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# Germany's vulnerability to Climate Change

## Summary

For our Environment

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# Germany’s vulnerability to Climate Change

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## Content

## 1 Introduction

Vulnerability assessments are key to adaptation planning, as they enable the identification of adaptation needs to inform adaptation strategies and plans. They also suggest where a country or a region is most vulnerable to the effects of climate change.

In 2008, the German Federal Cabinet adopted the German Strategy for Adaptation to Climate Change (DAS). The DAS refers to 15 fields of action (sectors). As requested by the first German national Adaptation Action Plan (APA I) in 2011, a standardised, cross-sector assessment of current and future climate impacts and the vulnerability of Germany was recently prepared in order to provide official evidence for the second Adaptation Action Plan (APAII). The second Adaptation Action Plan as well as the vulnerability analysis will be part of the progress report for the German Adaptation Strategy in 2015. The cross-sector assessment required the cooperation of many actors from various areas of expertise. For this reason, the Federal Ministry for the Environment (BMUB) and the Federal Environment Agency (UBA) put together the Vulnerability Network in 2011. This network is composed of sixteen Federal agencies and institutes and was supported by a consortium composed of adelphi, plan + risk consult, the European Academy of Bozen and IKU. Network partners are the Federal Office of Civil Protection and Disaster Assistance, the Federal Agency for Nature Conservation, the Federal Maritime and Hydrographic Agency, the Federal Office for Economic Affairs and Export Control, the Federal Institute for Geosciences and Natural Resources, the German Federal Institute of Hydrology, the Federal Highway Research Institute, the Federal Agency for Technical Relief, the Federal Institute for Research on Building, Urban Affairs and Spatial Development, the German Corporation for International Cooperation, the National Meteorological Service, the Johann Heinrich von Thünen Institute – Federal Research Institute for Rural Areas, the Forestry and Fisheries, KfW, the DLR Project Management Agency, the Robert Koch Institute, and the Federal Environment Agency.

The goal was to assess and consolidate the scientific and the various agencies' current knowledge on vulnerabilities of Germany to climate change. Alongside the actual findings of the project, the Vulnerability Network enabled cooperation across agencies, as for instance with the integration of data and models. The network has already enabled individual partners to initiate new projects. The network thus is a central component of the climate change adaptation processes in Germany.

## 2 Concept and Methodology

**The Vulnerability Network** unifies the expertise of several Federal agencies and disciplines. It was thus of key importance to the success of the Network to create a new consistent methodology based on a joint understanding of the concept of vulnerability and related terms based on the concept of vulnerability as set out in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change:

A **climate signal** refers to the indication provided by today's climate, or that of the near (2021 to 2050) and distant (2051 to 2100) future. **Sensitivity** indicates the extent to which a non-climate system (population, nature, economic sector) reacts to present or future climate signals. A **climate impact** is the impact of a present or future climate on the non-climate system. Climate impacts were assessed via models, indicators, and if no quantitative data was available via interviews with experts. The particular **significance of the climate impacts** for Germany was subsequently estimated by the network partners, rating each as either low, medium or high. For the distant future, climate impacts were described verbally and qualitatively due to the difficulty of establishing quantitative scenarios. Findings may be subject to some uncertainties; therefore, the Vulnerability Network assessed the level of confidence for each climate impact in a separate process in order to provide transparency. **Adaptive capacity** refers to the readiness of a system to adapt to climate change and minimise potential damage. It was evaluated by experts for each field of action. **Vulnerability** is defined verbally for the near future for each field of action.

To visualise the cause-effect relationships between climate signals and possible impacts, the network defined impact chains. These represent climate signals that influence particular climate impacts, as well as connections between the fields of action. Out of a number of impacts identified, network partners chose 72 for further analysis. Key sensitivities were subsequently workshopped by experts and network partners. They also identified an analysis methodology to analyse the 72 impacts involving impact models, proxy indicators or surveys of experts depending on the availability of data. In addition, the impact chains served as the basis for the analysis of interrelationships between the 14 analysed fields of action.

The fields of action – corresponding to the German Adaptation Strategy – were soils, biological diversity, agriculture, forestry, fisheries, coastal and marine protection, water management, transport, construction, trade and industry, energy, tourism, finance, human health and the cross-cutting issues of civil protection and of spatial, regional and urban planning.

