the German Federal Ministry of Transport (Bundesverkehrsministerium) estimates a 20% increase relative to 1997 of passenger transport by 2015, transport of goods is even estimated to increase by 64%. In spite of progress in lessening emissions of vehicles, this will go along with a tremendous increase in environmental stress, particularly in the emissions of the greenhouse gas CO_2 (UBA, 2005).

With regard to the impacts of climate change on transport, we anticipate that winter restrictions through frost and ice will decrease in future. This will profit all transport means equally. Impacts on transport are primarily to be expected from an increased frequency of extreme events. Hot summer temperatures will primarily impair road traffic. On non-regulated rivers, navigation will probably be increasingly impacted by high and low waters, and stronger fluctuations in water levels.

Furthermore, it is to be expected that streams of traffic will relocate due to shifts in agricultural areas, and climate change related changes in recreational and holiday behaviour. This can have both positive and negative effects.

4.7.5 Impacts of Climate Change – Assessment by Regional Experts

As described in detail in chapter 2.6, we conducted expert surveys with representatives from the relevant functional departments in various climate-sensitive sectors in Germany, including the transport sector. Sector-specific assessments of direct and indirect impacts of climate change are available for different environmental zones (see chapter 2.6) from the following five federal states: Schleswig-Holstein, Hamburg, Berlin, Mecklenburg-Western Pomerania, and Brandenburg. We did not get responses from southern federal states with their higher exposition to floods, frost, and snow, relative to Northern Germany. Negative ratings are regarded as acknowledgments of risks, positive ratings as acknowledgments of opportunities. Due to the low rate of return of the questionnaires, we did not graphically illustrate the results of the survey. The assessment, which is discussed in the following, must be seen as very preliminary due to various reasons. With 5 out of 16 federal states, only very few questionnaires were returned from the federal states, only one expert per federal state was approached, and none of the respondents based their assessment on studies of past and future climate development and its impacts.

General Assessment of Climate Change

On average over environmental zones and federal states, respondents rated the significance of climate change for the transport sector in recent years (1990 to today), and also in the short-term future (today to 2010) as "neither positive nor negative", with some ratings of "slightly positive". In the medium- (2010 to 2020) to long-term (2020 to 2050) the average ratings range from neutral to "slightly negative". Overall, there is appears to be a trend of slightly negative ratings in the past to slightly positive ratings in the future, with increasing differences between federal states the longer the future time horizon.

Risk Assessment

Among potential *elements of climate change*, respondents rated the more frequent occurrence of extreme rainfall events as most negative. In the short-term, they were rated as "slightly negative", and in the medium- to long-term nearly uniformly as "negative". Respondents saw increasing summer temperatures, more hot days and heat waves, and an increase in annual precipitation sums[26] as less negative. Respondents rated stronger inter-annual variations in precipitation and a decrease in the annual precipitation sum as almost neutral, with a slight tendency toward negative ratings.

Five out of seven surveyed *potential impacts of climate change* on the transport sector were seen as risks. The strongest negative ratings (short-term: "slightly negative", medium- to long-term: "negative") were given for the increased risk to road traffic through extreme events (e.g. flood and storm), and for the risk of low and high water in navigation. In rail traffic, respondents rated the risk through extreme events (e.g. flood and storm) in the near and distant future nearly uniformly as "slightly negative". Strong fluctuations in water levels were also seen as "slightly negative".

Opportunity Assessment

The *elements of climate change* increasing annual temperature and winter temperatures, as well as fewer frost days were rated as opportunities rather than risks. In accordance with this, the decreased risk of frost and snow in road and rail traffic was seen as a "slightly positive" *potential impact of climate change* on the transport sector.

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[26] According to the present state of knowledge increases and decreases in annual precipitation are possible, depending on the region. Therefore, both developments were offered to the respondents for rating.

Further Impacts

We also enquired about further possible impacts of climate change on the transport sector. One respondent listed the risk of more frequent and stronger storms for railroads and waterways, the specific danger to bridges due to more frequent storms, and the opportunity of less frequent icing on ships and waterways.

4.7.6 Adaptation to the Impacts of Climate Change

Since the potential impacts of climate change on the transport sector are mostly unstudied, it is understandable that little knowledge is available regarding suitable adaptation measures to climate change in the transport sector. In general, we can name technological adaptations to climate change. For example, to respond to extreme heat, new heat-resistant materials could be used in transport infrastructure (e.g. new pavements). Air conditioning can prevent high interior temperatures in cars. Technological measures can also be suitable against extreme events, e.g. protection against mudflows and relocation of routes (in potential flood areas). Improved water management and the construction of new dams can counteract fluctuating water levels in rivers. However, such large-scale technological intervention measures are costly, and can conflict with other objectives, in particular goals in nature conservation. In areas where navigation could only be sustained with large technological interventions, a shift to rail transport should be considered. To adapt to the decreasing frequency of frost and ice days with climate change, the long-term investment in protection against icing should be avoided (e.g. heating of bridges in road traffic).

4.7.7 Effectiveness, Degree of Implementation and Obstacles of Adaptation: Assessment of Regional Experts

We have responses from the expert survey (method described in chapter 2.6) on measures that are suitable for climate change adaptation in the transport sector from the following five federal states: Schleswig-Holstein, Hamburg, Berlin, Mecklenburg-Western Pomerania, and Brandenburg. There were no responses from Southern federal states. The following results of the survey must be seen as preliminary assessment of the measures that are suitable to adapt the German transport sector to climate change, since only one expert per federal state was approached and the return of the questionnaires from the federal states was scarce.

In the survey, different dimensions of the adaptation measures were evaluated; the effectiveness of the measures to mitigate the potential impacts and capitalize on potential opportunities of climate change introduced in section 4.7.5 (see Tab. 4-7), and the present degree of implementation of the adaptation measures (see Fig. 4.7-2).

Tab. 4-7: Rating of the degree of effectiveness of adaptation measures to mitigate risks and capitalize on opportunities of climate change in the transport sector. The number of respondents that rated a particular measure of mitigation resp. exploitation as effective is shown. Sample size: 5 questionnaires from the federal states Berlin, Hamburg, Mecklenburg-Western Pomerania, Schleswig-Holstein, and Brandenburg.

	Impacts				
Measures	Less risk through frost/snow (warmer winters)	Higher risk through extreme events	Risk of low water	Risk of high water	Greater fluctuations in water levels
Protection of roads against extreme events	2	2	-	3	1
Protection of railroad tracks against extreme events	-	1	-	1	-
Technical control of water levels	-	-	2	1	-
Improved coordination in water level control	-	-	1	1	1
Shifting the transport of goods from ships to rail	-	-	1	2	-

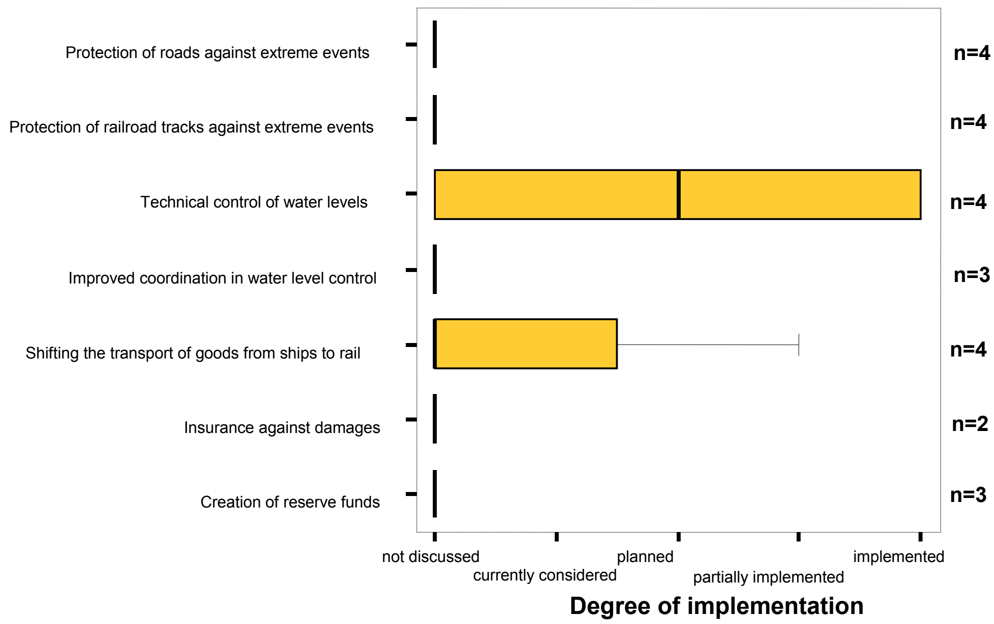

Fig. 4.7-2: Assessment of the degree of implementation of measures that are suitable to adapt to climate change in the transport sector. Sample size: 5 questionnaires from the federal states Schleswig-Holstein, Hamburg, Berlin, Mecklenburg-Western Pomerania, and Brandenburg. The n-values give the number of questionnaires each box-plot is based on [27].

[27] Illustration of the frequency distribution of ratings by various federal states as box-plot: Each box represents the central 50% of the distribution and therefore illustrates the values between the lower and the upper quartile. The more to the left the box is shown, the more negative a specific impact of climate change is rated. The thick vertical line represents the median value. The whiskers to the left and right of the box illustrate the range of responses. The n-values give the number of valid answers each box-plot is based on.

Road Traffic: Protection of Roads against Extreme Events

Respondents thought of the protection of roads against extreme events as an effective measure to respond to an increased risk of extreme events and floods[28] (see Tab. 4-7). However, according to 4 out of 5 respondents, this measure is so far "not discussed" in their federal states (see Fig. 4.7-2) (one expert did not respond to this question). One expert explained this lack of debate on the protection of roads against extreme events by the lack of a need to do so in his federal state. Owing to the lack of a debate on this topic, respondents did not name any obstacles and did not evaluate the complexity of this measure.

Rail Traffic: Protection of Railroad Tracks against Extreme Events

Only one respondent saw the protection of railroad tracks as an effective measure to respond to the increased risk of extreme events and floods (see Tab. 4-7). Four out of 5 respondents reported that this measure is so far "not discussed" in their federal states (see Fig. 4.7-2) (one expert did not respond to this question). To experts claimed that there was no danger of extreme events to the railroad tracks in their federal states. Again, there were no responses on obstacles or the complexity of implementation of this measure.

Navigation: Technological Maintenance and Control of Water Levels, Shifting Transport of Goods from Ships to Rail

Respondents thought of the three adaptation measures in navigation as equally effective with regard to the risk of high and low water (see Tab. 4-7).

The degree of implementation of these measures is different (see Fig. 4.7-2). The technological maintenance of water levels was reported as "not discussed" in two federal states (Hamburg and Mecklenburg-Western Pomerania), and as already "implemented" in two other federal states (Berlin and Brandenburg), resulting in the misleading average of "planned" (see Fig. 4.7-2). The expert of one federal state did not rate the degree of implementation of this measure. The expert from Hamburg explained the lack of a debate about technological maintenance of water levels with the lack of a need for this measure. The expert from Berlin explained the implementation of this measure with the assurance of navigability of the waterways; the respondent from Brandenburg gave the experiences with the Oder and Elbe floods as reasons. However, the potential impacts of climate change did not influence the implementation of this measure.

Improved control of water levels was only evaluated by three respondents (Berlin, Hamburg, Mecklenburg-Western Pomerania), who uniformly rated the degree of implementation of this measure as "not discussed". Again, the expert from Hamburg reported a lack of necessity.

The shifting of transport of goods from ships to rail has already been "partially implemented" in Hamburg (due to problems with capacity for transport of goods), while this measure is "not discussed" in the federal states Brandenburg, Berlin, and Schleswig-Holstein (there was no response from Mecklenburg-Western Pomerania).

Since the three surveyed measures were mostly "not discussed" in navigation, it is understandable that respondents did not reply to questions on obstacles and complexity of the measures.

Measures Integrating Several Risks: Insurances and Reserve Funds

Respondents reported that measures integrating several risks, such as insurances and the creation of reserve funds, which were also surveyed in the other climate-sensitive

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[28] We were puzzled by the response of two experts that the protection of roads against extreme events was an effective measure to respond to decreased risks of frost and snow following climate change.

sectors (e.g. forestry, agriculture), were "not discussed" in their federal states (see Fig. 4.7-2). From the responses in other climate-sensitive sectors we know that respondents – representatives of functional departments – mainly thought of an implementation of this measure through agencies and federal bodies, which is naturally not probable. It is well possible that we would have found higher degrees of implementation of these measures, had we surveyed transport enterprises.

Further Measures

Moreover, experts were asked for further measures in the transport sector that may be suitable to prevent risks of climate change or capitalize on opportunities. Only one expert responded to this. He named better predictions of storms (frequency and strength) for an increase safety in navigation and rail traffic.

Adaptation to Climate Change in Transport Departments

Only two out of five respondents from the transport departments of federal states reported that there is a debate about the adaptation to climate change within their administration. However, no practical programmes in these two federal states – Brandenburg and Mecklenburg-Western Pomerania – aimed at tackling the impacts of climate change in the transport sectors were named. Asked about the current relevance of climate adaptation in their administration in relation to other topics, these two experts responded "slightly important", the three other experts with "unimportant". None of the respondents chose "important" or "very important". Also with regard to the very low rate of return of questionnaires, we conclude that adaptation to climate change is currently of nearly no significance in the transport departments in most federal states.

Adaptation in the Transport Sector: Summary and Conclusions

Overall, the German transport sector so far is very little adapted to climate change. A debate about adaptation to climate change seems to occur only in very few transport departments of the federal states. The knowledge of potential impacts of climate change, as well as the degree of implementation of measures that are suitable to adapt to climate change is in general rather low. In comparison to the other surveyed climate-sensitive sectors, the transport sector exhibited the lowest rate of returns of questionnaires. This is also an indication that there is little debate about adaptation to climate change, and a low degree of adaptation in the transport sector in Germany (at least for federal bodies).

In general, the transport sector should be able to adapt to potential impacts of climate change in future. A range of effective adaptation measures is available. On the other hand, adaptation will probably be very complicated; it can hardly be based on existing knowledge or measures. At the same time, the transport sector is faced with other challenges (e.g. Toll Collect, the decree on particulate matter).

4.7.8 References

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5 Results of the Stakeholder-Workshop

In the final phase of the project, we discussed the results on potential impacts of climate change and possible adaptation strategies, which were reported in chapter 4, during a stakeholder-workshop. Besides representatives from science, policy and administration, the participants of this workshop were mainly representatives from free enterprises and associations from the studied climate-sensitive sectors forestry, water, tourism, nature conservation, health and transport. The representative of agriculture had to cancel at the last minute.

In addition to the presentation from the study reported here, two further scientists presented on the subjects "Probabilities of the Occurrence of Climatic Extreme Events in Germany" and "Decision-making, Communication and Dealing with Uncertainties". The workshop program, as well as the workshop goals are found in chapter 2.7.

5.1 Results of the Participants' Interviews Prior to the Workshop

Prior to the workshop we conducted participants' interviews via written questionnaires. We particularly assessed the expectations participants had concerning the workshop. The responses concerned two categories of expectations, (1) information and discussion, and (2) networking.

Expectations Regarding Information and Discussion

The highest proportion of expectations concerned scientific information on specific topics. Respondents expressed the need for information and discussion on the following topics: climatic development (and gaps of knowledge about this); impacts of climate change (as concrete and regionally specific as possible); probability of climate impacts; risk and vulnerability assessment; monetary/economic and ideal costs with and without adaptation; overview of the German situation and particularly impacted sectors, groups and regions; dealing with uncertainties; communication of uncertainties; help in the "translation" for policy consultancy and education; adaptation measures (present and future); overview of the expectations of different actors; work and goals of the Federal Environmental Agency concerning climate impacts; plans of the federal government and other activities in Germany.

Nearly all these topics were covered by the presentations during the workshop. Merely the demand for information on monetary/economic and ideal costs with and without adaptation could not be met. However, an approximate qualitative assessment of costs can be found in the comparison between vulnerabilities with and without further measures (see chapter 4).

Expectations Regarding Networking

Besides the need for information and discussion, respondents also voiced a demand for networking. Specifically, this included the networking between other enterprises within their sector, with other actors beyond their sector, between public and private stakeholders, between research institutions and federal states, and generally between economy, administration, policy and science.

In these networks, stakeholders hope to exchange information and seek opportunities to coordinate the implementation of adaptation measures to climate change. In this context stakeholders encouraged a coordinated push of information regarding climate impacts and adaptation in economy, administrations, policy and science.

Moreover, one participant wished to integrate between the topics climate adaptation and other challenges, primarily flood and climate protection.

The workshop was a first step to fulfil these needs for networking, which were partly already very implementation-oriented. For the Federal Environmental Agency, the workshop was the first event of a long-term dialogue on the adaptation to climate change in Germany between actors from policy, administrations, economy, and non-governmental organisations. The creation of such a network is in accordance with the plans of the Federal Environmental Agency to create a *Centre of Competence for Climate Impacts* starting in 2006, which will be an information platform for climate impacts and adaptation in Germany. In this context collaboration with the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung) is sought.

General Assessment of Climate Change

In the pre-interviews, respondents were also asked for their general assessment of climate change, in addition to their expectations. This question was also asked in the Regional Experts' Surveys, and those results are discussed in chapter 4.

The exact question was: If you look at climate change as a whole, what do you think of the climate change impacts on your professional sector? The average rating for the sectors for which we got responses was negative, with increasing negativity over time (see Tab. 5-1).

Tab. 5-1: General assessment of climate change by workshop participants. The mean response values of the following qualitative rating scale are shown: -3 (very negative), -2 (negative), -1 (slightly negative), 0 (neither positive nor negative), +1 (slightly positive), +2 (positive), +3 (very positive).

	Biodiversity	Forestry	Water	Health	State Representatives
in recent past	-0.3	-1	-0.4	-1	-0.5
in the short-term	-0.3	-2	-0.8	-1	-1
in the medium-term	-1	-2	-1.6		-1.33
in the long-term	-1.3		-2.33		-2.25

Current Importance of the Adaptation to Climate Change

Furthermore, we enquired about the current importance of climate change adaptation in the organisations and administrations of the workshop participants. The exact question was: What level of importance does the adaptation to climate change currently have in your organisation or administration – also with regard to other problems and challenges with which your organisation or administration is currently dealing?

This question had also been posed in the Regional Experts' Surveys (see chapter 4). Relative to their responses, the level of importance of the topic climate change adaptation was high in the organisations and administrations of the workshop participants (see Fig. 5-1).

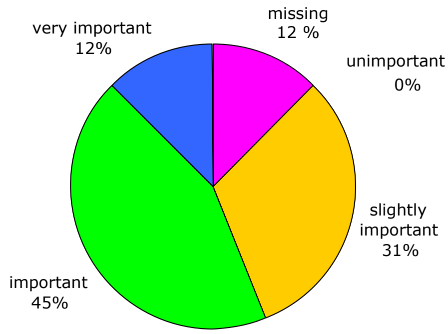

Fig. 5-1: Current importance of adaptation to climate change in the organisations of the workshop participants. Qualitative scale of replies: unimportant – slightly important – important – very important.

