Climate Change in Germany - Vulnerability and Adaptation of Climate-Sensitive Sectors

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It is widely recognised that global changes of considerable magnitude, in particular climatic changes, are already taking place (Crutzen 2002, Walther et al. 2002, Parmesan and Yohe 2003, Root et al. 2003). Furthermore, the nature and magnitude of future potential impacts could be dramatic (IPCC 2001). Since the 1980s, policy makers and scientists alike have mainly focussed on climate change mitigation. However, it is now clear that even if we stop greenhouse gas emissions today – a highly unlikely scenario – we will still be confronted with marked changes in the climate system, owing to the time lag with which past emissions take effect (Meehl et al. 2005). Therefore, in addition to our greatest efforts to mitigate climate change by cutting greenhouse gas emissions, we need to develop adaptation strategies designed to respond to the range of impacts that may occur, in order to lessen our vulnerability to global change. In fact, a recent study has focussed on translating multiple global change scenarios into potential impacts on European sectors such as agriculture, tourism, nature conservation, forestry and others (Schröter et al. 2005). The study involved stakeholders from the public and private sectors from the very beginning in order to ensure the applicability of the results and to develop adaptation strategies. The German Federal Environmental Agency (Umweltbundesamt, UBA) was one of these stakeholders, and has commissioned an additional in-depth vulnerability study based on this European study, but covering a wider range of sectors, and involving in particular decision-makers from the Functional Departments of each German Federal State (Zebisch et al. 2005). This chapter summarises the main findings of the German study conducted by the Potsdam Institute for Climate Impact Research (PIK).

The specific 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 sectors to global change, **(3)** to draw conclusions on the vulnerability of sectors and regions by considering potential impacts, degrees of adaptation and adaptive capacity, and **(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 entire study, including comprehensive background information on methods, concepts, historical global changes, detailed descriptions of potential impacts, as well as adaptation measures and strategies is available for download in German and English at the website of the Federal Environmental Agency (Zebisch et al. 2005)1.

[1] English: www.umweltbundesamt.org/fpdf-l/2974.pdf – German: www.umweltbundesamt.org/fpdf-l/2947.pdf.

The concepts of vulnerability and adaptive capacity

The term vulnerability refers to the risks of damage to human-environment systems. In particular we were concerned with the vulnerability to climate change. There are direct effects of climate change on human beings (e.g., by floods or heat waves), and indirect effects through impacts on climate-sensitive sectors (e.g., water management or agriculture).

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).

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.

Adaptive capacity – The ability of a system to implement planned adaptation measures (unchanged, IPCC, 2001). *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.

In addition to predispositions such as the current environmental and socio-economic state, the vulnerability of a region or sector depends mainly on three factors: **(1)** What is the degree of climate change and other elements of global change in the specific region? **(2)** What are the potential impacts of global change in the region on the different sectors? **(3)** 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 opportunities. The assumption of an unchanged state of adaptation in the future results in a vulnerability without further adaptation, or current vulnerability (business-as-usual scenario). 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. 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). Comparison of the vulnerability without further adaptation and the vulnerability with further adaptation renders an idea of the damage that could be avoided by implementing an adequate adaptation strategy.

Methods

In order to reach the objectives stated above we relied on the results of a European research project (ATEAM, Schröter et al. 2005) 2. This was 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 scenarios are based on the IPCC SRES (Intergovernmental Panel on Climate Change Special Report on Emission Scenarios) storylines A1FI, A2, B1, and B2 (Nakicenovic and Swart 2000) (Box 2, Table 1), and the general circulation models (GCMs) HadCM3, CSIRO2, NCAR-PCM and CGCM2 (Mitchell et al. 2004). Out of 16 combinations of storylines and GCMs, we selected seven scenarios for interpretation: B1, B2, A1FI, A2 calculated with HadCM3 (variation across storylines, “socio-economic options”), and A2 calculated additionally with three other GCMs (variation across climate models, “climatic uncertainty”). No probability of occurrence can presently be attached to any of these scenarios – they are regarded as a range of possible futures. The scenarios 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 spatial resolution was a longitudinal-latitudinal grid of 10’x10’. The time scale was from 1961 to 2100, with thirty-year time slices ending in 1990 (baseline), 2020, 2050 and 2080. In addition to the ATEAM results, numerous studies and projects on national and regional scale were consulted.