This approach considers the potential impacts of climate change over three time frames; the present, the short term future (2021 to 2050) and the long-term future (2071 to 2100). For the near future, two scenario combinations for a strong and a weak change based on socioeconomic and climate change scenarios) were used to cover the range of possible futures. For the long-term future, no socio-economic scenario was available. Therefore, the results only base on a range of climate scenarios.

## 3 Climate and Climate Change in Germany

Regional climate models were used to assess the range of potential future climates. Because of the uncertainty of future developments an ensemble of climate model projections was used. Even with a number of projections, it is never possible to take into account all influences on the climate system. Spectrums of climate changes identified must thus be interpreted as a subset of possible changes. The key climate parameters are air temperature, precipitation, drought, number of hot days, tropical nights and frosty days, strong winds, snow and swimming and heating days, and potential for flooding.

The annual mean temperature in Germany could increase by 0.5 degrees Celsius or more in the short term future. The highest temperatures in Germany are currently found in the East and along the Rhine, but the largest summer temperature increases are expected in the South and along the northern coast. The West currently sees the highest temperatures in winter. Mayor increases in winter temperature are expected in Baden-Württemberg, Bavaria and parts of Rhineland-Palatinate and Mecklenburg-Vorpommern.

For summertime precipitation, models outputs for the short term future are contradictory, some suggesting increases and some suggesting decreases in precipitation. For winter, increases in precipitation in large parts of the country can be expected; up to ten per cent in the short term future and up to 15 per cent in the long term. Decreases are predicted in parts of Bavaria, the Upper Rhine and central Germany.

The models used to predict the number of hot days show an increase of five to ten per cent annually in the north of Germany and from ten to 15 in the South. However, the North Sea coast could also see a decrease. Larger increases are expected in the long-term future. Tropical nights are possible to experience a small increase in the short term, and long term increases may occur in the Alpine foothills and parts of Brandenburg, East Saxony and North Rhine-Westphalia. An estimated 40 to 290 freezing days are observed per year at present. These are especially found in low mountain ranges and in the Alps. Fewer freezing days are expected in both the long and the short term.

In regards to extreme precipitation, heavy rain is currently mostly found in the Alpine foothills. An increase in heavy rain in summer may be seen in the southern Black Forest in the short term. Dry periods – periods with no precipitation for at least ten days – could experience small increases in the short term future. In the long term, increases are expected in the South-West; in comparison to today, six extra episodes per year can be expected in the Black Forest in the event of strong climate change, and up to four more per year in the north and east. No clear trends were found as regards extreme wind speeds. Today, snow cover of a minimum of 30 centimetres occurs in low mountain ranges in around 100 days per year and in the Alps a bit more often. Trends for the short term future are still unknown, but in the distant future, these days could decrease by more than 90 days per year in lower mountain ranges and more than 100 days per year in the Alps. Swimming days are relatively plentiful in the southern part of the Upper Rhine, with up to 30 per year at present expecting a strong increase in the short- and long-term future. Along the coast, there are many fewer; increases here will also be less dramatic.

Heating days are days of an average daily temperature of under 15 degrees Celsius. Currently, there are 34 to 191 such days a year. A decline is predicted in both the short and long-term. Flooding may increase in river areas; certainly, if strong climate change occurs. In the distant future, a reversal emerges in the northeast around Berlin. Potential storm events were shown to be likely across the entire northern coast.

## 4 Socio-economic developments

Socio-economic developments are key to the assessment of a society's sensitivity to climate change. Therefore, in this analysis, two scenarios – for growth and for stagnation – were considered for the short term. No socio-economic development scenarios are available for the long-term.

Population trends differ across the regions. In the growth scenario, Federal states in the east of Germany and a few in the west will see a decrease. With the stagnation scenario, certain eastern regions will also see decreases. Similar trends can be seen with the number of households; however, in the growth scenario, as well as decreases in the east, there will be regions (such as Munich) with large increases. In the stagnation scenario, this would be even clearer. In both scenarios, the absolute number of older people in weaker economic areas will remain stable, despite increases in the general population, as young people tend to leave economically weaker areas.