5.2 Results of the Workshop

Even if the pre-interviews with workshop participants indicated a high level of importance of climate change adaptation in their organisations and administrations, this did not mean that they relied on a high level of knowledge about climate change and its impacts in Germany. The strong desire to receive information, which was already apparent in the pre-interview responses, prevailed also during the workshop. This apparent need of decision-makers for information and support with regard to impacts of climate change in Germany may be seen as the main result of the workshop.

Trust in the Scientific Results on Climate Change

To explain climate change and its impacts, two presentations were given during the workshop. Prof. Schönwiese (Meteorological Institute of Frankfurt University) based his talk "Probabilities of the Occurrence of Extreme Events in Germany" on statistical analyses of climate and weather events *in the past*, and stressed that there always has been climate change. However, since approximately the middle of the last century, new positive trends in temperature establish, which have become stronger particularly in the recent decades. The development of this trend is mainly anthropogenic. Dr. Zebisch (Potsdam Institute of Climate Impact Research), co-author of this study, then gave a presentation on "Potential Impacts of Climate Change on Agriculture, Forestry, Water Management, Nature Conservation, Tourism, Transport and Health in Germany". This was based mainly on computer models of global change, which simulate climate change and its impacts in the future on the basis of scientific assumptions (see also chapter 2). The results presented in both talks have been integrated into chapters 3 and 4 of this report.

In the afternoon's discussions, these two presentations and their relevance for decision-makers were debated. The question was, whether decision-makers orient themselves rather on future scenarios and projections, or on time series and trends of the past. Some participants claimed the latter. In contrast, other participants reported to base their planning on climate scenarios of the future.

The discussion showed the significance of trust in scientific results. Some decision-makers voiced scepticism particularly with regard to climate models of the future, which, in contrast to trends of the past, they cannot compare with their own personal experience. The importance of trust in the results of climate models and the possibility to establish this trust are therefore subject of chapter 6.2.2. However, trust building does not include the concealment of existing uncertainties in future scenarios, as the flowing section shows.

Uncertainty

The assessment of future climate change and its potential impacts comes naturally with a certain uncertainty. Even with further improvement of scientific methods, results will always remain somewhat uncertain. The amount of greenhouse gases in the atmosphere is only predictable to a certain extent, as is the reaction of the climate system to these greenhouse gases.

The uncertainty of risk information often leads to obstacles in risk prevention. Therefore we explicitly addressed the constructive management of uncertainty and unspecific hazard potentials within the stakeholder-workshop with a presentation given by Prof. Gigerenzer (Max Planck Institute for Human Development, Berlin) on "Decision-making, Communication and Dealing with Uncertainties".

It is often assumed that the communication of uncertainty inherent in scientific results would impair their credibility. Using the Bank of England as an example, of Prof. Gigerenzer showed that the opposite is true. The Bank of England is known for transparent communication of uncertainties in its projections of the development of economy and currencies, at the same time it is the organisation enjoying the highest credibility in England. In the end, avoiding communication of uncertainty in projections results in loss of credibility of the communicating institutions, when the projections are wrong (see also chapter 6.2.2).

Following Prof. Gigerenzer's talk, a discussion about the model of the "informed citizen" sprang up. This model is currently used particularly on European level. A change in mentality is needed to transform the old ideal of the "protecting administration" to the model of "informed citizens". To make educated decision-making possible, citizens need many sources of information. Here, the adequate communication of risk will play an important role. According to Prof. Gigerenzer, the goal of this development should not only be the "informed" but also "serene citizen", who knows not only about the existing risks but also how to deal with them serenely.

Dealing with uncertainty takes not only a serene attitude, but also concrete decisions. How one can systematically deal with uncertainty of climate change in the decision-making process is illustrated by the decision support system introduced in chapter 6.2.4 (see also chapter 6.2.3).

Adaptation

Adaptation measures to respond to the impacts of climate change were the subject of the presentation "Adaptation Measures in Germany – Exploiting Opportunities and Mitigating Risks" given by Mr. Grothmann (Potsdam Institute for Climate Impact Research, PIK), co-author of this study. Primarily, results from an experts' survey with representatives of the functional departments of federal states for the sectors agriculture, forestry, water, nature conservation, tourism, transport, and health were presented. These representatives were asked about the effectiveness, the degree of implementation, the obstacles and the complexity of measures that are generally suitable to adapt to climate change (e.g. conversion to mixed forests in forestry), even if they had been implemented for other reasons (see also chapter 2.6). This survey was conducted to get an impression of the current state of adaptation in Germany and the vulnerability to future impacts of climate change without further adaptation measures (see chapter 2.8). The main result of this survey is that measures, which are generally suitable to adapt to climate change (e.g. flood protection measures), are already partially implemented in many sectors but still need to be adjusted accordingly. So far, none of the studies sectors seems to be fully adapted to climate change. Mr. Grothmann concluded that all sectors had the adaptive capacity to adapt to climate change in future, since they can often rely on existing measures and the obstacles for of adaptation to climate change rarely seem insurmountable.

The subsequent discussion revealed that the presentation of measures that are generally suitable to adapt to, but have not been motivated by climate change is mistakable. The rating of such measures as partially implemented was in particular misunderstood by participants and evoked the impression of the conclusion that there was hardly any need for further action to adapt to climate change. Furthermore, the reliability of the responses was doubted. Particularly the current degree of implementation of measures was believed to be easily overestimated. Therefore, when presenting these results in this report (particularly chapter 4) we strongly emphasize that the survey results are only a preliminary assessments, and that measures that are generally suitable to adapt to climate change are not yet fully implemented in most sectors, and also not yet adjusted to the particularities of climate change. Therefore, we conclude that none of the studied sectors is yet adapted to climate change.

One participant remarked, that there is a need to distinguish a general strategy for climate change adaptation from specific adaptation measures, whose implementation is justified also by motives besides climate change. This remark was related to the false impression, that the conclusion from the experts' survey was that there is hardly any further need for action in the adaptation to climate change. We have indeed enquired about the existence of specific strategies and programmes within the survey. The sobering outcome of this is presented in chapter 4.

Participants encouraged the inclusion of experts from outside federal administrations (e.g. from economy and environmental organisations), and the use of telephone interviews rather than written questionnaires to obtain more reliable experts' assessments in the future. Both were not possible in the presented survey, owing to financial restrictions.

Further Networking

It seems desirable to expand the network of actors that was initiated through this stakeholder-workshop, just as the inclusion of further experts in the surveys would be useful. Asked about institutions and organisations that should be invited as actors in the context of climate change adaptation, participants listed the following: further federal ministries besides the Federal Environmental Agency (e.g. German Federal Ministry of Education and Research, German Federal Ministry of Economic Affairs and Employment), the German committee of hazard prevention, national advisory bodies (German Advisory Council on Global Change (WBGU), the Sustainability Council etc.), The Association of German Cities and Towns, and trade associations. For the nature conservation sector, participants named the Working Group of the Federal States on Nature and Landscape Conservation and Recreation (LANA), for agriculture the National Farmers' Union, for forestry the German Forestry Council, for the water sector National/Federal Working Group on Water (LAWA), for transport the German Transport Forum, and for the health sector the Action Programme Environment and Health. Furthermore, the inclusion of the financial sector (banks and re-insurance companies) was demanded. From science, participants encouraged the inclusion of economic research institutions and climate researchers. Finally, networking with activities in other nations (e.g. within the EU) was suggested.

Expectations of Further Support

As apparent in the pre-interviews and the during the workshop, decision-makers had a high demand for information and support regarding the question which impacts of climate change threaten Germany and which adaptation measures are available.

Representatives from federal states voiced the need for a consistent database within Germany and standardised climate scenarios. Besides this, the information demands from the different sectors varied partly, but were often similar:

- Water sector: homogenisation of adaptation research; report of the state of affairs.
- Agriculture: regional climate scenarios; sustainable adaptation strategies.
- Forestry: future potential natural vegetation; research on ecological stability; sensitivity of different forest communities; possibilities of support for adaptation measures.

- Nature conservation: regional climate scenarios; information about other sectors.
- Health: systematic monitoring of the expansion of disease vectors.
- Tourism: sustainable adaptation strategies.
- Transport: Information on weather extremes (extreme rainfall events, storm risk); development of grass fire risk / grass fire index.

Centre of Competence for Climate Impacts at the Federal Environmental Agency (UBA)

As stated before, for the Federal Environmental Agency the workshop was the first event to establish an actors' network on the adaptation to climate change in Germany. The establishment of such an actors' network is part of the intention of the Federal Environmental Agency to build a *Centre of Competence for Climate Impacts* starting in 2006. This Centre is intended to function as a central information platform for climate impacts and adaptation in Germany. In this, collaboration with the Federal Ministry of Education and Research is sought.

In her presentation "Tasks and Structure of the Centre of Competence for Climate Impacts at UBA" Ms. Mahrenholz (Federal Environmental Agency, UBA, Dessau) introduced the envisioned goals, tasks and products of the Centre of Competence. In the subsequent discussion various questions enquired about the concrete orientation of the planned Centre. Ms. Mahrenholz stressed that the Centre will not conduct science, but focus on a pragmatic, demand-oriented exchange of information. Similar to the "United Kingdom Climate Impact Programme (UKCIP)" the main task is the praxis-oriented counselling and support of actors, whose sectors are potentially impacted by climate change.

The workshop participants welcomed UBA's initiative for such a Centre of Competence in the sense of a central German information and networking platform for the adaptation to climate change. Competences and tasks will need to be clearly defined, to make the division of tasks between the federation and the states transparent.

Ms. Harnisch (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, BMU, Berlin) explained that the adequate reference to the necessity of a national strategy for the adaptation to climate change is part of the agenda in the current evaluation phase of the "National Climate Protection Programme 2000".

In the Centre or Competence the dialogue between actors in adaptation is planned to play a major role. In this context, we discussed the question whether future workshops should be organised per specific sector or across sectors. One suggestion envisaged workshops with sections that address cross-sector issues and sections that are sector specific.

The next stakeholder-workshop is planned for the beginning of 2006 and coincides with the planned start of the Centre of Competence.

6 Conclusions and Recommendations

6.1 Vulnerable Regions and Sectors in Germany

The vulnerability to present and future climate change depends strongly on the initial situation, as the analysis of vulnerability of the climate-sensitive sectors (chapter 4) has shown. Often a region or sector is already under pressure today. Basic climatic or environmental conditions can pose constraints (e.g. insufficient precipitation or poor soils in agriculture and forestry). Many sectors are influenced by changes in socio-economic basic conditions (e.g. agriculture, forestry, health, tourism, transport). Such basic conditions strongly determine a region's or sector's predisposition with regard to the negative impacts of climate change and are decisive for the regional differentiation of vulnerability.

Besides its predisposition, the vulnerability of a region or a sector to climate change depends mainly on three factors (chapter 1.3.3):

- What are the characteristics of climate change and other elements of global change in the respective region?
- How large are the potential impacts of global change within the region on the specific sectors?
- What is the degree of adaptation in the specific sectors within the region to the potential impacts?

The degree of adaptation depends on the implementation of adaptation measures, which mitigate damages or capitalize on opportunities.

Vulnerability *without* further adaptation (business-as-usual scenario) results if the current degree of adaptation is maintained into the future. This kind of vulnerability is also referred to as *current vulnerability*. When assessing this vulnerability, we assume that no further adaptation measures beyond already existing ones (e.g. flood protection) are implemented. Under this assumption, future risks of damages due to global change are assessed on a qualitative scale with three categories (low – moderate – high vulnerability). In this way we convey an impression of which damages are to be expected in Germany, if no further adaptation to global change (particularly climate change) is achieved.

If we assume that present adaptive capacity will be fully used to improve the future degree of adaptation, we obtain vulnerability *with* further adaptation (improved-business scenario). As before, this vulnerability is assessed on a qualitative scale with three categories (low – moderate – high vulnerability). By comparing vulnerability *without* further adaptation (business-as-usual scenario) and vulnerability *with* further adaptation (improved-business scenario) we obtain an impression of the risks of damages due to global change (particularly climate change) with and without further measures of adaptation.

In summary of the results on vulnerability *without* further adaptation (business-as-usual scenario) on the different sectors, separated by region (environmental zones, Fig. 6-1), the highest vulnerability to climate change within the selected climate-sensitive sectors is exhibited by Southwest Germany (upper Rhine rift), the central parts of Eastern Germany (North-Eastern lowland, South-Eastern basin and hills), and the Alps (see Tab. 6-1). The lowest vulnerability is assessed for the German low mountain ranges and Northwest Germany. Among sectors, particularly the water, health and winter tourism sector are highly vulnerable.

The vulnerabilities in most regions could probably be lessened to a low level, if all available potential adaptation measures were implemented in the specific regions and environmental zones (improved-business scenario). However, in most regions adaptation measures to climate change are neither planned nor implemented. This is a strong call for action.

6.1.1 Regions

In *Eastern Germany* (North-Eastern lowland, South-Eastern basin and hills), low water availability and the risk of summer droughts account for the high current vulnerability in many sectors. The present unfavourable climatic water balance will be exacerbated by the already observed and further expected decrease in summer precipitation, as well as by increased evaporation due to increased temperatures. This will in particular impact agriculture and forestry, as well as the transport sector (navigation). Additionally, there is a "high" vulnerability without further adaptation with respect to flooding in the large river basins of the Elbe and Oder. In the Lausitz, where particularly high summer temperatures are expected, the current vulnerability in the health sector is "high", owing to strong heat stress.

In *Southwest Germany* (upper Rhine rift) especially the high temperatures will cause problems. This region, where the highest temperatures are measured today, is expected to show the strongest warming in Germany in the future. This causes "high" vulnerabilities *without* further adaptation in the health sector. Furthermore, agriculture and forestry are "highly" vulnerable to rapid warming. Moreover, the risk of flooding in the early spring increases, owing to a shift of precipitation from summer to winter, as well as an increase in extreme rainfall events.

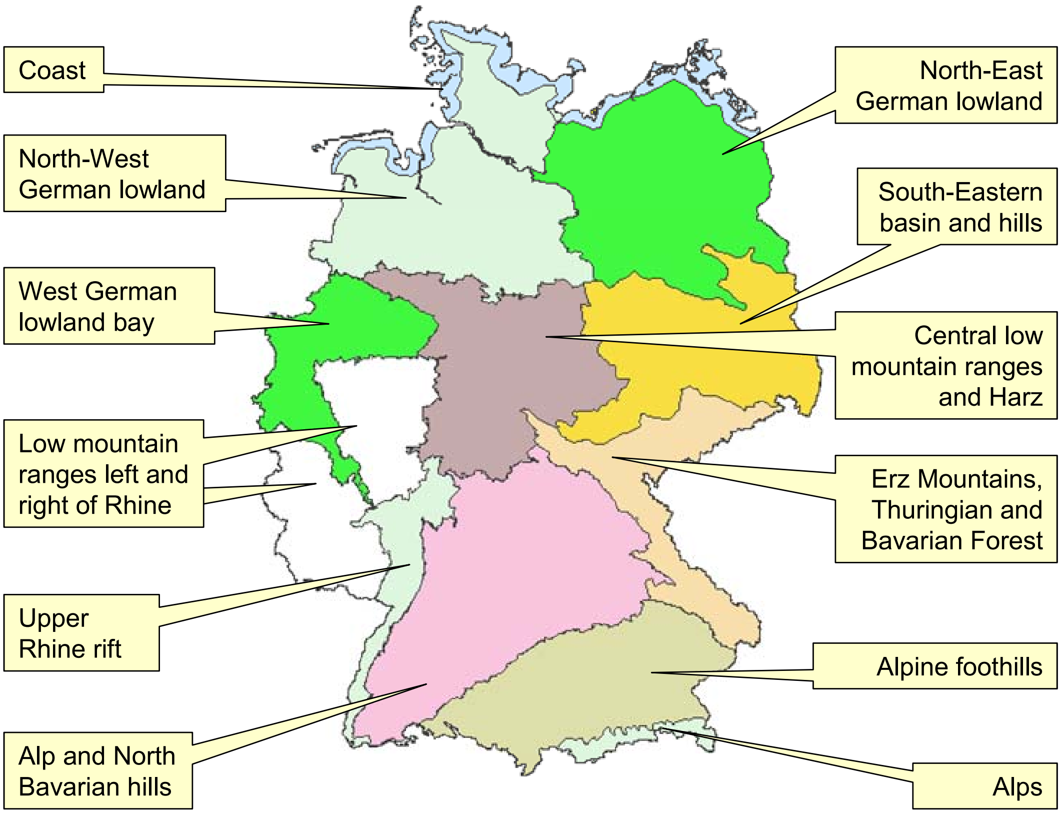

Fig. 6.1. Environmental zones in Germany (aggregated from BFN, 2005).

The sensitivity of many sectors is the main reason for the "high" vulnerability *without* further adaptation in the *Alps*, in addition to expected climate change, which is slightly above average in the Alpine region. Especially in the nature conservation sector, the Alps are very vulnerable, because they are characterised by many endemic plant and animal species, which hardly have any migratory alternatives when climate changes. Furthermore, the abundance of unique microclimatic locations and azonal biotopes increases vulnerability. In the Alps the risk of flooding is particularly high, owing to the lack of retention areas. Finally, the winter tourism sector is highly sensitive and not very adaptive to a decrease in snow safety.

In comparison, the German *low mountain ranges* currently show "medium" vulnerability. At present the climate in these regions is cool and moist, so that a change to a warmer climate can actually pose an opportunity for some sectors (e.g. agriculture). There is "high" vulnerability against flooding, especially for local high water events, caused by convective extreme rainfall events. Winter tourism, if present, also shows "high" current vulnerability.

Similar to the low mountain ranges, the *coastal regions* exhibit only "medium" vulnerability. However, there is "high" current vulnerability caused by possibly more intensive storm surges. Moreover, the immediate coastal areas are threatened by the rising sea level. But the implementation of adaptation measures has already advanced relatively far. In other sectors coastal regions may well profit from climate change. This concerns the sectors agriculture and forestry, as well as tourism, which will profit from rising summer temperatures and decreasing summer precipitation.

The lowest current vulnerability was assessed for Northwest Germany. Climate change will probably be least pronounced in this region, because it is attenuated by oceanic effects. Due to the presently very moderate climate, most sectors exhibit a wide range of tolerance. Again, the sectors agriculture and tourism, and with some limitations also forestry, may potentially profit from climate change.

Besides the regions and environmental zones portrayed in Tab. 6-1, *wetlands* and *congested urban areas* show "high" vulnerability without further adaptation. In wetlands, especially the sectors water and nature conservation are highly vulnerable. In congested urban areas, especially the sectors health (heat stress) and transport will be affected.