Experts’ surveys with representatives of Federal State Functional Departments of climate-sensitive sectors (forestry, agriculture, water management, tourism, nature conservation, health, and transport) were conducted, to gain estimations of the significance of potential impacts of climate change, of the existing degree of adaptation and of suitable adaptation measures. To assess vulnerability, the scenarios of potential impacts of global change in Germany (from the ATEAM and other projects) were integrated with results from these 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.

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

The IPCC-SRES Scenarios

The so-called marker scenarios, or IPCC-SRES-Scenarios are the starting point of scenario development (Nakicenovic and Swart, 2000). These scenarios are based on narrative descriptions of plausible future worlds (“storylines“) that were developed by a large group of experts and edited in a long-term open review process. 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. 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. 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. A1FI remains dominated by fossil fuels. In this study we focussed on the SRES-scenarios A1FI, A2, B1 and B2. A summary of the development of some main drivers in Europe can be found in Table 1 below.

Integrated assessment models are used to transform from narrative descriptions into quantitative scenarios of population, economic, and technological development, energy use etc. 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 (Table 1).

Table 1. Summary of exemplary main European drivers for each scenario (Schröter et al. 2004, Rounsevell et al. 2005 (in press)).

	Population	Economy	Technology	EU enlargement	GHG 2100* (ppmv)
A1FI	Slight increase to 2050, then decrease	Rapid growth	High rates of innovation	Proceeds rapidly	Ca. 960
A2	Steady increase	Moderate growth	Slower, uneven development	Stops or proceeds very slowly	Ca. 870
B1	Slight increase to 2050, then decrease	Moderate, sustainable growth	Rapid technological change	Proceeds at moderate rate	Ca. 520
B2	Stable	Low growth	Change unevenly distributed	Stops	Ca. 610

* Greenhouse gas concentration in the year 2100.

Scenarios of Future Climate Change in Germany

With regard to future temperature development in Germany, all seven analysed scenarios exhibit a definite warming trend. 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 +3.8 ºC (Figure 1). Many scenarios show a particularly strong warming in the Southwest, in some cases also in the far East of Germany. The scenarios exhibit heterogeneous seasonal changes. A trend of stronger warming during winter, which was observed in the past, cannot be found in the future scenarios.

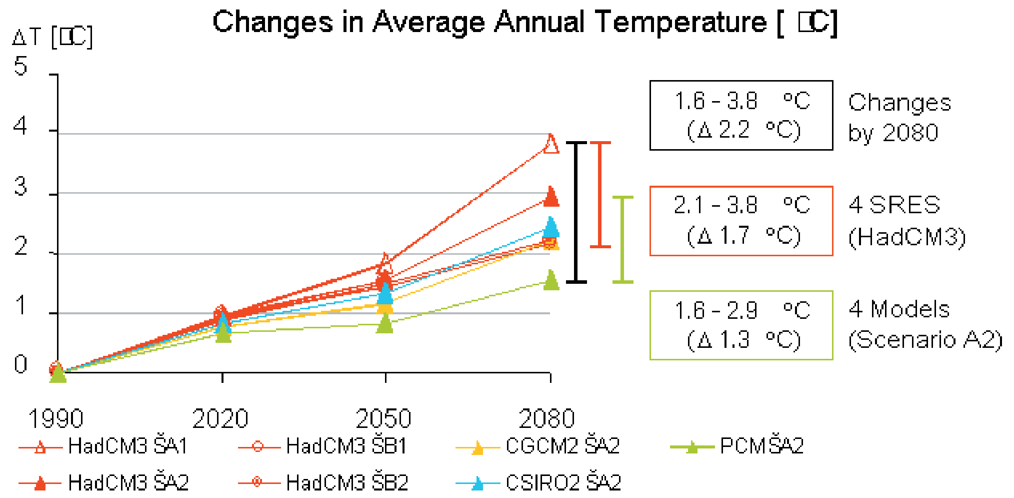

Fig. 1 ATEAM-scenarios of long-term annual average temperature change compared to 1990 in Germany up to 2080.