In both scenarios, changes to the gross domestic product (GDP) also differ across the regions, although only positive trends are predicted. In the growth scenario, most regions grow 40 to 60 per cent. Stagnation could see regions in the south and east experience very positive trends. Growth would be less dramatic in the west. Scenarios on disposable income in private households also differ across the regions. Most of Germany would see a positive increase in the event of growth. Stagnation would see a similar but less pronounced effect. A few regions that would see decreases even in the event of growth would be starkly hit in the event of stagnation. Decreases in disposable income would be seen in many eastern areas, with increases in others, including in the Munich area, Rhine-Neckar, and northeast Mecklenburg.

Many regions can expect an increase in the number of employed people. In the growth scenario, most areas would expect growth in this regard. Many parts of the east and some individual parts in the north and in the west would see a small decrease. The stagnation scenario would see an on average larger decrease than in the growth scenario. The land use scenarios presume an increase in areas used for settlements and transport by 2030. Changes predicted between 2010 and 2030 show that regions which increasing land use are those, which have already high land use today. The converse is true for areas with low land use for settlements and traffic.

## 5 Generic Adaptive Capacity and Spatial Planning Adaptive Capacity

Adaptive capacity represents current abilities to adapt to expected climate changes; the Vulnerability Network took into account three forms this may take. These were 1) field of action-related adaptive capacity, determined and reported for every field of action, 2) generic adaptive capacity, i.e. the key conditions for a society to adapt to climate change, and 3) the cross-cutting issues of spatial, regional and urban planning and civil protection, and their contribution to general climate change adaptation.

A society's general adaptive capacity needs structural frameworks in place for the implementation of adaptation measures. For the assessment of this, public administration, the private sector and civil society were chosen as the main governing entities and tailored indicators were allocated and agreed with authorities and institutions in the Vulnerability Network. Results included maps of generic adaptive capacities; information on these separated into six categories, from "very low adaptive capacity" to "very high adaptive capacity". To visualise generic adaptive capacities, results based on the indicators examined were normalised and merged into a map.

Findings showed high generic adaptive capacity in densely populated areas such as Berlin, Munich, and Düsseldorf. Medium generic adaptive capacity is to be observed in almost all parts of North Rhine-Westphalia, as well as in areas in Lower Saxony, Bavaria and Hesse. Relatively low capacity was to be found in parts of Rhineland-Palatinate, Baden-Württemberg, Schleswig-Holstein and Bavaria. Alongside Saarland, the lowest capacities were to be found in much of the east. A significant issue is that only potential readiness to adapt to climate change is shown, rather than actual willingness to adapt; an attempt was thus made to approach this issue in conjunction with spatial planning, as this shows which measures the regions actually utilise.

The issues of civil protection and of spatial, regional and urban planning are noted as cross cutting issues in the German Strategy for Adaptation. Whilst spatial, regional and urban planning are at the beginning of the risk prevention chain, civil protection involved all civil measures taken to protect the population. Spatial planning activities at both the regional and the local levels were taken into account. It is however not yet possible to make comprehensive, quantifiable statements on the contribution made by civil protection to climate change adaptation capacities.

## 6 Analysis of Existing Vulnerability Studies

The Climate Studies Catalogue was developed by the Vulnerability Network on basis of a comprehensive review of available literature. Around three quarters of the studies consulted relate to Germany and regions of Germany. These may be direct or part of international studies. Around a third (45 out of 155) were commissioned by Federal states and another 27 by federal German agencies.

The fields of action set out in the German Adaptation Strategy were used as the basis for indexing. The majority of the studies indexed related to more than one field of action; 59 were limited to statements on just one. The most studied fields of action were water resources and management, agriculture, human health and forestry. For the whole of Germany and each Federal State specific statements for individual fields of action from climate impact and vulnerability studies were extracted and assessed to create an index, enabling an overview of current information and also highlighting gaps. Limits to the meaningfulness of the index must be taken into account in the use of the catalogue and the interpretation of the findings. The catalogue should be used as a summary of current knowledge, rather than the basis for a vulnerability assessment at the federal level.

# 7 Integrated Analysis

## 7.1 Comparison of the Fields of Action

Many climate impacts are and will continue to be influenced by temperature and precipitation. Today, only heat impacts have a major impact on human health. Moderate impacts are caused by extremes such as floods, heat, dryness and strong winds, which can damage streets, railway lines, buildings and infrastructure and the availability of water for power plants.