The vulnerabilities in most regions could probably be lessened to a low level, if all available potential adaptation measures were implemented in the specific regions and environmental zones (improved-business scenario). However, in most regions adaptation measures to climate change are neither planned nor implemented. In the Alpine region, vulnerability can probably only be reduced to a medium level, since the adaptive capacity to the potential impacts of climate change on winter tourism, biodiversity and flood risk is limited.

6.1.2 Sectors

In all parts of Germany current vulnerability is "high" in the *water* sector, due to increasing flood risk and high potential for damage. Further regional differentiation of the expected impacts is currently not possible due to the uncertainties related to the modelling of regional precipitation patterns. In addition, the risk of droughts is increasing, particularly in Eastern Germany. Currently, few adequate adaptation measures to this stress are locally available. This results in locally "high" current vulnerability. However, for the entire country there appears to be only moderate current vulnerability to droughts in Germany.

Tab. 6-1. Summary of vulnerability to global change (particularly climate change) in Germany *without* further adaptation (business-as-usual scenario). Vulnerabilities in almost all sectors and regions could probably be reduced to a low level, if all potential measures of adaptation in the specific sectors and regions were implemented (improved-business scenario).

Sector / Environmental zone	Water		Agri-cul-ture	Forest-ry	Nature conserva-tion	Health		Tourism		Trans-port	All sectors
	Flood	Drought				Heat stress	Vector-borne diseases	Winter tourism	Other forms of tourism		
Coastal zone	– –[1]	~	~	~	–/– –?[2]	~	–?	n.d.	–	–	–
North-West German lowland	– –	~	~	~	–/– –?[2]	~	–?	n.d.	–	–	–
North-East German lowland	– –	– –	– –	– –	–/– –?[2]	–	–?	n.d.	–	–	– –
West German lowland bay	– –	–	–	–	–/– –?[2]	– –	– –?	n.d.	–	–	–
Central low moun-tain ranges and Harz	– –	–	~	–	–/– –?[2]	–	–?	– –	–	–	–
South-Eastern basin and hills	– –	– –	– –	– –	–/– –?[2]	– –	– –?	n.d.	–	–	– –
Erz Mountains, Thuringian and Bavarian Forest	– –	–	–	–	–/– –?[2]	–	– –?	– –	–	–	–
Low mountain ranges left and right of Rhine	– –	–	–	–	–/– –?[2]	–	– –?	– –	–	–	–
Upper Rhine rift	– –	–	–	– –	–/– –?[2]	– –	– –?	n.d.	–	–	– –
Alp and North-Bavarian hills	– –	–	–	–	–/– –?[2]	–	– –?	– –	–	–	–
Alpine foothills	– –	–	–	– –	–/– –?[2]	–	– –?	n.d.	–	–	–
Alps	– –	~	~	–	– –	~	–?	– –	–	–	– –
Germany	– –	–	–	–	–/– –?[2]	–	– –?	– –	–	–	–

Rating:

– – high vulnerability

– moderate vulnerability

~ low vulnerability

? High uncertainty or difficulty of evaluation

n.d. - no data

Rating „all sectors":

high vulnerability, if more than 2 sectors high

moderate vulnerability, if 1-2 sectors high

low vulnerability, if no sector high

("half" sectors count as half)

Rating "Germany": mean value

(1) Storm surges and sea level rise

(2) Vulnerability dependent on conservation goal.
- Conserving status quo: high vulnerability
- Conserving processes: moderate vulnerability

The *agricultural sector* is primarily impacted by aridity in summer. Climate change also impacts indirectly through increased risk of diseases and pest outbreaks. However, the agricultural sector can adapt to changed climate and weather condition on a short-term basis due to its large choice of crop types and varieties, as well as short rotation times. The sector has adapted frequently on the past. Therefore, the agricultural sector seems to be only "moderately" vulnerable to climate change without further adaptation specifically to climate *change*. Vulnerability is rated to be "high" merely in the drought-prone areas of Eastern Germany with poor soils.

Similarly, the *forestry sector* is impacted by aridity and increased risk of diseases and pests. In addition, there is increased risk of forest fires and extreme events. The forestry sector has limited adaptive capacity due to long rotation times and high costs. Drought-prone areas (Eastern Germany), as well as regions with a high proportion of out-of-natural-habitat spruce stands (lower regions in Western and South-Western Germany) are rated as "highly" vulnerable. In general, the forestry sector is classified as "moderately" vulnerable to climate change.

To rate vulnerability in the sector *nature conservation* is especially difficult. Definite impacts of climate change are expected (shifts in species' distribution, changes in species communities etc.), however, there is no consensus on the relevance of these impacts. The current vulnerability is rated as "moderate" to "high", depending on the conservation goal. Adaptation measures (e.g. improved connections within the conservation network) can only support natural processes (e.g. migration), but clearly cannot conserve the current community of species.

Without further adaptation, the *health sector* is rated as regionally "highly" vulnerable to impacts of heat waves, generally in Germany as "moderately" vulnerable. High uncertainty exists with regard to climate change impacts on vector-borne diseases. Nevertheless, due to the high potential risk and the current lack of adaptation the vulnerability to vector-borne diseases seems to be "high".

In the *tourism sector*, winter sports particularly are classified as "highly" vulnerable. Decreasing snow safety must be expected, for which no adequate long-term adaptation measures are available. Other forms of tourism are "moderately" vulnerable. Leisure-oriented summer tourism will probably profit from climate change. To date, there has been little debate on vulnerability to climate change in the German tourism sector.

The *transport sector* is primarily at risk due to a potential rise in the frequency of extreme events (storms and extreme rainfall events), as well as due to extreme heat in summer. This impacts both the flow of traffic and the infrastructure. In winter, the transport sector is likely to profit from climate change (less frost days). In general, the vulnerability of the transport sector is rated as "moderate". Navigation is likely to be the area of highest impact, due to strongly fluctuating water levels of rivers. As with tourism, to date, there has been little debate on vulnerability to climate change in the German transport sector.

The vulnerabilities in most sectors could probably be lessened to a "low" level, if all in the specific sectors available potential adaptation measures were implemented (improved-business scenario). In the nature conservation sector alone, vulnerability can probably be reduced only to a "moderate" degree due to limited adaptation options.

However, in most sectors – as well as in most German regions – adaptation measures to climate change are neither planned nor implemented. Consequently there is an urgent need for action.

6.2 Adaptation to the Impacts of Climate Change in Germany

6.2.1 Adaptation and Emission Reduction

The rate and degree of climate change, which took place during the 20th century, are unprecedented. Meanwhile, there is overwhelming consensus in the scientific community that the main cause of climate change is human activity, in particular the emission of greenhouse gases (see chapter 1). Long-term records of meteorological observations show that Germany is impacted by climate change already today (see chapter 3), and it is likely that these impact will be even stronger in future. So far, Germany is hardly prepared for such impacts (see chapter 4 and 6.1).

To reduce our vulnerability, both measures to adapt to impacts of climate change, as well as measures to reduce greenhouse gas emissions to abolish the causes of climate change have to be implemented. Adaptation measures to reduce negative impacts and to take advantage of positive impacts are necessary, because climate change is already taking place, and will continue to happen. Due to the inertia of the climate system, climate change would continue for several centuries even after a highly unlikely immediate reduction of greenhouse gases. Emission reductions are nevertheless indispensable for a long-term reduction of vulnerability. Further warming of our global climate beyond the adaptive capacity of Germany and the world can only be counteracted by emission reductions. Adaptation measures and emission reduction are therefore not alternative strategies, but have to be carried out in parallel.

6.2.2 Adaptation as a Task of Communication

In Germany, outside the scientific community climate change is so far discussed almost exclusively in the context of the need for emission reductions. Adaptation to the impacts of climate change has only recently received more attention, but is still highly under-represented in public awareness and in the consciousness of decision-makers in economy, policy and administration (see also chapters 4 and 5).

With regard to this, the first step towards a Germany that is adapted to the impacts of climate change is to raise awareness of its risks and opportunities – a task of communication.

Using the Existing Awareness of Climate Change

Although in Germany at the moment it foremost the need for emission reductions that is seen as a necessary response to climate change, the underlying awareness of the existence of climate change can be used as a basis for communication measures towards a facilitation of climate adaptation. Particularly in the international comparison, Germany is characterised by a high public awareness of climate change. This awareness is not limited to *global* climate change, but includes the conviction that there are *local* impacts of climate change in Germany, as was especially shown during the Elbe flood 2002 and the heat wave in 2003. This awareness needs to be complemented by the insight that not only emission reductions, but also adaptation to climate change is necessary. The fact that emission reductions will only become effective in the long-term, and therefore adaptation measures need to be implemented for the short- and medium-term is a very helpful argument.

It should, however, always be stressed that not an either-or strategy, but a parallel implementation of emission reduction and climate adaptation is needed. Whenever there are synergies between these two parallel strategies this needs to be emphasized, such as e.g. in the insulation of buildings, which reduces energy use and protects against heat waves.

Using Extreme Weather Events as Windows of Attention

Adaptation to a risk can be seen as a process that starts with an awareness of the risk. Often, this risk awareness cannot be brought about by communication measures that exclusively talk of potential risks in the future. Extreme events, which exemplify the risks are a crucial trigger for the development of risk awareness.

In Germany, such extreme events, which can be associated with climate change, were primarily the already mentioned Elbe flood in the summer of 2002, the heat wave in the summer of 2003, and even the fictive collapse of the North Atlantic Current in the film "The Day After Tomorrow". The media related these events strongly to climate change and the necessity of greenhouse gas emission reductions.

Furthermore, extreme events are "windows of attention" to promote adaptation measures with regard to climate change. Besides extreme weather events, there are hardly any windows of attention for climate change, owing to the current economic and social problems in Germany.

An essential prerequisite to using extreme weather events as a means of communication to promote climate adaptation is that the necessary concepts of communication are readily available and can be "pulled out of the drawer". It would take to much time to develop such concepts after an event, so that the communication measure could only be realised when the window of attention has already been closed again.

Not only be concepts for communication measures need to be readily available. Furthermore, concepts for concrete adaptation measures that can be rapidly implemented need to be prepared, since extreme weather events are often followed by an increased readiness to act in decision-makers that will look for suitable measures. In this way, windows of attention can become windows of opportunity for decisions that would not be taken in the every-day course of events, in which other problems have higher priority.

Promoting Trust Between Science and Society

However, adaptation to climate change should be more than adaptation to past events. Since climate change is proceeding further, exclusively adapting to events that have already occurred would always stay a step behind climate change and its impacts. For example, the preparation for heat waves should not only take place in such regions that were impacted by the heat wave in 2003. Scientific climate scenarios show that such heat waves can alos occur in other regions of Germany. Large damages of climate change can only be avoided if reactive planning of measures and their implementation (!) becomes proactive, and takes into account results from future scenarios.

The trust in analyses of past developments is often larger than in scenarios of the future. However, this trust can be increased when trust in the scientists that develop these scenarios is built. Personal contacts to scientists are often helpful in this. Some scientists appear frequently in the media to council on climate change. These scientists should be encouraged to demand not only the reduction of greenhouse gas emissions, but also the implementation of adaptation measures as adequate responses to climate change.

Stressing the Link Between Climate Change and Current Societal Problems

Problems besides climate change dominate the public and political debate in Germany (unemployment, demographic development, reform of the welfare state, economic growth etc.), as already mentioned when we recommended the use of extreme weather events as windows of attention for communication measures to promote climate adaptation.

Many potential impacts of climate change are directly linked to such problems. After the Elbe flood 2002 a tax reform to boost economy and employment had to be postponed for a year in order to finance governmental damage reparation payments. When temperatures are high, work productivity decreases and the mortality of elderly and infirm increases in buildings in which no cooling measures were implemented. As a consequence of the potential increase in vector-borne diseases (e.g. lyme borreliosis), sick leave and health costs increase and further stress the health care system (see chapter 4.5).

However, there are also opportunities. For example, productivity in agriculture and forestry may possibly be increased (see chapters 4.2 and 4.3). Economic growth also seems possible in the tourism sector, particularly at the coasts of the North and Baltic

Sea, when beach tourists look for alternatives to the exceedingly hot Mediterranean region (see chapter 4.6).

Raising awareness of the necessity of adaptation measures to climate change beyond weather extremes seems possible, when the links between adaptation to climate change and the problems and challenges that currently receive more societal awareness are communicated clearly.

Using Synergies Between the Adaptation to Climate Change and Other Issues

The recommendation to make use of synergies with other issues is tightly related to the previous section. This could concern issues that currently receive a lot of attention in Germany (e.g. unemployment). But there are also many issues, particularly preventive measures that currently receive less attention, but would deserve more with regard to their actual significance. Some of these issues will be exacerbated by climate change. Two examples are flood prevention (see chapter 4.1) and preventive measures against lyme borreliosis (see chapter 4.5). This issues urgently demand action, even without climate change; and climate change increases this urgency.

Conflicts regarding attention and resources between these issues should be avoided and synergies should be used. Furthermore, conflicts with institutions that mainly support the reduction of greenhouse gas emissions should be avoided, and synergies between emission reduction and climate adaptation should be emphasized (e.g. insulation of buildings, see above).

Coupling Risk Communication to Communication of Adaptation Options

The goal of communication of risks and opportunities of climate change is the promotion of adaptation measures. However, increased awareness of risks will only result in an increased intention to prevent risks and adapt when adaptation options are seen. Those who do not identify options to adapt will not be forced to act adaptively even by the strongest risk communication. Instead, there will be denial ("Nothing will happen."), fatalism ("What ever will be, will be – I cannot do anything against it."), or pushing off the responsibility to others ("The Government must take care of this.") (Grothmann & Patt, 2005).

Therefore, the communication of risks of climate change should always be coupled to the communication of concrete and possibly simple adaptation options. For example, if the goal is to promote the individual preventive behaviour of inhabitants of flood-prone areas, region-wide maps of flood risk, as were often demanded after the Elbe flood, will not suffice. Knowing of a risk and being aware of it does not necessarily mean that affected people will implement preventive measures against flood damages.

Avoiding Catastrophism

In tight relation to the previous section, the communication of climate change impacts should not evoke "catastrophism", since a risk perception that is too high will quench damage prevention and lead to problem-avoiding reactions like denial, fatalism, and the pushing off of responsibilities. In catastrophism, no adaptation options are seen. When catastrophic impacts are anticipated, the perception of lacking adaptation options is often justified. Drastic examples of possible catastrophes rather evoke feelings of fear, helplessness and excessive demands, in other cases also defence – thus they result in paralysis rather than stimulating adaptation. To promote adaptation measures, films like the disaster movie "The Day After Tomorrow", which depicts a new ice age on the Northern hemisphere as a consequence of the collapse of the North Atlantic Current, are counterproductive, but might possibly facilitate emission reductions. Also when using extreme weather events as windows of attention to promote climate adaptation – as described above – communication concepts that stress an increased intensity of extreme events without naming possible preventive measures should be avoided.

Creating Role Models

Communication of risks and adaptation options does not have to be a pure information transfer. An often much more effective form of communication uses role models. Particularly to communicate possible practical adaptation measures, role models are a very good means. Just as weather extremes can illustrate risks of climate change, role models that have successfully adapted to climate change can illustrate possible adaptation measures.

Such role models can already be found in Germany in various federal states and sectors (see chapter 4). Outside of Germany adaptation measures have proceeded even further (e.g. United Kingdom). To point out such role models in communication measures conveys not only an impression of possible adaptation measures and their necessity, but also a certain competitive pressure.

Communicating Uncertainty Openly

In this entire report we emphasize uncertainty of impacts of climate change through terms like "potential" impacts, "scenarios" or "projections" (not predictions!). In the following sections we will deal with uncertainty in detail: We discuss the sources of uncertainty and the related fact that projections of climate change impacts will always be uncertain, even if scientific methods are further refined (see 6.2.3), and we will show how justified adaptation decisions can be made despite uncertainty (see 6.2.4). In this section we will start by discussing the challenge that the uncertainty of climate change impacts poses to communication measures promoting adaptation.

Many citizens and decision-makers express a need for certain statements and clear diagnosis, including equally clear recommendations of therapy. Apparently, this expectation is particularly aimed at natural scientists, to which climate researchers belong. On the other hand, the uncertainty of the future is accepted as a matter of course in other aspects of life, and adequate precautionary measures are taken (e.g. in the form of insurances). In places, uncertainty is dealt with rather relaxedly and consciously.

The communication of uncertain impacts of climate change and the necessity of adaptation measures should appeal to this aspect of normality. The future impacts of climate change are uncertain, just like future illness. Just as people attempt to avoid getting ill by precautionary measures, precaution for the potential impacts of climate change should be taken. It should be stressed that the impacts are not entirely uncertain, but uncertain within certain ranges.

It is no alternative to avoid the communication of uncertainty; this leads to incredibility when concrete predictions are not met. The example of the Bank of England shows that a transparent handling of uncertainty can increase the credibility of an institution. The Bank of England is known for transparent communication of uncertainties in its projections of economic and currency development, and is at the same time the institution with the highest credibility in England.

6.2.3 Adaptation as Decision-Making under Uncertainty

To create awareness of potential impacts of climate change (as discussed in the previous section), can only be a first step towards a Germany adapted to climate change. The uncertainty of climate change impacts becomes a challenge, just as in communication of risks and opportunities, when concrete decisions concerning adaptation need to be made – for example the heightening of a dike because of increased flood risk.

This uncertainty adds to the large range of uncertain conditions (e.g. economic and political development) that decision-makers are usually faced with. Decision-making under uncertainty therefore is not a new challenge for most decision-makers, but rather ordinary. Nevertheless, climate change poses a particular challenge with its partially very large ranges of uncertainty, which may range from positive to negative impacts.

Unfortunately, uncertainty increases with severity of impact (see Fig. 6-2). For example, the range of possible precipitation changes, which are extremely important for the water sector, agriculture and forestry, are more uncertain than the expected temperature increases.