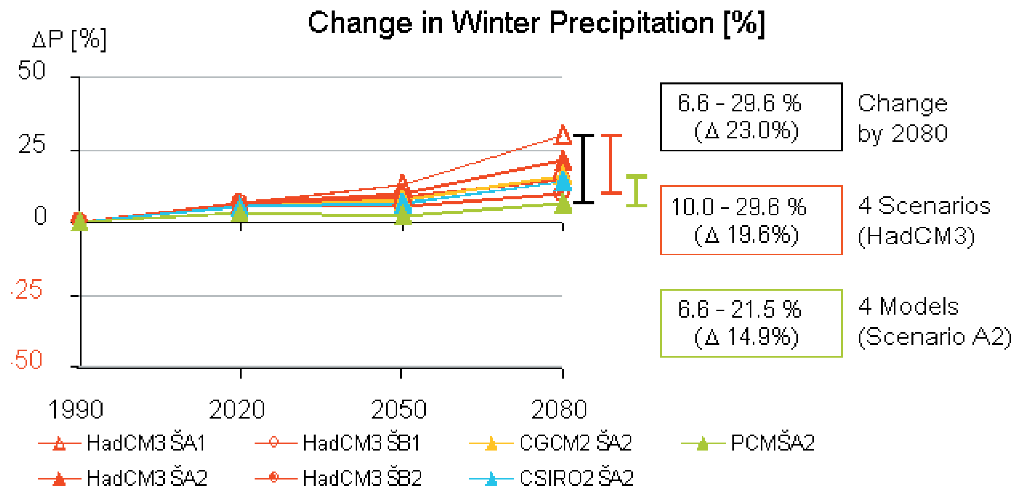

Fig. 2 Change in winter precipitation compared to 1990 for seven ATEAM scenarios in Germany up to 2080.

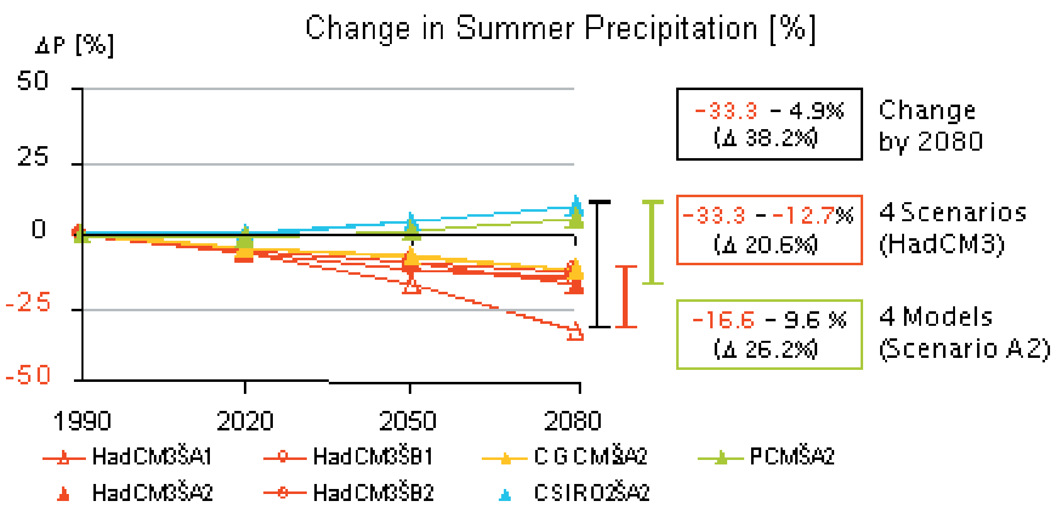

Fig. 3 Change in summer precipitation compared to 1990 for seven ATEAM scenarios in Germany up to 2080.