A large number of major climate impacts could be observed in the construction field of action: four of five climate impacts analysed in this field of action will be of major significance in the event of strong climate change in the short term future; for coastal and marine protection, there were three impacts with high significance; and two in the forestry sector, fisheries and human health fields of action. With regards to timescales long-term adaptation measures must be implemented in the forestry and coastal and marine protection fields of action now in order to be able to deal with future developments; the same is true in the human health and construction fields of action, which are already dealing with significant climate impacts. A comparison of medium to high vulnerabilities points to the construction, biological diversity and fisheries fields of action, as the latter have a very low adaptive capacity.

Finally, the question of which systems are impacted by the climate impacts analysed by the Vulnerability Network was considered. Distinctions were made between the environment, the economy, infrastructure and health. Most climate impacts can be assigned to the economy or the environment. The analysis showed that the climate impacts on the environment, the economy and on infrastructure are currently mostly of low relevance. Impacts on health are already estimated to be of moderate significance. In the event of weaker climate change in the nearby future, this would remain so; the majority of climate impacts would be of higher significance with stronger climate change. Climate impacts on health tended to be evaluated as being of medium certainty, and as being more certain than climate impacts to other systems.

According to the Vulnerability Network's estimations, the health, infrastructure and environmental systems will be more strongly hit by climate change than the economic system.

## 7.2 Linking the Fields of Action

A total of 636 impact relationships have been analysed and subsequent thematic clusters identified. Water management had the greatest number of impact relationships with 67, playing a major role in the energy sector, in industry and trade, agriculture and in the health sector. It is connected with fisheries and marine and coastal protection to a Water cluster. In the Land cluster (soil, agriculture, forestry, biological diversity) biological diversity has the highest number with 43 impact relationships. An Infrastructure cluster could be determined, comprising the highly connected fields of action construction, transport and energy. A fourth cluster – Business – comprises tourism, finance, and industry and trade. Finance in particular is connected to nearly all other fields of action. Human health is the action area with the most incoming impact relationships, because it is affected at the end of many impact chains. The sixth and final cluster comprises the cross-cutting issues of civil protection and of spatial, regional and urban planning. In the fields of action water, energy, biological diversity and human health, a multi-action area strategy for planning adaptation measures appears to be necessary.

## 7.3 Implications for Climate Types

A cluster analysis was used to identify climate types, thus enabling the identification of regional priorities. The climate change signals used were strong winds, heavy rains, hot days, tropical nights, freezing days, average winter temperatures, average summer temperatures, dry winter periods, dry summer periods, winter precipitation and summer precipitation. Results gave six climate types for each time period. The names given to the climate types are descriptive and easy to understand: warm, dryer, cooler, sub-alpine, foothills and mountain. Warm climates will see great expansion as a result of climate change; here, a large increase in hot days and tropical nights can be expected. Around the end of the century, more intense heatwaves will be accompanied by more drought. Heat and drought will increasingly also affect forestry, transport infrastructure and rural areas.

Regions with a dryer climate are marked by strong seasonal variation in temperature and precipitation. The anticipated trend towards higher temperatures will further affect available water resources. These effects will predominantly be seen in the east of Germany. Regions with a cooler climate are marked out by strong winds and heavy rains, moderate temperatures and a low number of freezing and hot days. Climate projections suggest that in the future, the damage potential of extreme weather events such as river flooding will increase markedly. In addition, the increase in winter precipitation and a reduction in the number of dry days in winter could create challenges for city drainage in these areas. At present, this climate type is to be found in the northwest, and in the North and Baltic Sea coasts. At the Baltic coast, however, it will be in time gradually replaced by a dryer climate.

Regions with a sub-alpine climate experience a large number of freezing days and a lot of heavy rain. Summer precipitation will decline significantly in the distant future. In the winter months, precipitation will decrease, and less snow will fall, impacting water supply and causing problems for the winter sports industry. Regions with a foothills climate have above average rainfall, a large number of days with heavy rainfall and many freezing days. Summer temperatures will likely increase markedly. This will increase demand for energy needed for cooling purposes. Settlement and transport growth may amplify climate impacts further. Mountain climate regions have many days with heavy rains and frost and a lot of precipitation. Summer precipitation is expected to increase. This area is limited to the Alps and a part of the Black Forest.