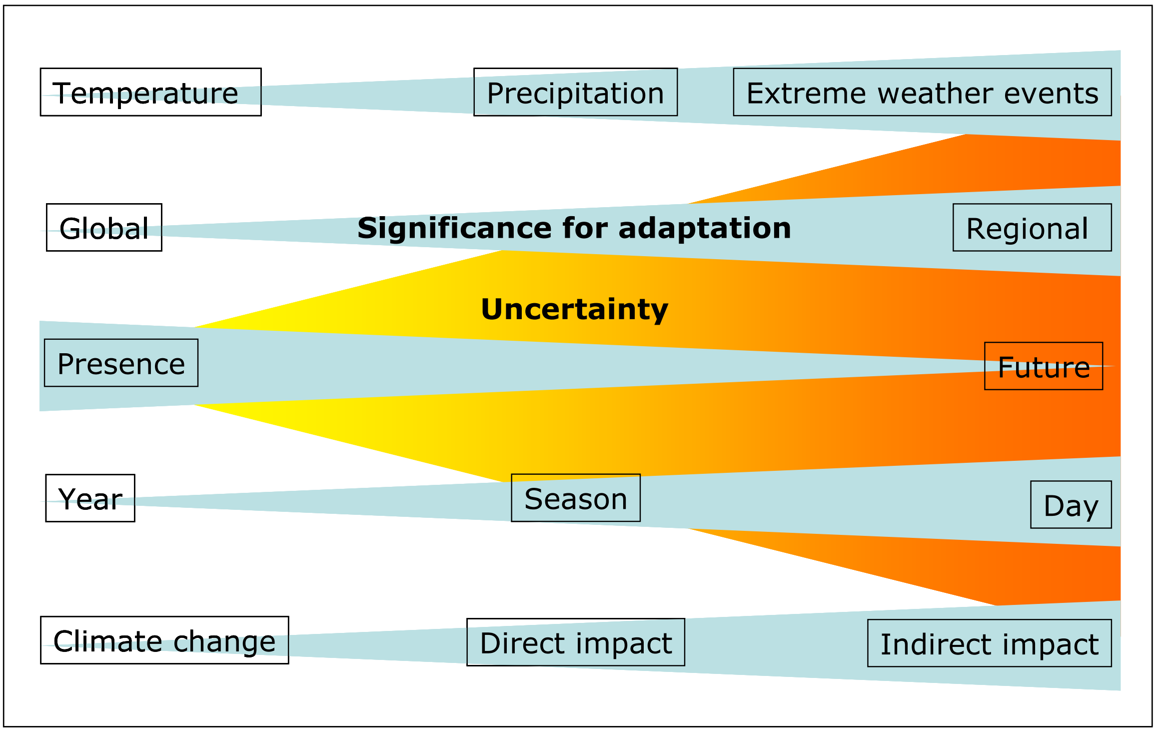

Fig. 6-2: Uncertainty increases with the severity of the impacts of climate change.

However, waiting for less uncertain results before implementing adaptation measures to climate change is an irresponsible strategy in the sense of the precautionary principle, since climate change and its impacts will not wait to occur until we understand them fully. Also, waiting for less uncertain results is a treacherous hope, since even with further refined scientific methods, future results will remain uncertain. The future greenhouse gas emissions, which are an essential cause of climate change, and the only partially known effects of these emissions on the climate system will remain sources of uncertainty. Binding long-term (!) international contacts can reduce the uncertainty caused by uncertain greenhouse gas emissions. Improved regional climate models could reduce the uncertainties in the reactions of the climate system.

With regard to the precautionary principle, it is a very dangerous strategy to agree on one emission scenario and one climate model, in order to reduce the range of uncertainty in the results on impacts of climate change – an alternative suggested by some German political actors. We lack the knowledge to do such a selection, which could lead to the masking of possible worst-case developments. Both sources of uncertainty, future greenhouse gas emission trajectories and understanding of the climate system, are explicitly addressed in this study by using various emission scenarios and different climate moclels (see chapter 2), so that ranges of results are given for each estimated indicator.

The uncertainty of impacts of climate change often becomes a crucial obstacle for adaptation measures, as became apparent in the survey with experts from functional departments of federal states (see chapter 4), in the "Expert Talks on Climate" (Klimafachgespräche), which were organised by the Federal Environment Agency (UBA), and in the Stakeholder-Workshop we conducted during this study (see chapter 5). We found that there often was a lack of knowledge about systematic and conscious strategies to make decisions under uncertainty, and that therefore the already described strategies of waiting for less uncertain studies or automatic psychological mechanisms (wishful thinking, denial of the risks, "the truth lies somewhere in between", etc.) came into play.

There seems to be a need for support on how to reach well-founded adaptation decisions despite existing uncertainty. This need is met in the following section. Here we introduce a decision support system that was particularly developed to tackle the issue of uncertainty in climate change and describes the entire process from clarification of goals and interests, over the choice of adaptation measures, to their implementation and control.

6.2.4 Eight-Stage Decision Support System for the Adaptation to Climate Change

This study can only provide a coarse overview of the risks and opportunities of climate change and suitable adaptation measures. It offers useful, but not sufficient knowledge for adaptation decisions in specific regions of Germany or a specifically impacted enterprise.

Decisions always depend on the goals, interests and values of the decision-maker. The climate impacts, and also the adaptation measures can be judged very differently. For example, the assessment of vulnerability of the nature conservation sector in this study was especially difficult, since it depends highly on the goals of the conservation of biodiversity. Vulnerability needs to be rated as high if the conservation of present level species richness is the goal; because of climate change (especially consequent shifts in species distribution) and the lack of adaptation measures this goal cannot be reached. The rating becomes more moderate, if a change in species composition is accepted.

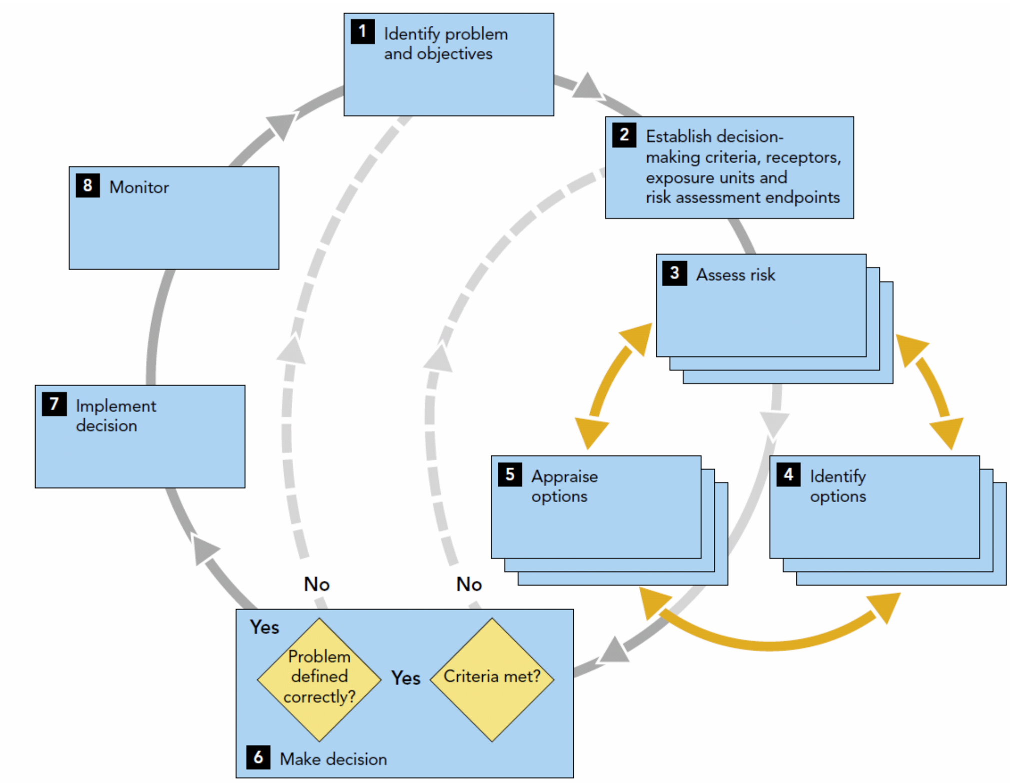

Fig 6-3: Eight-stage concept for decisions on adaptation to climate change (source: Willows & Connel, 2003, p. 7)

In the end, every decision-maker needs to go through the same process of evaluating the impacts of climate change and suitable adaptation measures in their specific field of interest and region, as exercised in this study for various climate-sensitive sectors in Germany by scientists.

A decision-maker even has to go further, since she/he has to reach decisions on adaptation, implement them and monitor their success despite the existing uncertainties of the concrete impacts of climate change.

The United Kingdom Climate Impact Programme (UKCIP) commissioned an 8-stage decision support system to structure this decision process (see Fig. 6-3), with special regard of the uncertainties of climate change impacts. In the following we give an overview of this 8-stage concept, linking it to the methods and results of this study to illustrate the opportunities of integrating our results into the decision-making process. A detailed description with concrete guiding questions, methods and techniques can be found in Willows and Connel (2003).

General Features of the Decision Concept

The decision concept is a *flexible* approach to make decisions about the adaptation to uncertain impacts of climate change, and is suitable for decisions made in administrations, enterprises, as well as non-governmental organisations and private households:

- It is *circular*. The performance of adaptation decisions is reviewed and revisited through time in light of new insights, and new adaptation decisions are taken if necessary.
- It is *iterative*: The decision support system contains feedback loops to earlier stages in the decision-making in various places, in order to allow new insights to be taken into account, even when the decision-making process has already begun. These iterations are important to yield robust decisions in the unknown decision field of climate change adaptation.
- Specific parts of the decision (stages 3, 4 and 5) are *tiered*: Prior to detailed analyses of risks, opportunities and adaptation measures, the decision-maker can screen, evaluate and prioritise them and will proceed with the analysis only when they are important or suitable.

The decision concept stresses the importance of taking into account the interests of *stakeholders and impacted groups*. Wherever possible, these people should be actively engaged in the decision process. Besides other advantages, involving stakeholders and impacted groups decreases the danger of overlooking important impacts of climate change and obstacles for the implementation of adaptation measures. Moreover, differences in values and interests can be identified and sustainable solutions can be found and yield compromises that are supported by large groups. It has been shown in the past that impacted groups will support even disagreeable decisions when they were engaged in the decision-making process.

Stage 1: Identify Problem and Objectives

In the first stage of the decision concept the problem, the objectives of the decision and the further context of the decision are identified. The context of how a problem developed often determines also part of the decision. The need to make a decision may arise from a range of factors, including: the development of a new product or project, changes in legislation or policy, regular reviews of existing activities, pressure from interest groups, or information about the impacts of climate change.

Climate change can be the crucial trigger for the decision process. The main trigger can also be another issue, and climate change plays a subdued role.

The objectives of the decision can be conservation goals. We have already discussed the significance of conservation goals in the nature conservation sector. This difficulty also arises in other sectors, e.g. agriculture, forestry and tourism. If the goal is to conserve today’s cultural landscape with its current composition of species and varieties, the evaluation of climate change is far more negative as if the goal is to conserve or create diverse landscapes.

The interests of stakeholders and impacted groups need to be taken into account particularly when identifying the decision objectives. Whenever possible, they should be actively engaged in the decision process.

If there is uncertainty, the problem should be formulated as open as possible, so that decision options will not be lost at early stages in the decision-making process.

Stage 2: Establish Decision-Making Criteria, Receptors, Exposure Units and Risk Assessment Endpoints

The objectives of the decision identified in stage 1 (e.g. mitigation of the impacts of heat waves) are translated into operational decision-making criteria (e.g. reduction of heat wave related fatalities by 50% relative to 2003 by 2010), which are used as benchmarks for reviewing risks and adaptation measures.

Furthermore, the decision-maker – often supported by a risk-analyst who will evaluate the risks and measures in stages 3 to 5 – should decide upon the following, as a preparation of the review process:

- Exposure units (e.g. regions, enterprises) that the evaluation of risks and measures is concerned with.
- Receptors within these exposure units (e.g. a specific group of citizens, a specific sensitive species).
- Risk Assessment Endpoints (e.g. 90% certainty of reduction of heat wave related fatalities by 50% relative to 2003 by 2010)

Stage 3: Assess Risk and Opportunities

The third stage in the decision-making process identifies the risks and opportunities through climate change and other developments. In contrast to the concept of Willows and Connel (2003) we suggest to take opportunities into account, in addition to risks. To capitalize on opportunities, decisions on adaptation measures have to be made also (for example, the opportunity to host more summer tourists at the North and Baltic Sea owing to exceedingly hot temperatures at the Mediterranean Sea).

The risk and opportunity assessment has a number of levels (tiers). Prior to detailed analysis it is suggested to screen, evaluate and prioritise the risks and opportunities, and to continue with the detailed quantitative analysis only when ranked as important.

Scenarios of potential impacts of climate change as introduced in this study (see chapters 3, 4 and 6.1) are a crucial source of information to screen and evaluate risks and opportunities. The same qualitative scale that was used in the experts' survey on risk and opportunity assessment during this study (very negative – negative – slightly negative – neither positive nor negative – slightly positive – positive – very positive; see chapter 2.6) can be used for the identification of particularly important risks and opportunities, but also to reveal different evaluations within a decision committee. Examples for such assessments in various climate-sensitive sectors and environmental zones of Germany can be found in the sub-chapters of chapter 4, in the section "Impacts of Climate Change – Assessment by Regional Experts".

Stage 4: Identifying possible Adaptation Measures

In the fourth stage of the decision-making process, possible adaptation measures are identified, to mitigate the risks and capitalize on the opportunities characterized in stage 3, and to fulfil the decision criteria formulated in stage 2.

The decision-maker should particularly seek "no-regret" and "low-regret" options. With these options, uncertainty is low or inexistent. They bring advantages, independent of which of the future scenarios of climate change and other developments will occur. In many cases, such options will not be available and alternative decision rules will have to be applied.

Stage 5: Appraise Adaptation Measures

The adaptive measures identified in stage 4 are specifically evaluated in stage 5. To identify the most favourable options, the same dimensions of evaluation can be used as were applied during the experts' survey of this study on the appraisal of adaptation measures (see chapter 2.6):

- *Effectiveness* of various measures, to mitigate risks, and capitalize on opportunities of climate change and with regards to other economic, social and ecological prospects. Rule: "Choose the measures of broad effectiveness; since these make most sense with regard to possibly only partly known impacts of climate change."
- *Present degree of implementation* of measures. Often measures have already been implemented for other reasons that are also suitable to adapt to climate change, and need only to be adjusted to changing conditions due to climate change. Rule: "Choose measures that are already partially implemented; since the costs of implementation of such measures are often lower than of new measures."
- *Complexity and obstacles* of the implementation of the measures (financial, organisational, legislative, lacking knowledge, others obstacles). Again, stakeholder and impacted groups should be involved in this, to elicit the acceptance of the various measures, Rule: "Choose the measure of lowest complexity and facing the smallest obstacles."

Examples for the appraisal of adaptation measures in various climate-sensitive sectors and environmental zones of Germany can be found in the sub-chapters of chapter 4, in the section "4.4.7 Effectiveness, Degree of Implementation and Obstacles of Adaptation: Assessment of Regional Experts".

Especially in this fifth stage of the decision support system, the problem of uncertainty is addressed. Here, a recapturing of economic decision theory is necessary. It differentiates two types of decisions under uncertainty:

1. *Decisions taken under precise uncertainty*: The probability of the potentially occurring environmental condition is known (stochastic decision model).

2. *Decisions taken under uncertainty*: The environmental condition that may occur is know, but not its probability of occurrence.

The latter types of decision need to be taken for most potential impacts of climate change. On the basis of multiple emission scenarios and climate models a range of potential impacts is simulated, but it is impossible to attach a probability to any of these scenarios. Therefore decisions on the adaptation to climate change are mostly decisions under uncertainty. For decisions under uncertainty, economic decision theory identifies rules, which allow a systematic and founded decision-making process despite uncertainty. These rules are listed in Box 6-1.

Stage 6: Making a Decision about Adaptation Measures

In stage 6 of the decision support system the decision, which adaptation measure will be implemented, in what form, and when is taken.

In some cases, stages 3 to 5 reveal that the criteria formulated in stage 2 are not sufficient or not suitable to make a decision (e.g. because unexpected risks have emerged). Then the decision criteria have to be revised, and stages 3 to 5 have to be run through again, using the revised criteria.

Sometimes it may become apparent during stages 3-5 that the problem as such was insufficiently identified, so that stage one has to be revisited and the problem has to be characterised more sufficiently.

Stage 7: Implementing the Adaptation Decision

In the seventh stage, the decision taken in stage 6 is implemented practically. Willows and Connell (2003) do not describe stages 7 and 8 in detail within their decision concept. However, many studies and recommendations on this can be found in the scientific literature on organisations and policy.

It is in general sensible to accompany the implementation of measures with communication measures, addressing the wider public. If uncertainty played an important role in the decision-making process, this should be communicated clearly, to prevent public blame in case the implemented measure fails in the sense of under- or over-adapting to climate change or other developments.

Box 6-1 – Rules for Decision-Making under Uncertainty (v. Zwehl, 1993)

MaxiMin-Rule (choice of the alternative with the maximal minimum) / pessimism-principle: Only the worst event is regarded that occurs as a consequence of the implementation of a specific adaptation measure under the possible environmental conditions is regarded. Alternative adaptation measures are compared only on the grounds of their worst outcome.

MaxiMax-Rule (choice of the alternative with the maximal maximum) / optimism-principle: Each adaptation measure is appraised only on the grounds of the outcome that is produced under the environmental conditions that is best for this alternative.

Critique: Both rules do not consider all possible outcomes of an alternative adaptation measure, but focus on the best (MaxiMax) or worst (MaxiMin) result.

Hurwicz-Rule: Allows compromises between pessimistic and optimistic decision rules, because the decision-maker can express his/her personal and subjective attitude through the so-called "parameter of optimism".

Critique: The Hurwicz-rule also does not consider all possible outcomes of an alternative adaptation measure, but appraises the alternatives using a weighted mean of their best and worst outcomes.

Laplace-Rule: All possible outcomes receive the same probability. The alternative, which then promises the best outcome is chosen.

Savage-Niehans-Rule / Minimax-Regret-Rule: The appraisal of the alternatives is not based directly on their outcomes, but on the respective degrees of regret. The alternative that minimises potential regret, which is suffered through the lack of knowledge of the true course of the world, is chosen (rule of the smallest regret).

Stage 8: Monitoring the Implementation and Effectiveness of the Measure

To evaluate if the implementation of the adaptation measure succeeds as planned and the anticipated effectiveness is achieved systematic monitoring is necessary. A process evaluation should be conducted, in order to appraise not only the effectiveness of the measure after implementation (evaluation of effectiveness), but also to reveal unexpected obstacles for implementation.

For this evaluation the dimensions already used in stage 5 can be used again:

- *Effectiveness* of the measure to mitigate risks, and capitalize on opportunities of climate change and with regards to other economic, social and ecological prospects.
- *Degree of implementation* of the measure.
- *Complexity and obstacles* of the implementation of the measures (financial, organisational, legislative, lacking knowledge, others obstacles).

If the monitoring or other information (e.g. new climate scenarios) results in the necessity of a new identification of problems and objectives, the decision-making process starts again from stage 1.

6.2.5 Adaptation as a Challenge to Society

The decision-making process described in the previous section ultimately has to be performed in all sectors, regions, and organisations in Germany that are impacted by climate change. As stressed several times, stakeholders and impacted groups should be involved in the decision-making process.

Often the adaptation to climate change will be achieved through a partitioning of responsibility between various actors. Therefore, in many cases stakeholders and impacted groups will not only be involved in the decision-making process, but also in the implementation of adaptation measures.

The adaptation to climate change needs to be understood as a task for the whole society, just as the reduction of greenhouse gas emissions. Every citizen, as well as actors from economy, policy, administration, media, environmental organisations, education and research can and should contribute to this task.