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 scenarios show an increase in winter precipitation (Figure 2), while most scenarios show a decrease in summer precipitation (Figure 3). 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 (Table 2, Figure 5). The lowest vulnerability is assessed for the German low mountain ranges and Northwest Germany.

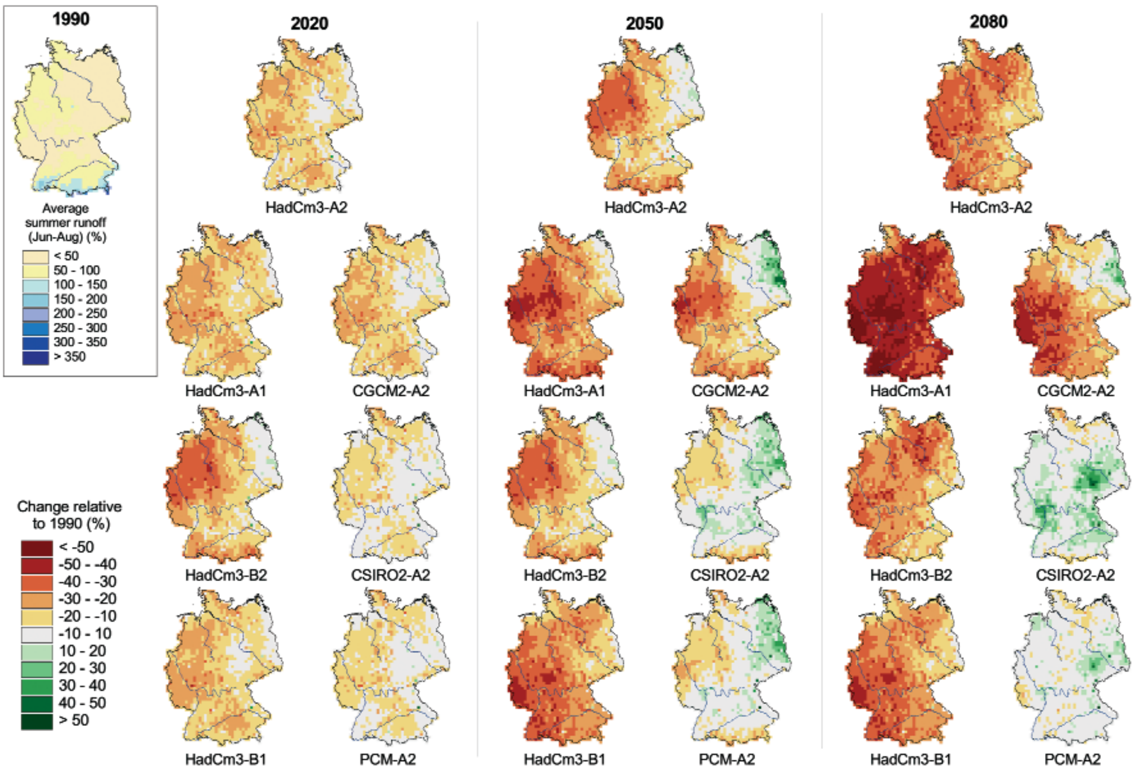

Fig. 4 Environmental zones in Germany (aggregated from BFN, 2005).

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 (Figure 5). 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.