Clearly adaptation will not always be achieved in cooperation, but also in competition between actors (e.g. between different companies), and pushing off of responsibility may play a role (e.g. to the government). Particularly the pushing off of responsibility toward the government should be avoided, with regard to the financial situation of communities, federal states and the federation. Private personal responsibility and a just and efficient sharing of responsibilities between state and society should be demanded and supported.

Science and Education

Science and education play an essential role in the facilitation of adaptation to climate change, owing to the complexity of the climate issue. Scientists and teachers should possibly not only convey concrete knowledge on potential impacts of climate change in Germany, but should to a certain extent be able to name possible adaptation measures to these impacts. This applies especially when they appear in the mass media, and it cannot be expected that the audience or readers know of possible adaptation measures, so that they can develop feelings of fear or helplessness (see also section 6.2.2).

Media

Besides science and education, the media play a crucial role in conveying potential climate impacts and necessary adaptation measures. The previous focus on reduction of greenhouse gas emissions as necessary response to climate change needs to be complemented by climate adaptation. However, it should always be stressed that not an either-or strategy, but a parallel implementation of emission reduction and climate adaptation is needed. The uncertainties in impacts of climate change should be communicated, their sources explained (see 6.2.3), and it should be made clear how uncertainties could be dealt with (see 6.2.4).

Policy and Administration

Policy and administration have to create the necessary financial, legislative and organisational conditions to adapt to climate change. Moreover, policy and administration are themselves actors in adaptation measures. This report contains concrete results on effectiveness, degree of implementation, obstacles and complexity of adaptation measures in governmental institutions in the climate-sensitive sectors forestry, agriculture, water, tourism, nature conservation, health and transport (see chapter 4).

The administration also needs to facilitate adaptation measures in the private sector and households by providing information and coordination. This is of special importance regarding the financial situation in many communities, federal states and the federation. It is important to support and coordinate adaptation measures in regions and sectors through information on potential regional or sectoral impacts of climate change and possible adaptation strategies (see 6.2.2). Public-private partnerships are a useful option to finance specific projects of adaptation. In this respect, the Centre of Competence for Climate Impacts planned by the Federal Environmental Agency as a central platform for information on climate impacts and possible adaptation measures in Germany will be a very welcome resource.

Private Sector and Households

Besides the climate-sensitive sectors analysed in this study (forestry, agriculture, water management, tourism, nature conservation, health, and transport), also other sectors are impacted by climate change, e.g. the construction sector and finance (banks and insurances). The latter plays a central role in the facilitation of adaptation measures in the entire economy. Finance holds an important instrument in the granting of credits and insurances, and even today the analysis of climate and weather risks play a decisive role particularly in large investments.

Moreover, the adaptation of every single German citizen is called for, e.g. with increased precaution against tick bites (see chapter 4.5), when building a house in the precaution against heat waves (see chapter 4.5) or against increased flood risk (see chapter 4.1).

Nature Conservation and Environmental Organisations

In the past, environmental organisations have played a crucial role in raising public awareness concerning climate change. As a necessary response to climate change they have in the past primarily demanded greenhouse gas emission reductions. Often they have opposed adaptation to climate change as unsustainable strategy, since some representatives of economy and some nations propagated it as an alternative to emission reduction.

It is important to gain support of environmental organisation also for climate adaptation, since climate change proceeds and adaptation is a short- and medium-term necessity in addition to emission reductions. In addition to their previous role in raising awareness of climate change and the necessity of emission reductions, they could play a central role in communicating necessary adaptation measures, since they host considerable knowledge about the climate system.

In the nature conservation sector, which will undergo significant changes through climate change, nature conservation organisations are very important. They can play a central role in promoting the necessary societal dialogue on conservation goals in German nature conservation.

Crating Networks

The dialogue and coordination between different adaptation actors from economy, policy, administration, society, media, environmental organisations, education and research should be promoted, since adaptation to climate change is a task for the whole society.

Networking is a very suitable means to promote mutual learning and sharing of responsibilities, and was explicitly asked for by participants of the stakeholder-workshop conducted within this study (see chapter 5). Such networks should not only be build within Germany, but should get in contact with other countries, since some of these have vastly larger experiences with adaptation to climate change than Germany. Here not only the United Kingdom with their central “United Kingdom Climate Impact Programme (UKCIP)” needs to be named, but also the so-called developing countries, which have a particular head start with respect to promoting private damage prevention against weather extremes.

Germany has already begun to build an actors-network through the efforts of the Federal Environmental Agency to build a Centre of Competence for Climate Impacts, which also seeks cooperation with the Federal Ministry of Education and Research (see chapter 5). Further complementary initiatives already exist in some federal states.

Further financial and organisational support of this actors-network through governmental and increasingly private sources would be desirable, since such networks provide necessary information for vulnerability assessments, and also constitute communication platforms for coordinated adaptation measures.

6.3 References

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7 Summary & Zusammenfassung

7.1 Summary

This report is the result of a study conducted by the Potsdam Institute for Climate Impact Research (PIK), commissioned and financed by the Federal Environmental Agency, Germany (Umweltbundesamt, UBA), and carried out between March 1st, 2003 and June 30th, 2005.

Objectives

The objectives of this study were

1. to document existing knowledge on global change (and particularly climate change) in Germany and analyse its current and potential future impacts on seven climate-sensitive sectors (water management, agriculture, forestry, nature conservation, health, tourism and transport),

2. to evaluate the present degree of adaptation and the adaptive capacity of these climate-sensitive sectors to global change,

3. to draw conclusions on the vulnerability to global change of sectors and regions in Germany by considering potential global change impacts, degrees of adaptation and adaptive capacity,

4. to discuss the results of the study with decision-makers from government, administration, economy, and society, in order to develop a basis for the development of strategies of adaptation to global change in Germany.

The concepts of vulnerability and adaptive capacity

The term vulnerability refers to the risks of damage to human-environment systems. This study is concerned with the vulnerability to global change, with special attention to climate change. There are direct effects of global change on human beings (e.g., by floods or heat waves), and indirect effects through impacts of global change on climate-sensitive sectors (e.g., water management or agriculture).

Vulnerability to present and future global change is highly dependent on the initial situation. Often a region or sector is under pressure already today. Current climatic or local environmental conditions can impose restrictions (e.g., low precipitation or poor soils limit agriculture and forestry). Many sectors are affected by changes in socio-economic circumstances (e.g., agriculture, forestry, health, tourism, transport). Such circumstances determine to a large extent the predisposition of a region or sector to impacts of global change and are largely responsible for the regional differentiation of vulnerability.

In addition to this predisposition, the vulnerability of a human-environment system, a region or sector to global change depends mainly on three factors:

- What is the degree of climate change and other elements of global change in the specific region?
- What are the potential impacts of global change in the region on the different sectors?
- What is the degree of adaptation of the specific sectors within the region to these potential impacts?

The degree of adaptation is determined by the presence of adaptation measures, which can prevent damage or make use of favourable opportunities.

The assumption of an unchanged state of adaptation in the future results in a vulnerability *without* further adaptation (business-as-usual scenario). This vulnerability is also described as the *current vulnerability*. In determining this vulnerability it is assumed that in addition to the existing measures (e.g., in flood protection) no further measures will be taken in the future. The current vulnerability gives an idea of the damage that has to be expected if no further adaptation measures to global change (particularly climate change) are taken. In this study the current vulnerability is presented on a qualitative scale with three categories (small – medium – high vulnerability). A quantitative vulnerability index is deliberately avoided, since such an index would pretend a precision that does not exist – neither with regard to potential impacts of global change nor concerning the adaptation to such impacts.

The assumption of a fully used existing adaptive capacity in order to improve the future degree of adaptation results in a vulnerability *with* further adaptation (improved-business scenario). As before, the vulnerability with further adaptation is assessed on a qualitative scale with three categories (small – medium – high vulnerability). Comparison of the vulnerability *without* further adaptation (business-as-usual scenario) and the vulnerability *with* further adaptation (improved-business scenario) renders an idea of the damage from global change (particularly from climate change) with and without further adaptation.

Therefore, vulnerability of a human-environment system exists only if this system is not adapted to the potential impacts of global change. The degree of adaptation is determined by the adaptive capacity of the human-environment system. The adaptive capacity is small if the necessary resources (financial, organisational, legislative, knowledge, etc.) to implement a sufficient degree of adaptation are lacking. In this case the human-environment system will not be able to adapt to the impacts of global change.

Methods

In order to reach the objectives stated above we relied on the results of a European research project (ATEAM[29]), which was coordinated by PIK. These results are based on a set of consistent, spatially explicit scenarios of global change, a range of ecosystem models and indicators for ecosystem services, as well as a continuous dialogue with stakeholders. The bulk of scientific information on global change and its potential impacts in this report is drawn from analyses of the results of the ATEAM project. In addition to the ATEAM results, numerous studies and projects on national and regional scale were consulted.

To gain estimations of the regional and sector-specific significance of potential impacts of climate change, of the existing degree of adaptation and of suitable adaptation measures, surveys of climate-sensitive sectors (forestry, agriculture, water management, tourism, nature conservation, health, and transport) were carried out in various regions of Germany.

To assess vulnerability, the scenarios of potential impacts of global change in Germany (from the ATEAM and other projects) were integrated with results from the surveys.

The results were discussed during several “Expert Talks on Climate” (Klimafachgespräche) which were organised by the Federal Environment Agency (UBA) and during a stakeholder workshop with representatives from government, administrative bodies, the economy, and the wider public.

Global Climate Change – Historical Development

The rate and degree of climate change, which took place during the 20th century are unprecedented – for example the current temperatures on the Northern Hemisphere are probably the warmest for at least 2000 years. The 1990s were the warmest decade, and the years 1998, 2002 and 2003 were the three warmest years in the last thousand years in the Northern Hemisphere. Since 1900 the global mean temperature has risen by 0.7 ± 0.2 °C. Precipitation over the middle and high latitudes of the Northern Hemisphere increased by 0.5 to 1% per decade in the 20th century, while it decreased over the subtropical latitudes. Furthermore, climate extremes were

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[29] ATEAM – Advanced Terrestrial Ecosystem Analysis and Modelling (EU Project No. EVK2-2000-00075), www.pik-potsdam.de/ATEAM.

observed more frequently, such as for example an accumulation of temperature anomalies in the Pacific Ocean since 1970 (so called "El Niño events"). Since 1950, there has been a pronounced increase in the damage caused by natural disasters and flooding.

Only a small fraction of this climate change can be explained by natural factors such as eruptions of volcanoes, changes in solar activity or deviations in the Earth's orbit around the sun. In the scientific community there is overwhelming consensus that the main cause of climate change is human activity, in particular the emission of greenhouse gases. In a few generations we are using up fossil fuels that took hundreds of millions of years to form, in order to meet our energy demands. Burning of fossil fuels produces greenhouse gases, e.g. carbon dioxide. Greenhouse gases such as water vapour, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) reflect part of Earth's heat radiation (infrared radiation) and thereby cause a "greenhouse effect" that is warming the atmosphere and the Earth's surface.

Since the beginning of industrialisation the atmospheric concentration of the most important greenhouse gas CO_2 has risen by 34% from 280 to 375 ppm, due to burning of fossil fuels and land-use change, and has probably reached its highest level in 400'000 years. Over the same time the concentration of methane, the second most important greenhouse gas, has even risen by more than 150%. In the absence of drastic measures to reduce emissions, the atmospheric carbon dioxide concentration is expected to double even within the next few decades (to almost 600 ppm, relative to pre-industrial level).

Global Climate Change – Projections of Future Development

The European Union is committed to keeping global warming below 2ºC, relative to pre-industrial temperatures, in order to prevent "dangerous clime change" (see Article 2 of the UNFCCC). Climate sensitivity, that is the rise in temperature following a doubling of the CO_2 concentration, is assumed to lie between 1.5 and 4.5ºC globally. The probability of overshooting the 2-degree target in the long term rises rapidly under concentrations that lie much higher than today's values. To reach the 2-degree target, today's global emissions need to be lowered from 7 Gt carbon per year to 2 Gt per year. This is a formidable challenge, in view of the emissions of the United States of America and of densely populated countries such as India and China that also exhibit rapid economic growth. The projection of emission trajectories is very uncertain. In this study we use the SRES scenarios published by the IPCC. They do not consider any explicit climate policy, but nevertheless embrace a range of emissions that are possible in the light of today's climate policy strategies.

The IPCC acts on the assumption of the continued increase of all greenhouse gas concentrations to values of between 650 and 1215 ppm CO_2 equivalents. The carbon dioxide concentration alone will therefore rise to values of between 607 and 958 ppm, ranging between a doubling and a tripling of pre-industrial levels. In consequence, a continued, accelerated rise in global mean temperature by 1.4-5.8ºC is expected by the year 2100. Global average precipitation is expected to rise slightly, with a very heterogeneous distribution over space and time.

The exact prediction of extreme clime events is currently impossible. However, extreme weather and climate events, such as hot summer days, summer drought and extreme rainfall will probably or very probably occur more frequently during the 21st century. Moreover an increase in cyclone activity in the tropics is likely. A decrease in cold extremes is very likely.

Global Change in Germany – Historical Trends in Climate

Long-term weather recording shows that Germany is already affected by climate change. Regarding *temperature* development, the 1990s were observed to be the warmest decade in Germany during the 20th century, in accordance to the global observation. The annual average temperature increased by ca. 0.8 to 1ºC between 1900 and 2000. However, this warming did not occur linearly. A strong warming up to 1911 was followed by a heterogeneous period. The 1940s were exceptionally warm.

After a cooling trend up to the 1970s we now observe a continuous and rapid temperature increase that still continues today. There is strong regional variation. In the last decade (1990s), the temperature rise in southern and south-western Germany was exceptionally strong. Observations on seasonal trends in the warming depend on period in time and method. During the last twenty years a trend toward stronger temperature increase in winter than in summer has been observed. For example, the temperature increase in the winter months in Germany during the period between 1981 and 2000 was 2.3ºC, while in the summer months it was merely 0.7ºC.

Precipitation in Germany is characterised by strong regional and seasonal variations. In the long term, neither the average values nor the seasonal or regional distribution show significant trends. During the last 100 years there has been a small trend towards increased winter precipitation, but this trend is not significant. In the last 30 years, however, there was indeed a definite increase in winter precipitation. Summer precipitation in contrast showed little change.

Changes in the *duration of snow cover* are also relevant. Since 1950, a decrease by 30-40% in the duration of snow cover has been observed in altitudes below 300m in Bavaria and Baden-Württemberg. In the medium altitudes (300-800m) the decrease was 10-20%. In higher altitudes over 800m only small decreases and in places even increases were observed, due to increased winter precipitation and sufficiently low temperatures for snowfall.

There is only partial evidence for an increase in *climate extremes*, such as heat waves, extreme rainfalls and storms. *Extreme heat events*, such as heat days (T>30ºC) or heat waves (intervals of more than three days during which the maximum daily temperature lies above a certain high threshold, relative to the specific temperature standard of the weather station) exhibit a definite trend. For example, the probability of occurrence of heat days in the months of July and August has risen over the last one hundred, and especially markedly during the last twenty years at almost all weather stations in Germany. The intensity and frequency of occurrence of *extreme rainfall events* have increased especially during the last forty years of the 20th century. In general, this trend is more pronounced in the winter than in the summer. The intensity and frequency of occurrence of *squalls* have also been investigated. However, at present no statistically significant trend can be found. There is a tendency of increased probability of occurrence of extremely high daily wind speed maxima (Bft > 8) during winter (with the exception of coastal regions), and decreased occurrence of such maxima in summer (with the exception of southern Germany).

Global change in Germany – Scenarios of Future Climate Change

With regard to future *temperature* development, all ATEAM scenarios that were analysed in this study exhibit a definite warming trend for Germany. The range of warming of the long-term annual average temperatures up to the year 2080 within the seven climate scenarios considered was +1.6 to +3.8ºC. Many scenarios show a particularly strong warming in the south-west, in some cases also in the far east of Germany. The scenarios exhibit heterogeneous seasonal changes. The trend of stronger warming during winter, observed in the past, cannot be found in the future scenarios.

All climate scenarios show very small changes in annual *precipitation,* which lie mostly below 10% up to the year 2080. Stronger trends can be found in winter and summer precipitation. All seven climate scenarios show an increase in winter precipitation, while most scenarios show a decrease in summer precipitation. This is in accordance with the observed trend of a shift of precipitation into the winter half year. An especially pronounced increase in winter precipitation was projected for Southern Germany, at least in the scenarios that are based on the climate model HadCM3. In these scenarios, the decrease of summer precipitation is concentrated on Southwest Germany (Rhineland) and central parts of Eastern Germany. However, the projections of the other climate models partly produce regionally contradicting trends.

Vulnerable Regions in Germany

In summary of the results on vulnerability *without* further adaptation (business-as-usual scenario) on the different sectors, separated by region (environmental zone), the highest vulnerability to climate change within the selected climate-sensitive sectors is exhibited by Southwest Germany (upper Rhine rift), the central parts of Eastern Germany (North-Eastern lowland, South-Eastern basin and hills), and the Alps (see Tab. 7-1). The lowest vulnerability is assessed for the German low mountain ranges and Northwest Germany.

In *Eastern Germany* (North-Eastern lowland, South-Eastern basin and hills), low water availability and the risk of summer droughts account for the high current vulnerability in many sectors. The present unfavourable climatic water balance will be exacerbated by the already observed and further expected decrease in summer precipitation, as well as by increased evaporation due to increased temperatures. This will in particular impact agriculture and forestry, as well as the transport sector (navigation). Additionally, there is a high vulnerability with respect to flooding in the large river basins of the Elbe and Oder. In the Lausitz, where particularly high summer temperatures are expected, the current vulnerability in the health sector is high, owing to strong heat stress.

In *Southwest Germany* (upper Rhine rift) especially the high temperatures will cause problems. This region, where the highest temperatures are measured today, is expected to show the strongest warming in Germany in the future. This causes high vulnerability *without* further adaptation in the health sector. Furthermore, agriculture and forestry are highly vulnerable to rapid warming. Moreover, the risk of flooding in the early spring increases, owing to a shift of precipitation from summer to winter, as well as an increase in extreme rainfall events.

The sensitivity of many sectors is the main reason for the high vulnerability *without* further adaptation in the *Alps*, in addition to expected climate change, which is slightly above average in the Alpine region. Especially in the nature conservation sector, the Alps are very vulnerable, because they are characterised by many endemic plant and animal species, which hardly have any migratory alternatives when climate changes. Furthermore, the abundance of unique microclimatic locations and azonal biotopes increases vulnerability. In the Alps the risk of flooding is particularly high, owing to the lack of retention areas. Finally, the winter tourism sector is highly sensitive and not very adaptive to a decrease in snow safety.

In comparison, the German *low mountain ranges* currently show medium vulnerability. At present the climate in these regions is cool and moist, so that a change to a warmer climate can actually pose an opportunity for some sectors (e.g. agriculture). There is high vulnerability against flooding, especially for local high water events, caused by convective extreme rainfall events. Winter tourism, if present, also shows high current vulnerability.

Similar to the low mountain ranges, the *coastal regions* exhibit only medium vulnerability. However, there is high current vulnerability caused by possibly more intensive storm surges. Moreover, the immediate coastal areas are threatened by the rising sea level. But the implementation of adaptation measures has already advanced relatively far. In other sectors coastal regions may well profit from climate change. This concerns the sectors agriculture and forestry, as well as tourism, which will profit from rising summer temperatures and decreasing summer precipitation.

The lowest current vulnerability was assessed for Northwest Germany. Climate change will probably be least pronounced in this region, because it is attenuated by oceanic effects. Due to the presently very moderate climate, most sectors exhibit a wide range of tolerance. Again, the sectors agriculture and tourism, and with some limitations also forestry, may potentially profit from climate change.

Tab. 7-1: Summary of vulnerability to global change (particularly climate change) in Germany without further adaptation (business-as-usual scenario). Vulnerabilities in almost all sectors and regions could probably be reduced to a low level, if all potential measures of adaptation in the specific sectors and regions were implemented (improved-business scenario).

Sector / Environmental zone	Water		Agri-culture	Forest-ry	Nature conserva-tion	Health		Tourism		Trans-port	All sectors
	Flood	Drought				Heat stress	Vector-borne diseases	Winter tourism	Other forms of tourism		
Coastal zone	– – (1)	~	~	~	–/– –?(2)	~	–?	n.d.	–	–	–
North-West German lowland	– –	~	~	~	–/– –?(2)	~	–?	n.d.	–	–	–
North-East German lowland	– –	– –	– –	– –	–/– –?(2)	–	–?	n.d.	–	–	– –
West German lowland bay	– –	–	–	–	–/– –?(2)	– –	– –?	n.d.	–	–	–
Central low mountain ranges and Harz	– –	–	~	–	–/– –?(2)	–	–?	– –	–	–	–
South-Eastern basin and hills	– –	– –	– –	– –	–/– –?(2)	– –	– –?	n.d.	–	–	– –
Erz Mountains, Thuringian and Bavarian Forest	– –	–	–	–	–/– –?(2)	–	– –?	– –	–	–	–
Low mountain ranges left and right of Rhine	– –	–	–	–	–/– –?(2)	–	– –?	– –	–	–	–
Upper Rhine rift	– –	–	–	– –	–/– –?(2)	– –	– –?	n.d.	–	–	– –
Alp and North-Bavarian hills	– –	–	–	–	–/– –?(2)	–	– –?	– –	–	–	–
Alpine foothills	– –	–	–	– –	–/– –?(2)	–	– –?	n.d.	–	–	–
Alps	– –	~	~	–	– –	~	–?	– –	–	–	– –
Germany	– –	–	–	–	–/– –?(2)	–	– –?	– –	–	–	–

Rating:

– – high vulnerability

– moderate vulnerability

~ low vulnerability

? High uncertainty or difficulty of evaluation

n.d. - no data

Rating „all sectors“:

high vulnerability, if more than 2 sectors high

moderate vulnerability, if 1-2 sectors high

low vulnerability, if no sector high

("half" sectors count as half)

Rating "Germany": mean value

(1) Storm surges and sea level rise

(2) Vulnerability dependent on conservation goal.
- Conserving status quo: high vulnerability
- Conserving processes: moderate vulnerability

Besides these portrayed regions and environmental zones (see Tab. 7-1), *wetlands* and *congested urban areas* show high vulnerability without further adaptation. In wetlands, especially the sectors water and nature conservation are highly vulnerable. In congested urban areas, especially the sectors health (heat stress) and transport will be affected.

The vulnerabilities in most regions could probably be lessened to a low level, if all available potential adaptation measures were implemented in the specific regions and environmental zones (improved-business scenario). However, in most regions adaptation measures to climate change are neither planned nor implemented. In the Alpine region, vulnerability can probably only be reduced to a medium level, since the adaptive capacity to the potential impacts of climate change on winter tourism, biodiversity and flood risk is limited.

Vulnerable Sectors in Germany

Looking at the vulnerability of different climate-sensitive sectors, especially the sectors water, health and winter tourism appear highly vulnerable.

In all parts of Germany current vulnerability is high in the *water* sector, due to increasing flood risk and high potential for damage. Further regional differentiation of the expected impacts is currently not possible due to the uncertainties related to the modelling of regional precipitation patterns. In addition, the risk of droughts is increasing, particularly in Eastern Germany. Currently, few adequate adaptation measures to this stress are locally available. This results in locally high current vulnerability. However, for the entire country there appears to be only moderate current vulnerability to droughts in Germany.

The *agricultural sector* is primarily impacted by aridity in summer. Climate change also impacts indirectly through increased risk of diseases and pest outbreaks. However, the agricultural sector can adapt to changed climate and weather condition on a short-term basis due to its large choice of crop types and varieties, as well as short rotation times. Therefore, the agricultural sector seems to be only moderately vulnerable to climate change without further adaptation specifically to climate *change*. Vulnerability is rated to be high merely in the drought-prone areas of Eastern Germany with poor soils.

Similarly, the *forestry sector* is impacted by aridity and increased risk of diseases and pests. In addition, there is increased risk of forest fires and extreme events. The forestry sector has limited adaptive capacity due to long rotation times and high costs. Drought-prone areas (Eastern Germany), as well as regions with a high proportion of out-of-natural-habitat spruce stands (lower regions in Western and South-Western Germany) are rated as highly vulnerable. In general, the forestry sector is classified as moderately vulnerable to climate change.

To rate vulnerability in the sector *nature conservation* is especially difficult. Definite impacts of climate change are expected (shifts in species' distribution, changes in species communities etc.), however, there is no consensus on the relevance of these impacts. The current vulnerability is rated as moderate to high, depending on the conservation goal. Adaptation measures (e.g. improved connections within the conservation network) can only support natural processes (e.g. migration), but clearly cannot conserve the current community of species.

Without further adaptation, the *health sector* is rated as regionally highly vulnerable to impacts of heat waves, generally in Germany as moderately vulnerable. High uncertainty exists with regard to climate change impacts on vector-borne diseases. Nevertheless, due to the high potential risk and the current lack of adaptation the vulnerability to vector-borne diseases seems to be high.

In the *tourism sector*, winter sports particularly are classified as highly vulnerable. Decreasing snow safety must be expected, for which no adequate long-term adaptation measures are available. Other forms of tourism are moderately vulnerable. Leisure-oriented summer tourism will probably profit from climate change. To date, there has been little debate on vulnerability to climate change in the German tourism sector.

The *transport sector* is primarily at risk due to a potential rise in the frequency of extreme events (storms and extreme rainfall events), as well as due to extreme heat in summer. This impacts both the flow of traffic and the infrastructure. In winter, the transport sector is likely to profit from climate change (less frost days). In general, the vulnerability of the transport sector is rated as moderate. Navigation is likely to be the area of highest impact, due to strongly fluctuating water levels of rivers. As with tourism, to date, there has been little debate on vulnerability to climate change in the German transport sector.

The vulnerabilities in most sectors could probably be lessened to a low level, if all in the specific sectors available potential adaptation measures were implemented (improved-business scenario). In the nature conservation sector alone, vulnerability can probably be reduced only to a moderate degree due to limited adaptation options.

However, in most sectors – as well as in most German regions – adaptation measures to climate change are neither planned nor implemented. Consequently there is an urgent need for action.

Recommendations for Adaptation Strategies

In addition to specific adaptation needs in different sectors and regions we identify several general challenges for adaptation in Germany. To reduce our vulnerability to climate change both measures to adapt to impacts of climate change, as well as measures to reduce greenhouse gas emissions, which are decisively responsible for climate change, have to be implemented. Adaptation measures to reduce negative impacts and to take advantage of positive impacts are necessary, because climate change is already taking place, and will continue to happen. Due to the inertia of the climate system, climate change would continue for several centuries even after a highly unlikely immediate reduction of greenhouse gases. Emission reductions are nevertheless indispensable for a long-term reduction of vulnerability. Further warming of our global climate beyond the adaptive capacity of Germany and the world can only be counteracted by emission reductions. Adaptation measures and emission reduction are therefore not alternative strategies, but have to be carried out in parallel.

In Germany, outside the scientific community climate change is discussed so far almost exclusively in the context of the need for emission reductions. Adaptation to the impacts of climate change has only recently received more attention, but is still highly under-represented in public awareness and in the consciousness of decision-makers in economy, policy and administration. The first step to a Germany that is adapted to climate change therefore must be to create awareness of the risks and opportunities. To do so, the existing public awareness of the existence of climate change should be used, as well as extreme weather events (extreme rainfall events, heat waves etc.) that provide "windows of attention" for the climate problem. The existing link between risks and opportunities of climate change and the dominating political themes in Germany (unemployment, economic growth etc) should be stressed, in order to secure public attention to the debate beyond the context of weather extremes. When communicating the potential impacts of climate change, the inherent uncertainties of the scenarios need to be made transparent; failure to do so will result in dented credibility, when exact predictions are not met. The risks of climate change can trigger mechanisms of repression or even fatalistic reactions ("I cannot do anything anyway."). To prevent such reactions from the start, "catastrophism" – i.e. stressing potential climate impacts of catastrophic extent – should be avoided. The communication of risks should always be linked to the communication of possible adaptation measures. Role models are particularly suited to communicate adaptation measures by providing a living example.

Creating awareness of potential impacts can only be a first step to a Germany that is adapted to climate change. As when communicating risks and opportunities, the uncertainty in the assessment of potential impacts of climate change is a special challenge when concrete decisions about adaptation measures have to be made, e.g.

the raising of dykes to face increasing flood risk. With regard to the precautionary principle, it is an irresponsible strategy to wait for less uncertain assessments before implementing adaptation measures, since climate change and its impacts are already taking place. Furthermore, waiting for less uncertain scenarios is a treacherous hope; the results will remain uncertain in future even with increased refinement of scientific methods. Decision-makers often lack awareness of systematic and conscious strategies to make decisions in the face of uncertainty. Therefore support is needed. In this respect the 8-stage decision support system for decision-making about adaptation to climate change, which is introduced in this report, is a first stimulus.

Often adaptation to the impacts of climate change will only be possible if responsibilities are shared between different actors. Ultimately, climate change adaptation – just like the reduction of greenhouse gas emissions – is a task for society as a whole, to which every single citizen, as well as actors from the economy, the political sphere, administration, the media, nature conservation organisations, education and research can and should contribute. Science and education are of special importance in this, due to the complexity of the climate problem. The media will be of significant relevance in communicating potential climate impacts and necessary adaptation measures to the public. Nature conservation organisations also play a major role in this communication. Politicians and administrators must create the necessary financial, legal and organisational conditions. Administrative bodies have the additional function of informing and coordinating adaptation measures in private industry and households; this is an especially significant function in view of the current budgetary position in many communities, federal states and in the federal government. In addition to the climate-sensitive sectors that were analysed in this study (forestry, agriculture, water, tourism, nature-conservation, health and transport), further adaptation measures are necessary in other sectors (e.g., the construction sector). Finance (banks and insurances) is of central importance; it possesses decisive instruments for the regulation of adaptation through the granting of loans and insurance. Finally, every German citizen needs to adapt, e.g. through taking increased precaution against tick bites or through building structures that are adapted to higher flood risk.

Dialogue and coordination between different actors in the process of adaptation should be facilitated, since climate adaptation is a task for society as a whole. Networking is an efficient instrument for this. These networks should be organised not only within Germany, but also seek contacts outside the country: some countries have far more experience with climate change adaptation than Germany. A network of adaptation actors has already started to form through the efforts of the Federal Environment Agency (UBA) to initiate and build a "Centre of Competence for Climate Impacts", in cooperation with the Federal Ministry of Education and Research. Furthermore, such initiatives already exist in several federal states. Further organisational and financial support of such networks of actors through public and increasingly also through private sources is desirable, since such networks provide necessary information for vulnerability assessment, as well as communication platforms for coordinated adaptation measures.

7.2 Zusammenfassung

Der vorliegende Bericht ist das Ergebnis einer Studie des Potsdam-Instituts für Klimafolgenforschung (PIK), die im Auftrag des Umweltbundesamtes (UBA) im Rahmen des Umweltforschungsplanes im Zeitraum vom 1. März 2003 bis 30. Juni 2005 durchgeführt wurde.

Ziele

Die Ziele dieser Studie waren,

1. den aktuellen Kenntnisstand zum Globalen Wandel (insb. Klimawandel) in Deutschland zu dokumentieren und aktuelle und potenzielle zukünftige Auswirkungen des Globalen Wandels auf sieben klimasensitive Bereiche (Wasser-, Land-, Forstwirtschaft, Biodiversität/Naturschutz, Gesundheit, Tourismus und Verkehr) zu analysieren,
2. den momentanen Anpassungsgrad und die Anpassungskapazität der verschiedenen klimasensitiven Bereiche an den Globalen Wandel zu untersuchen,
3. aus der Gegenüberstellung von Auswirkungen des Globalen Wandels, Stand der Anpassung und Anpassungskapazität Schlussfolgerungen über die *Vulnerabilität* (Anfälligkeit) einzelner Bereiche und Regionen in Deutschland gegenüber dem Globalen Wandel zu ziehen,
4. die Ergebnisse der Studie mit Entscheidungsträgern aus Politik, Verwaltung, Wirtschaft und Gesellschaft zu diskutieren, um eine Basis für die Entwicklung von Strategien zur Anpassung an den Globalen Wandel in Deutschland zu entwickeln.

Die Konzepte Vulnerabilität und Anpassungskapazität

Der Begriff Vulnerabilität bezeichnet die Schadensrisiken von Mensch-Umwelt-Systemen. In dieser Studie geht es um die Vulnerabilität gegenüber dem Globalen Wandel, unter dem hier vor allem der Klimawandel verstanden wird. Die Einwirkungen durch den Globalen Wandel auf den Menschen geschehen direkt (wie z.B. durch Flutkatastrophen und Hitzewellen) und indirekt durch Auswirkungen des Globalen Wandels auf klimasensitive Bereiche bzw. Sektoren (z.B. Wasser- od. Landwirtschaft).

Die Vulnerabilität gegenüber dem aktuellen und zukünftigen Globalen Wandel ist stark von der Ausgangssituation abhängig. Oft steht eine Region bzw. ein Bereich schon heute unter Druck. So können aktuelle klimatische oder naturräumliche Rahmenbedingungen Beschränkungen mit sich bringen (z.B. geringe Niederschläge oder arme Böden für die Bereiche Land- und Forstwirtschaft). Viele Bereiche werden von Veränderungen in den sozioökonomischen Rahmenbedingungen beeinflusst (z.B. Land- und Forstwirtschaft, Gesundheit, Tourismus, Verkehr). Solche Rahmenbedingungen bestimmen zum großen Teil die Prädisposition einer Region bzw. eines Bereichs gegenüber Auswirkungen des Globalen Wandels und sind in hohem Maße mitverantwortlich für die regionale Differenzierung von Vulnerabilität.

Wie vulnerabel ein Mensch-Umwelt-System, eine Region bzw. ein Bereich gegenüber dem Globalen Wandel bewertet wird, hängt neben der Prädisposition im Wesentlichen von drei Faktoren ab:

- Wie ausgeprägt sind der Klimawandel und andere Elemente des Globalen Wandels in der betrachteten Region?
- Wie stark wirkt sich der Globale Wandel in der Region potenziell auf die einzelnen Bereiche aus (auch als potenzielle Auswirkungen des Globalen Wandels bezeichnet)?
- Wie hoch ist der Anpassungsgrad in den einzelnen Bereichen innerhalb der Region an die potenziellen Auswirkungen?

Dabei bestimmt sich der Anpassungsgrad aus dem Vorhandensein von

Anpassungsmaßnahmen, die Schäden mindern oder günstige Gelegenheiten nutzen.

Wird der momentane Anpassungsgrad in die Zukunft verlängert, ergibt sich eine Vulnerabilität *ohne* weitere Maßnahmen (Ohne-Maßnahmen-Szenario). Diese Vulnerabilität wird auch als *aktuelle Vulnerabilität* bezeichnet. Bei der Bestimmung dieser Vulnerabilität wird also angenommen, dass über die bereits bestehenden Maßnahmen (z.B. im Hochwasserschutz) in Zukunft keine weiteren Maßnahmen umgesetzt werden. So wird ein Eindruck davon vermittelt, welche Schäden zu erwarten sind, wenn keine weitere Anpassung an den Globalen Wandel (v.a. an den Klimawandel) erfolgt. Die aktuelle Vulnerabilität wird auf einer dreistufigen qualitativen Skala (geringe – mäßige – hohe Vulnerabilität) abgeschätzt. Ein quantitativer Vulnerabilitätsindex wird bewusst vermieden; denn dieser würde eine Genauigkeit vortäuschen, die es weder hinsichtlich der potenziellen Auswirkungen des Globalen Wandels noch hinsichtlich der Anpassung an diese Auswirkungen gibt.

Wird angenommen, dass die vorhandene Anpassungskapazität maximal genutzt wird, um den zukünftigen Anpassungsgrad zu verbessern, ergibt sich eine Vulnerabilität *mit* weiteren Maßnahmen (Mit-Maßnahmen-Szenario). Auch diese Vulnerabilität wird auf einer dreistufigen qualitativen Skala (geringe – mäßige – hohe Vulnerabilität) abgeschätzt. Durch den Vergleich der Vulnerabilität *ohne* weitere Maßnahmen (Ohne-Maßnahmen-Szenario) und der Vulnerabilität *mit* weiteren Maßnahmen (Mit-Maßnahmen-Szenario) entsteht ein Eindruck der Schäden aufgrund des Globalen Wandels (v.a. des Klimawandels) mit und ohne weitere Anpassungsmaßnahmen.

Eine Vulnerabilität eines Mensch-Umwelt-Systems ist demnach nur dann gegeben, wenn dieses System nicht an die potenziellen Auswirkungen des Globalen Wandels angepasst ist. Dieser Anpassungsgrad wird seinerseits durch die Anpassungskapazität des Mensch-Umwelt-Systems bestimmt. Die Anpassungskapazität ist gering, wenn die notwendigen Ressourcen (finanziell, organisatorisch, legislativ, wissensbezogen etc.) zur Realisierung eines ausreichenden Anpassungsgrads nicht zur Verfügung stehen. In diesem Fall wird sich das Mensch-Umwelt-System nicht an die Auswirkungen des Globalen Wandels anpassen können.

Methodische Umsetzung

Zur Erreichung der genannten Ziele standen Ergebnisse des vom PIK koordinierten europäischen Verbundprojektes ATEAM[30] zur Verfügung. Diese Ergebnisse basieren auf einem Satz konsistenter, räumlich expliziter Szenarien des Globalen Wandels, einer Reihe von Ökosystemmodellen, Indikatoren für Ökosystemfunktionen sowie einem kontinuierlichen Dialog mit Stakeholdern. Ein Großteil der naturwissenschaftlichen Informationen zum Globalen Wandel und seinen potenziellen Auswirkungen in diesem Bericht beruht auf Auswertungen von Ergebnissen dieses Projektes (für eine genauere Beschreibung der naturwissenschaftlichen Methoden siehe Kap. 2.1-2.4). Neben dem Projekt ATEAM dienten zahlreiche andere Studien und Projekte auf nationaler und regionaler Ebene als Informationsquelle (siehe Kap. 2.5).