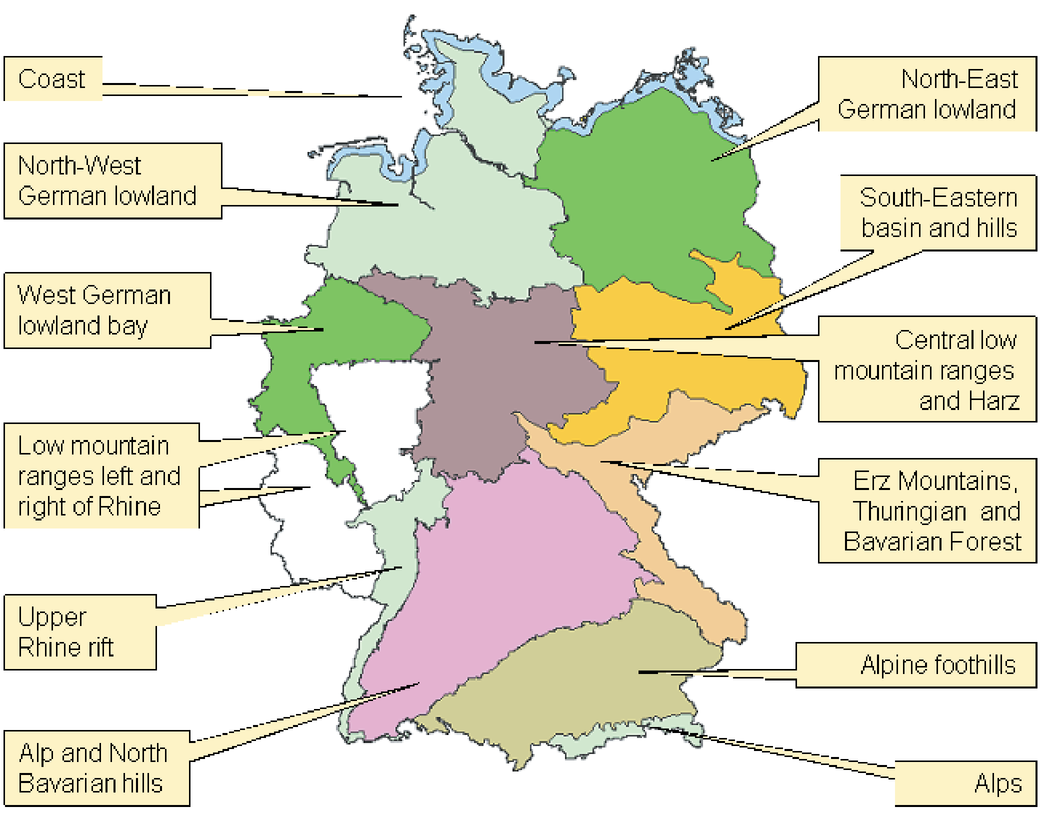

Fig. 5 Regional relative change in average summer runoff (%) across Germany up to 2080 compared to 1990 for seven ATEAM scenarios. Jun = June, Aug = August.

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.

Tab. 2 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	Water		Agri-culture	Forest-ry	Nature conserva-tion	Health		Tourism		Trans-port	All sectors
Environ-mental zone	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

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 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 these portrayed regions and environmental zones, 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 have to be implemented. Climate change is already taking place, and will continue to happen. Adaptation measures and emission reduction are therefore not alternative strategies, but have to be carried out in parallel.

In Germany, climate change adaptation has only recently received more attention, but is still highly under-represented in public awareness and in the consciousness of decision-makers. 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, extreme weather events (extreme rainfall events, heat waves etc.) that provide “windows of attention” for the climate problem can be used. The existing link between risks and opportunities of climate change and the dominating political themes in Germany (unemployment, economic growth etc.) should be stressed. When communicating climate change, the inherent uncertainties of the scenarios need to be made transparent; failure to do so will result in dented credibility, when 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. The uncertainty inherent in scenarios 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. An 8-stage decision support system for decision-making about adaptation to climate change is introduced in the full report as a first stimulus (Zebisch et al. 2005).

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. 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, 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. Networking is an efficient instrument for this. 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”. Further organisational and financial support of such networks through public and private sources is desirable. Such networks provide necessary information for vulnerability assessment, as well as communication platforms for coordinated adaptation measures.

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