Um Einschätzungen der regionalen und bereichsspezifischen Bedeutsamkeit von potenziellen Auswirkungen des Klimawandels des bisherigen Anpassungsgrades und geeigneter Anpassungsmaßnahmen an diese Auswirkungen zu erhalten, wurde eine Umfrage in den sieben untersuchten klimasensitiven Bereichen (Forstwirtschaft, Landwirtschaft, Wasserwirtschaft, Tourismus, Naturschutz / Biodiversität, Gesundheit und Verkehr) in verschiedenen Regionen Deutschlands durchgeführt (siehe Kap. 2.6).

Zur Einschätzung der Vulnerabilität wurden die Ergebnisse der innerhalb dieses Projektes berechneten Szenarien potenzieller Auswirkungen des Globalen Wandels in Deutschland, Befunde anderer Studien und Projekte und die Resultate der Befragungen integriert (siehe Kap. 2.8).

Die Ergebnisse wurden auf mehreren, vom UBA durchgeführten Klimafachgesprächen

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[30] ATEAM – Advanced Terrestrial Ecosystem Analysis and Modelling (EU Project No. EVK2-2000-00075), www.pik-potsdam.de/ATEAM.

und auf einem Stakeholder-Workshop mit Vertretern aus Politik, Verwaltung, Wirtschaft und Gesellschaft zur Diskussion gestellt (siehe Kap. 2.7).

Globaler Klimawandel – Historische Entwicklung

Rate und Ausmaß des Klimawandels im 20. Jahrhundert sind einzigartig – z.B. sind die derzeitigen Temperaturen auf der Nordhalbkugel wahrscheinlich die wärmsten seit mindestens 2000 Jahren. In der Nordhemisphäre waren die 1990'er Jahre die wärmste Dekade und die Jahre 1998, 2002 und 2003 die drei wärmsten Jahre in den letzten tausend Jahren. Seit 1990 stieg die globale Mitteltemperatur um 0,7 ± 0,2 °C an. Der Niederschlag über den mittleren und höheren Breiten der Nordhemisphäre nahm im 20. Jahrhundert um 0,5 bis 1% pro Dekade zu, während er über den subtropischen Breiten abnahm. Zudem wurde ein verstärktes Auftreten von Klimaextremen beobachtet, wie z.B. eine ungewöhnliche Häufung von Temperaturanomalien im pazifischen Ozean (sog. „El Niño - Ereignisse") seit 1970. Seit 1950 ist ein deutlicher Anstieg der Schäden durch Naturkatastrophen und Überschwemmungen zu verzeichnen.

Natürliche Faktoren wie Vulkanausbrüche, Veränderungen in der Sonnenaktivität oder Schwankungen der Umlaufparameter der Erde um die Sonne tragen nur einen kleinen Teil zur Erklärung dieses Klimawandels bei. In der Wissenschaft herrscht mittlerweile große Einigkeit, dass der größte Teil des Klimawandels auf menschliche Aktivitäten, insbesondere die Emission von Treibhausgasen zurückzuführen ist. Um unseren Energiebedarf zu decken, verbrauchen wir in wenigen Generationen fossile Brennstoffe, die in Hunderten von Millionen Jahren entstanden sind. Dabei entstehen Treibhausgase wie zum Beispiel Kohlendioxid. Treibhausgase wie Wasserdampf, Kohlendioxid (CO_2), Methan (CH_4) und Lachgas (N_2O) strahlen die von der Erde ausgestrahlte Wärmestrahlung zum Teil zurück und tragen durch diesen „Treibhauseffekt" zu einer Erwärmung der Atmosphäre und der Erdoberfläche bei.

Seit Beginn der Industrialisierung hat sich durch die Verbrennung fossiler Energieträger und Landnutzungsänderungen die atmosphärische Konzentration von CO_2, dem wichtigsten Treibhausgas, um 34% von 280 auf 375 ppm erhöht und damit wahrscheinlich das höchste Niveau der letzten 400'000 Jahre erreicht. Die Konzentration von Methan, dem zweitwichtigsten Treibhausgas, erhöhte sich in dieser Zeit sogar um mehr als 150%. Bereits für die nächsten Jahrzehnte wird mit einer Verdopplung der atmosphärischen Kohlendioxidkonzentration gerechnet (auf bis zu nahezu 600 ppm, verglichen mit dem vorindustriellen Niveau), wenn nicht drastische Emissionsminderungen dem entgegenwirken (siehe auch Kap. 1.2).

Globaler Klimawandel – Klimaprojektionen in die Zukunft

Das erklärte Ziel der Europäischen Union ist, die globale Klimaerwärmung unter 2ºC relativ zu vorindustriellen Werten zu halten, um „gefährlichen Klimawandel" zu verhindern (siehe Artikel 2 der UNFCCC). Die Klimasensitivität, d.h. der Temperaturanstieg bei verdoppelter CO_2-Konzentration, wird global zwischen 1,5 und 4,5ºC angenommen. Die Wahrscheinlichkeit, das 2-Grad-Ziel langfristig zu überschreiten, steigt mit CO_2-Konzentrationen, die viel höher als heutige Werte liegen, rapide an. Um das 2-Grad-Ziel zu erreichen, müssten die heutigen globalen Emissionen von ca. 7 Gt Kohlenstoff pro Jahr auf 2 Gt pro Jahr gesenkt werden. Das ist eine beachtliche Herausforderung angesichts der Emissionen der USA und bevölkerungsreicher Länder wie China und Indien, die zudem ein großes Wirtschaftswachstum aufweisen. Die Vorhersage von Emissionsverläufen ist äußerst unsicher. In dieser Studie benutzen wir die vom IPCC herausgegebenen SRES-Szenarien. Sie beinhalten keine aktive Klimapolitik, umspannen aber dennoch eine Bandbreite auch angesichts heutiger klimapolitischer Strategien möglicher Szenarien.

Für die Zukunft geht der IPCC von einem weiteren Anstieg der Konzentration aller Treibhausgase auf Werte zwischen 650 bis 1215 ppm CO_2-Equivalente aus. Allein die CO_2-Konzentration steigt demnach auf Werte zwischen 607 und 958 ppm, was einer Verdopplung bis Verdreifachung der Werte der vorindustriellen Zeit gleichkommt. In der Folge wird mit einem weiter beschleunigten Anstieg der globalen Mitteltemperatur um 1,4-5,8°C bis zum Jahr 2100 gerechnet. Im globalen Mittel wird eine leichte

Zunahme der Niederschläge erwartet, die sich aber zeitlich und räumlich sehr heterogen verteilt.

Die exakte Vorhersage von Klimaextremereignissen ist derzeit unmöglich. Aber extreme Wetter- und Klimaereignisse wie heiße Tage, sommerliche Dürre und Starkniederschläge werden wahrscheinlich oder sehr wahrscheinlich im 21. Jahrhundert zunehmen. Auch eine Zunahme der Zyklonenaktivität in den Tropen ist wahrscheinlich. Kälteextreme werden sehr wahrscheinlich abnehmen (siehe auch Kap. 1.2).

Globaler Wandel in Deutschland – Historische Trends im Klima

Langjährige Reihen der Wetteraufzeichnung zeigen, dass Deutschland bereits vom Klimawandel betroffen ist. Hinsichtlich der *Temperaturentwicklung* zeigt sich, dass in Deutschland wie im weltweiten Durchschnitt die 1990er Jahre das wärmste Jahrzehnt im 20. Jahrhundert waren. Die Jahresmitteltemperatur hat von 1900-2000 um ca. 0,8 - 1°C zugenommen. Allerdings verlief die Erwärmung nicht linear. Einer starken Erwärmung bis 1911 folgte eine wechselhafte Periode. Die 1940er Jahre waren außergewöhnlich warm. Nach einer erneuten Abkühlung ist seit Ende der 1970er Jahre ein kontinuierlicher und rapider Anstieg zu beobachten, der bis heute anhält. Regional variiert das Bild sehr stark. In der letzten Dekade (1990'er Jahre) war der Anstieg in Süd- und Südwestdeutschland überdurchschnittlich. Aussagen zu der saisonalen Ausprägung des Temperaturanstiegs schwanken je nach Zeitraum und Methode. In den letzten 20 Jahren ist ein Trend zu einer stärkeren Erwärmung im Winter als im Sommer zu beobachten. So betrug in Deutschland die Erwärmung in der Periode von 1981 – 2000 in den Wintermonaten 2,3°C, in den Sommermonaten nur 0,7°C.

Die *Niederschläge* in Deutschland sind räumlich und saisonal von starken Schwankungen geprägt. Langfristig lassen sich weder in den Mittelwerten noch in der saisonalen oder regionalen Verteilung signifikante Trends ermitteln. In den letzten 100 Jahren findet sich zwar ein leichter Trend zu mehr Niederschlag im Winter, aber auch dieser ist nicht signifikant. In den letzten 30 Jahren ist allerdings eine deutliche Zunahme der Winterniederschläge zu verzeichnen. Die Sommerniederschläge änderten sich hingegen nur wenig.

Von Bedeutung sind auch Veränderungen in der *Schneedeckendauer*. Für Bayern und Baden-Württemberg wurden in Lagen unter 300m Abnahmen von 30-40% seit 1950 beobachtet. In mittleren Lagen (300-800m) beträgt die Abnahme 10-20%. In höheren Lagen über 800m sind aufgrund vermehrter Niederschläge im Winter und für Schneefall ausreichend niedriger Temperaturen nur geringe Abnahmen, teilweise sogar Zunahmen zu verzeichnen.

Eine Zunahme von *Klimaextremen*, wie Hitzewellen, Starkniederschlägen oder Stürmen lässt sich nur teilweise belegen. Für *Hitzeextreme* wie Hitzetage (T>30°C) oder Hitzewellen (Zeitintervalle von mehr als 3 Tagen, in denen die Tagesmaxima über einer, bezogen auf das stationsabhängige Temperaturniveau hohen oberen Schwelle liegen) ist ein deutlicher Trend zu beobachten. So hat sich z.B. die Wahrscheinlichkeit des Eintretens von Hitzetagen in den Monaten Juli und August an fast allen Stationen in Deutschland in den letzen hundert und besonders deutlich in den letzten zwanzig Jahren erhöht. *Starkniederschläge* haben insbesondere in den letzten 40 Jahren des 20. Jahrhunderts an Häufigkeit und Intensität zugenommen. Insgesamt ist dieser Trend für das Winterhalbjahr deutlicher als für das Sommerhalbjahr. Auch zur Häufigkeit und Intensität von *Sturmböen* liegen Untersuchungen vor. Hier lässt sich bis heute allerdings kein statistisch gesicherter Trend herauslesen. Tendenziell hat die Wahrscheinlichkeit extrem hoher täglicher Maxima (Bft > 8) im Winter überwiegend zugenommen (Ausnahme Küstenbereich) und im Sommer überwiegend abgenommen (Ausnahme Süddeutschland) (siehe auch Kap. 3.1.1).

Globaler Wandel in Deutschland – Szenarien zum zukünftigen Klimawandel

Bezogen auf die zukünftige *Temperaturentwicklung* ist in allen innerhalb dieser Studie verwendeten ATEAM-Szenarien eine deutliche Erwärmung Deutschlands zu erkennen. Die Spanne der Erwärmung der langjährigen Jahresmitteltemperaturen der berücksichtigten sieben Klimaszenarien bis zum Jahr 2080 reicht von +1,6 bis +3,8°C. Räumlich zeigen viele Szenarien eine besonders starke Erwärmung im Südwesten, z.T. auch im äußersten Osten Deutschlands. Saisonal ergibt sich in den verschiedenen Szenarien ein uneinheitliches Bild. Der Trend zur stärkeren Erwärmung im Winter, der in der Vergangenheit beobachtet wurde, wird in den Zukunftsszenarien nicht wiedergegeben.

Für den Jahres*niederschlag* zeigen alle Klimaszenarien nur sehr geringe Veränderungen, die bis 2080 im Wesentlichen unter 10% liegen. Stärkere Veränderungen zeigen sich bei Sommer- und Winterniederschlägen. Während in allen sieben Szenarien eine Erhöhung der Winterniederschläge zu beobachten ist, nehmen die Sommerniederschläge in den meisten Szenarien ab. Dies ist konsistent mit dem bereits zu beobachtenden Trend einer Verschiebung der Niederschläge in den Winter. Regional ergibt sich für die Winterniederschläge eine besonders deutliche Zunahme in Süddeutschland, zumindest in den auf dem Klimamodell HadCM3 aufbauenden Szenarien. Der Rückgang der Sommerniederschläge konzentriert sich in diesen Szenarien auf Südwestdeutschland (Rheinland) und die zentralen Teile Ostdeutschlands. Die Ergebnisse der anderen Modelle liefern allerdings räumlich z.T. widersprüchliche Trends (siehe auch Kap. 3.1.2).

Vulnerable Regionen in Deutschland

Fasst man die Ergebnisse zur Vulnerabilität ohne weitere Maßnahmen (Ohne-Maßnahmen-Szenario) der einzelnen Bereiche zusammen und gliedert sie nach Regionen (Naturräume), zeigt sich, dass Südwestdeutschland (Oberrheingraben), die zentralen Teile Ostdeutschlands (Nordostdeutsches Tiefland, Südostdeutsche Becken und Hügel) und die Alpen aktuell die höchste Vulnerabilität gegenüber dem Klimawandel in den ausgewählten klimasensitiven Bereichen aufweisen (Tab. 7-). Die geringste Vulnerabilität zeigen die deutschen Mittelgebirge und Nordwestdeutschland (siehe auch Kap. 6.1.1 und Kap. 4).

In *Ostdeutschland* (Nordostdeutsches Tiefland und Südostdeutsche Hügel und Becken) ist die geringe Wasserverfügbarkeit und die Gefahr von Dürren im Sommer ausschlaggebend für die „hohe" aktuelle Vulnerabilität in vielen Bereichen. Die schon aktuell ungünstige klimatische Wasserbilanz wird durch die bereits zu beobachtende und weiter zu erwartende Abnahme der Sommerniederschläge und durch eine erhöhte Verdunstung als Folge steigender Temperaturen weiter verschlechtert. Davon betroffen sind insbesondere die Land- und Forstwirtschaft, aber auch der Verkehrsbereich (Schifffahrt). Hinzu kommt eine „hohe" Vulnerabilität ohne weitere Maßnahmen gegenüber Hochwasser in den Einzugsgebieten der großen Flüsse Elbe und Oder. In der Lausitz, wo mit besonders hohen Sommertemperaturen zu rechnen ist, muss von einer „hohen" aktuellen Vulnerabilität im Bereich Gesundheit aufgrund hoher Hitzbelastung ausgegangen werden.

In *Südwestdeutschland* (Oberrheingraben) stellen vor allem die hohen Temperaturen ein Problem dar. Hier, wo schon aktuell die höchsten Temperaturen in Deutschland gemessen werden, wird in Zukunft mit der stärksten Erwärmung innerhalb Deutschlands gerechnet. Das bringt „hohe" Vulnerabilitäten ohne weitere Maßnahmen im Bereich Gesundheit mit sich. Auch Land- und Forstwirtschaft sind aktuell „hoch" vulnerabel gegenüber einer schnellen Erwärmung. Hinzu kommt eine steigende Gefahr von Hochwasser im frühen Frühjahr, ausgelöst durch eine Verschiebung der Niederschläge vom Sommer in den Winter sowie eine Zunahme von Starkregenereignissen.

In den *Alpen* stellt neben der Ausprägung des Klimawandels, welche in dieser Region leicht überdurchschnittlich ist, die Sensitivität vieler Bereiche die Hauptursache für die

„hohe" Vulnerabilität ohne weitere Maßnahmen dar. Vor allem im Bereich Biodiversität sind die Alpen sehr anfällig, da sie durch eine hohe Anzahl endemischer Tier- und Pflanzenarten geprägt sind, denen sich im Zuge des Klimawandels kaum Ausweichmöglichkeiten bieten. Auch die Vielzahl an kleinklimatischen Sonderstandorten und azonalen Biotopen erhöht die Vulnerabilität. In den Alpen ist aufgrund der geringen Retentionsflächen die Hochwassergefahr besonders hoch. Hinzu kommt die Anfälligkeit und die geringe Anpassungsfähigkeit des Bereichs Wintersport gegen einen Rückgang der Schneesicherheit.

Die deutschen *Mittelgebirge* erweisen sich im Vergleich aktuell nur als „mäßig" vulnerabel. Hier ist das Klima aktuell eher kühl und feucht, so dass eine Veränderung zu einem wärmeren Klima für manche Bereiche (z.B. Landwirtschaft) sogar eher eine Chance darstellen kann. „Hoch" ist die aktuelle Vulnerabilität im Bereich Hochwasser, speziell gegenüber lokalen Hochwasserereignissen, die von konvektiven Starkniederschlägen ausgelöst werden. Der Wintersport, sofern vorhanden, weist hier ebenso eine „hohe" aktuelle Vulnerabilität auf.

Bereich / Naturraum	Wasser: Hochwasser	Wasser: Dürre	Landwirtschaft	Forstwirtschaft	Biodiversität und Naturschutz	Gesundheit: Hitzebelastung	Gesundheit: Vektor übertragene Krankheiten	Tourismus: Wintersporttourismus	Tourismus: Sonst. Tourismusformen	Verkehr	Alle Bereiche
Küste	– –[1]	~	~	~	–/– –?[2]	~	–?	k.A.	–	–	–
Nordwestdeutsches Tiefland	– –	~	~	~	–/– –?[2]	~	–?	k.A.	–	–	–
Nordostdeutsches Tiefland	– –	– –	– –	– –	–/– –?[2]	–	–?	k.A.	–	–	– –
Westdeutsche Tieflandsbucht	– –	–	–	–	–/– –?[2]	– –	– –?	k.A.	–	–	–
Zentrale Mittelgebirge und Harz	– –	–	~	–	–/– –?[2]	–	–?	– –	–	–	–
Südostdeutsche Becken und Hügel	– –	– –	– –	– –	–/– –?[2]	– –	– –?	k.A.	–	–	– –
Erzgebirge, Thüringer und Bayerischer Wald	– –	–	–	–	–/– –?[2]	–	– –?	– –	–	–	–
Links- und rechtsrheinische Mittelgebirge	– –	–	–	–	–/– –?[2]	–	– –?	– –	–	–	–
Oberrheingraben	– –	–	–	– –	–/– –?[2]	– –	– –?	k.A.	–	–	– –
Alp und nordbayerisches Hügelland	– –	–	–	–	–/– –?[2]	–	– –?	– –	–	–	–
Alpenvorland	– –	–	–	– –	–/– –?[2]	–	– –?	k.A.	–	–	–
Alpen	– –	~	~	–	– –	~	–?	– –	–	–	– –
Deutschland gesamt	– –	–	–	–	–/– –?[2]	–	– –?	– –	–	–	–

Bewertung:

– – hohe Vulnerabilität

– mäßige Vulnerabilität

~ geringe Vulnerabilität

? Hohe Unsicherheit bzw. Schwierigkeit bei der Einschätzung

k.A. keine Angaben

Bewertung „alle Bereiche“:

hohe Vulnerabilität, wenn mehr als 2 Bereiche hoch

mäßige Vulnerabilität, wenn 1-2 Bereiche hoch

geringe Vulnerabilität, wenn kein Bereich hoch

(„halbe“ Bereiche zählen nur halb)

Bewertung „Deutschland gesamt“: Mittelwert

(1) Sturmfluten und Meeresspiegelanstieg

(2) Vulnerabilität abhängig von Schutzziel.
- Schutz des Status Quo: hohe Vulnerabilität
- Prozessschutz: mäßige Vulnerabilität

Tab. 7-2: Zusammenfassende Darstellung der Vulnerabilität gegenüber dem Globalen Wandel (insb. Klimawandel) in Deutschland ohne weitere Maßnahmen (Ohne-Maßnahmen-Szenario). Unter der Annahme, dass in den einzelnen Bereichen und Regionen alle potenziell zur Verfügung stehenden Anpassungsmaßnahmen genutzt werden, ließen sich wahrscheinlich die Vulnerabilitäten in fast allen Bereichen und

Regionen auf ein geringes Ausmaß vermindern (Mit-Maßnahmen-Szenario).

Wie die Mittelgebirge wird das *Küstengebiet* als aktuell nur „mäßig" vulnerabel eingeschätzt. Zwar besteht hier eine „hohe" aktuelle Vulnerabilität aufgrund evtl. intensiverer Sturmfluten. Zudem sind die unmittelbaren Küstenbereiche durch den steigenden Meeresspiegel bedroht. Allerdings sind hier die Anpassungsmaßnahmen bereits relativ weit vorangeschritten. In anderen Bereichen können die Küstengebiete eher vom Klimawandel profitieren. Das betrifft sowohl die Bereiche Land- und Forstwirtschaft als auch den Tourismus, der von steigenden Sommertemperaturen und abnehmenden Sommerniederschlägen profitiert.

Die geringste aktuelle Vulnerabilität wird für *Nordwestdeutschland* gesehen. Hier dämpfen die ozeanischen Einflüsse die Auswirkungen des Klimawandels ab, so dass hier vermutlich mit den geringsten Klimaveränderungen zu rechnen ist. Aufgrund des aktuell sehr gemäßigten Klimas weisen die meisten Bereiche hier einen relativ hohen Toleranzbereich auf. Auch hier werden die Bereiche Landwirtschaft und Tourismus, mit Einschränkungen auch die Forstwirtschaft, potenziell eher vom Klimawandel profitieren.

Neben diesen in Tab. 7- dargestellten Regionen bzw. Naturräumen zeigen außerdem *Feuchtgebiete und Ballungsräume* eine „hohe" Vulnerabilität ohne weitere Maßnahmen. In Feuchtgebieten sind vor allem die Bereiche Wasser und Biodiversität hoch vulnerabel. In Ballungsräumen sind die Bereiche Gesundheit (Hitzebelastung) und Verkehr besonders betroffen.

Unter der Annahme, dass in den verschiedenen Regionen bzw. Naturräumen jeweils alle potenziell zur Verfügung stehenden Anpassungsmaßnahmen genutzt werden, ließen sich wahrscheinlich die Vulnerabilitäten in fast allen Regionen auf ein „geringes" Ausmaß vermindern (Mit-Maßnahmen-Szenario). Allerdings sind in den meisten Regionen Anpassungsmaßnahmen an den Klimawandel weder in Planung noch umgesetzt. Ausschließlich im Alpenraum lässt sich die Vulnerabilität wahrscheinlich nur auf ein „mittleres" Maß reduzieren, denn für die potenziellen Auswirkungen des Klimawandels auf den Wintersport, auf die Biodiversität und die Hochwassergefahr bestehen nur begrenzte Anpassungsmöglichkeiten.

Vulnerable Bereiche in Deutschland

Wird die Vulnerabilität hinsichtlich der untersuchten sieben klimasensitiven Bereiche betrachtet, erweisen sich vor allem die Bereiche Wasser, Gesundheit und Wintersporttourismus als hoch vulnerabel (siehe auch Kap. 6.1.2 u. Kap. 4).

Im Bereich *Wasser* ist allen Teilen Deutschlands mit einer „hohen" aktuellen Vulnerabilität aufgrund steigender Hochwassergefahr und hohem Schadenspotenzial zu rechnen. Die hohe Unsicherheit bei der Modellierung der regionalen Niederschlagsverteilung lässt eine weitere regionale Differenzierung im Moment noch nicht zu. Des weiteren besteht insbesondere in Ostdeutschland eine Gefahr von Dürren. Hier stehen bisher kaum geeignete Anpassungsmaßnahmen zur Verfügung. Das führt lokal zu einer „hohen" aktuellen Vulnerabilität. Deutschlandweit ist die aktuelle Vulnerabilität gegenüber Dürren jedoch nur „mäßig".

Die *Landwirtschaft* ist vor allem von Trockenheit im Sommer betroffen. Indirekt steigt durch den Klimawandel auch die Gefahr von Schädlingsbefall und Krankheiten. Jedoch kann sich die Landwirtschaft aufgrund der umfangreichen Auswahl an Fruchtarten und Sorten und der kurzen Umtriebszeiten relativ kurzfristig an veränderte Klima- und Wetterbedingungen anpassen. Folglich ist die Vulnerabilität der Landwirtschaft gegenüber dem Klimawandel ohne weitere Anpassungsmaßnahmen, die sich spezifisch auf den Klima*wandel* beziehen, insgesamt als „mäßig" zu bezeichnen. Nur in den von Dürren bedrohten Regionen Ostdeutschlands mit ihren oft armen Böden wird die aktuelle Vulnerabilität als „hoch" eingestuft.

Auch die *Forstwirtschaft* ist von Trockenheit und der zunehmenden Gefahr von Krankheiten und Schädlingsbefall betroffen. Hinzu kommt eine erhöhte Waldbrandgefahr sowie die Gefahr durch Extremereignisse. Die

Anpassungsmöglichkeiten sind in der Forstwirtschaft aufgrund der langen Umtriebszeiten und hoher Kosten beschränkt. Als aktuell „hoch" vulnerabel werden hier von Dürre betroffene Regionen (Ostdeutschland) und Regionen mit sehr hoher Erwärmung und einem hohen Anteil nicht standortangepasster Fichtenbestände (niedere Regionen in West- und Südwestdeutschland) eingestuft. Insgesamt kann aber die Forstwirtschaft als „mäßig" vulnerabel gegenüber dem Klimawandel angesehen werden.

Besonders schwer fällt die Einschätzung der Vulnerabilität für den Bereich *Biodiversität und Naturschutz*. Hier wird zwar mit deutlichen Auswirkungen des Klimawandels gerechnet (Verschiebung der Artenareale, Veränderung von Lebensgemeinschaften etc.), allerdings herrscht noch keine Einigkeit über die Bedeutung dieser Auswirkungen. Die aktuelle Vulnerabilität wird als „mäßig" bis „hoch" bewertet, je nachdem, welches Schutzziel man betrachtet. Klar ist, dass Anpassungsmaßnahmen (z.B. Verbesserung der Vernetzung) nur die natürlichen Prozesse (z.B. die Migration) unterstützen können, nicht aber den heutigen Stand der Artenzusammensetzung konservieren können.

Im Bereich *Gesundheit* besteht ohne weitere Maßnahmen hinsichtlich der Auswirkungen von Hitzewellen regional eine „hohe", deutschlandweit eine „mäßige" Vulnerabilität. Im Bereich vektorübertragener Krankheiten herrscht noch große Unsicherheit über die Klimawirkung. Aufgrund des potenziell hohen Risikos und des aktuellen Anpassungsdefizits ist dennoch von einer „hohen" Vulnerabilität gegenüber vektorübertragenen Krankheiten auszugehen.

Im Bereich *Tourismus* ist der Wintersporttourismus aktuell als „hoch" vulnerabel einzuschätzen. Hier muss mit einer zurückgehenden Schneesicherheit gerechnet werden, für die langfristig kaum geeignete Anpassungsmaßnahmen bestehen. Für die übrigen Tourismusformen besteht eine „mäßige" Vulnerabilität. Der freizeitorientierte Sommertourismus in Deutschland wird vom Klimawandel wahrscheinlich eher profitieren. Im Tourismus hat bisher insgesamt kaum eine Auseinandersetzung mit dem Thema Klimawandel stattgefunden.

Der Bereich *Verkehr* ist vor allem durch die potenzielle Zunahme klimatischer Extremereignisse (Stürme und Starkregenereignisse) sowie von extremer Hitze im Sommer gefährdet. Betroffen ist sowohl der Verkehrsfluss als auch die Infrastruktur. Im Winter wird der Bereich Verkehr eher vom Klimawandel profitieren (weniger Frostage). Insgesamt ist die Vulnerabilität des Verkehrsbereiches als „mäßig" einzustufen. Wahrscheinlich am stärksten betroffen ist die Schifffahrt, die durch stark schwankende Pegelstände der Flüsse beeinträchtigt sein kann. Auch im Bereich Verkehr hat bisher nahezu keine Auseinandersetzung mit dem Thema Klimawandel stattgefunden.

Unter der Annahme, dass in den einzelnen Bereichen alle potenziell zur Verfügung stehenden Anpassungsmaßnahmen genutzt werden, ließen sich wahrscheinlich die Vulnerabilitäten in fast allen Bereichen auf ein „geringes" Ausmaß vermindern (Mit-Maßnahmen-Szenario). Ausschließlich im Biodiversitätsbereich lässt sich die Vulnerabilität aufgrund beschränkter Anpassungsmöglichkeiten wahrscheinlich nur auf ein „mittleres" Maß reduzieren.

In den meisten Bereichen – wie auch in den meisten Regionen Deutschlands – sind Anpassungsmaßnahmen an den Klimawandel bisher allerdings weder in Planung noch umgesetzt. Hier besteht demnach großer Handlungsbedarf.

Anpassungsempfehlungen

Neben den spezifischen Anpassungsnotwendigkeiten in den verschiedenen Bereichen und Regionen (siehe Kap. 4) ergeben sich für die Anpassung in Deutschland einige übergreifenden Herausforderungen (siehe Kap. 6.2). Um die Vulnerabilität gegenüber dem Klimawandel zu reduzieren, müssen sowohl Anpassungsmaßnahmen an die Auswirkungen des Klimawandels als auch Maßnahmen zur Minderung der Treibhausgasemissionen, die den Klimawandel entscheidend verursachen, umgesetzt werden. Anpassungsmaßnahmen zur Minderung der negativen Auswirkungen und zur

Nutzung positiver Auswirkungen sind notwendig, denn der Klimawandel findet bereits statt und wird weiter stattfinden. Selbst bei einer sehr unwahrscheinlichen sofortigen Reduzierung der den Klimawandel entscheidend bedingenden Treibhausgasemissionen würde der Klimawandel aufgrund der Trägheit des Klimasystems noch einige Jahrhunderte weiter voranschreiten. Andererseits sind zur langfristigen Minderung der Vulnerabilität Emissionsminderungen unabdingbar; denn nur so kann einer weiteren Aufheizung des Weltklimas entgegengewirkt werden, die letztlich die Anpassungsfähigkeit Deutschlands und der Welt übersteigen würde. Anpassungsmaßnahmen und Emissionsminderungen stellen also keine Alternativen dar, sondern müssen parallel durchgeführt werden.

Der Klimawandel wird in Deutschland außerhalb der Wissenschaft bisher fast ausschließlich im Sinne der Notwendigkeit zur Reduktion von Treibhausgasemissionen diskutiert. Die Anpassung an die Folgen des Klimawandels in Deutschland erhält erst seit kurzer Zeit vermehrte Aufmerksamkeit, ist jedoch im Bewusstsein der Öffentlichkeit und von Entscheidungsträgern in Wirtschaft, Politik und Verwaltung noch weit unterrepräsentiert (siehe auch Kap. 4 und 5). Vor diesem Hintergrund muss in einem ersten Schritt auf dem Weg zu einem an den Klimawandel angepassten Deutschland ein Risiko- aber auch Chancenbewusstsein geschaffen werden. Hierbei können und sollten das weithin bestehende Bewusstsein von der Existenz eines globalen Klimawandels ebenso genutzt werden wie extreme Wetterereignisse (Starkniederschläge, Hitzewellen etc.), die „Aufmerksamkeitsfenster" für die Klimaproblematik darstellen. Um die Aufmerksamkeit auch außerhalb des Wetterextrem-Kontextes zu binden, sollte der bestehende Bezug vieler Risiken und Chancen des Klimawandels zu den dominierenden Themen in Deutschland (Arbeitslosigkeit, Wirtschaftswachstum etc.) betont werden. In der Kommunikation der potenziellen Auswirkungen des Klimawandels sollten die bestehenden Unsicherheiten in den Szenarien transparent gemacht werden; ein Verzicht darauf führt langfristig zur Unglaubwürdigkeit, wenn konkrete Vorhersagen nicht eintreffen. Die Risiken des Klimawandels können zu Verdrängungsreaktionen oder sogar zu fatalistischen Reaktionen („Ich kann ja doch nichts tun.") führen. Um diese Reaktionen von vornherein zu verhindern, sollte ein „Katastrophismus" – d.h. die Betonung von potenziellen Klimafolgen katastrophalen Ausmaßes – vermieden und die Kommunikation von Risiken immer mit der Kommunikation von Anpassungsmöglichkeiten verbunden werden. Zur Kommunikation von Anpassungsmöglichkeiten sind Vorbilder, die Anpassungsmaßnahmen „vorleben", besonders geeignet.

Die Schaffung eines Bewusstseins möglicher Auswirkungen des Klimawandels kann aber nur ein erster Schritt auf dem Weg zu einem an den Klimawandel angepassten Deutschland sein. Wenn es um konkrete Anpassungsentscheidungen geht – beispielsweise die Erhöhung von Deichen aufgrund steigender Hochwassergefahr – wird die Unsicherheit der Folgen des Klimawandels, wie schon in der Kommunikation der Chancen und Risiken des Klimawandels, zu einer besonderen Herausforderung. Auf genauere Studien zu warten, bevor man Anpassungsmaßnahmen an den Klimawandel vornimmt, ist im Sinne des Vorsorgeprinzips eine unverantwortliche Strategie, denn der Klimawandel und seine Auswirkungen finden bereits statt. Zum anderen wäre das Warten auf weniger unsichere Szenarienergebnisse eine trügerische Hoffnung; denn auch bei weiterer Verfeinerung der wissenschaftlichen Methoden werden die Ergebnisse in Zukunft unsicher bleiben. Oft fehlt bei Entscheidungsträgern aber Wissen über systematische und bewusste Strategien zum Entscheiden unter Unsicherheit. Daher besteht hier Unterstützungsbedarf. Das in diesem Bericht vorgestellte 8-stufige Entscheidungsunterstützungssystem zur Anpassung an den Klimawandel (siehe Kap. 6.2.4) liefert hierzu erste Anregungen.

Oft wird die Anpassung an die Folgen des Klimawandels nur im Sinne einer Verantwortungsteilung zwischen verschiedenen Akteuren zu bewerkstelligen sein. Letztlich ist die Klimaanpassung – wie auch die Verminderung der Treibhausgasemissionen – eine gesamtgesellschaftliche Aufgabe, zu der jeder einzelne Bürger ebenso wie Akteure aus Wirtschaft, Politik, Verwaltung, Medien, Umweltverbänden, Bildung und Forschung beitragen können und sollten. Wissenschaft und Bildung kommen dabei aufgrund der Komplexität der Klimaproblematik eine entscheidende Bedeutung zu. Die Medien werden besonders für die öffentliche Vermittlung möglicher Klimafolgen und notwendiger Anpassungsmaßnahmen wichtig sein. Auch Umweltorganisationen spielen hier eine große Rolle. Durch Politik und Verwaltung müssen die notwendigen finanziellen, gesetzlichen und organisatorischen Rahmenbedingungen geschaffen werden. Der Verwaltung kommt darüber hinaus auch eine Informations- und Koordinationsfunktion für Anpassungsmaßnahmen in Privatwirtschaft und -haushalten zu, die vor dem Hintergrund der Haushaltslage in vielen Kommunen, Ländern und im Bund besondere Bedeutung erhalten. Zusätzlich zu den in dieser Studie untersuchten klimasensitiven Bereichen Forstwirtschaft, Landwirtschaft, Wasserwirtschaft, Tourismus, Naturschutz / Biodiversität, Gesundheit und Verkehr sind auch in weiteren Bereichen (z.B. im Bausektor) Anpassungsmaßnahmen notwendig. Der Finanzwirtschaft (Banken und Versicherungen) kommt eine zentrale Bedeutung zu; denn über die Kredit- und Versicherungsvergabe verfügt sie über entscheidende Steuerungsinstrumente für Vorsorgemaßnahmen. Auch die Anpassung jedes einzelnen Bürgers in Deutschland ist gefragt, z.B. bei einer gesteigerten Vorsicht vor Zeckenbissen oder im hochwasserangepassten Bauen.

Da die Anpassung an den Klimawandel eine gesamtgesellschaftliche Aufgabe ist, sollte der Dialog und die Abstimmung zwischen den verschiedenen Anpassungsakteuren gefördert werden. Die Bildung von Netzwerken ist hier ein sehr geeignetes Mittel. Dabei sollten sich diese Netzwerke nicht nur innerhalb Deutschlands organisieren, sondern Kontakte auch im Ausland aufbauen; denn dort liegen zum Teil weit umfangreichere Erfahrungen mit der Anpassung an den Klimawandel vor als in Deutschland. Der Aufbau eines solchen Akteurs-Netzwerks in Deutschland wurde im Rahmen der Bemühungen des Umweltbundesamtes, ein Kompetenzzentrum Klimafolgen einzurichten, bei dem auch eine Kooperation mit dem Bundesministerium für Bildung und Forschung angestrebt wird, bereits begonnen (siehe auch Kap. 5). Auch in einigen Bundesländern existieren bereits entsprechende Initiativen. Eine weitere organisatorische und finanzielle Unterstützung dieser Akteurs-Netzwerke durch staatliche und zunehmend auch privatwirtschaftliche Quellen wäre wünschenswert, da diese Netzwerke notwendige Informationen für Vulnerabilitätsabschätzungen liefern, aber auch Kommunikationsplattformen für abgestimmte Anpassungsmaßnahmen darstellen.