## 7.4 Overall Evaluation

Increased climate change in the coming decades will have increased the potential for damage to nature, society and the economy by the end of the century. It can thus be assumed that the importance for Germany of many climate impacts will increase. Six main points could be drawn from the analyses:

1. Damage caused by increasing heat stress in densely populated areas can affect city climates, air quality and conditions inside buildings. Impacts could be seen to a lesser extent on streets, railway infrastructures, runways and the availability of water in energy production.
2. Reduced water availability can occur through climatic warming and increased summer drought. Drought damage could also impact agriculture and cause stress in the forestry sector.
3. Damage to buildings and infrastructure caused by heavy rains and flash floods can affect streets, railway lines, curtail land-based goods transport, buildings and sewer systems.
4. Damage to buildings and infrastructures via river flooding will have major impacts in the short term, harming streets, railway lines, goods transport, buildings, canal networks and sewage treatment plants.
5. Coastal damage is a long-term threat caused by rising sea levels. In the short-term, there could be impacts on traffic areas and buildings alongside possible curtailment of land-based transport.

6. Changes in the composition and natural developmental phases of species such as the spread of alien species and impacts on fish populations, the spread of invasive species and changes to growth periods.

A high adaptive capacity can help mitigate a region's vulnerability, even in the case of strong climate change. Whilst more densely populated agglomerations tend also to have a relatively strong adaptive capacity, areas with less infrastructure are less well prepared. These are mainly peripherally located regions with strong structural deficits and high density regions with structural weaknesses.

Findings ultimately show that Germany has a moderate vulnerability to climate change when considered across all fields of action.

## 8 Research Needs and Policy Recommendations

The scientific challenges of an integrated vulnerability assessment can be identified in three key areas:

1. **Future uncertainties.** Predictions based on climate-related and socio-economic scenarios are subject to uncertainty. This project was thus assembled as to allow an analysis of a range of possibilities. More research needs to be done to provide climate parameters that can make clearer statements on climate impacts. There is also a need to establish chronological consistency between socioeconomic and climate scenarios, to be able to identify which climate/ sensitivity parameters are important to particular projected climate impacts.
2. **Complexity.** Complex causal relationships have been mapped with the help of impact chains. However, few of these impacts have corresponding quantitative models or established indicators. Several potentially important climate impacts thus could not be quantified. There is thus a need for further development in this regard.
3. **Assessment.** There are in general no established and standardised methods for vulnerability assessments. Unanswered questions include the aggregation of information from diverse sources. A decisive factor will be the question of normative ratios and/or evaluation target systems. Such a system is currently only available in very few fields of action.

Additionally, the need for further research was studied in relation to each field of area. In the Land Clusters (soil, biological diversity, forestry) it is predominantly the direct climate impacts for which plenty of material is available. More complex climate impacts are less well understood. Even less well understood are longer impact chains, which cause impacts in fields of action such as industry and commerce. It is the Vulnerability Network's recommendation that more work should be done to research these kinds of chains in the future.

## 9 Policy Recommendations

### First Recommendation: Get Expert Networks Involved

The Vulnerability Network's positive, inter-agency and interdisciplinary cooperation was decisive to the success of the project. So comprehensive a vulnerability analysis could only be conducted because experts from various authorities and institutions participated, offering their knowledge, data and models. This transfer of knowledge did not only stimulate the Vulnerability Network's efforts: the authorities and institutions involved also were able to profit from the processes of the network themselves. The discussions which took place in the network thus promoted new cooperative efforts between network partners and encouraged the exchange of models and data.

At all regional levels, it is advisable that vulnerability analyses involve a network of experts whose specialist knowledge collectively covers all the fields of action which are being observed. This is because this kind of network does not only improve the understanding of problems, but creates a greater awareness regarding potential climate impacts.

### Second Recommendation: Use a Unified Methodology at all Levels and across all Fields of Action

A comparison of the findings from existing climate impact and vulnerability studies on particular fields of action and regions is made considerably easier if they use the same concepts and methodology. The Vulnerability Network has for this reason developed a methodology which can be used not only in all fields of action but at various regional levels. Departments and federal states can thus conduct detailed analyses of individual issues and regions so that they can be directly connected to the Network's findings and can be taken into account when conducting a subsequent vulnerability analysis for the whole of Germany. A unified methodology for vulnerability analyses of Germany, its federal states and regions would also have the advantage of simplifying the interpretation and communication of findings. Data gaps which currently still hinder the quantitative analysis of some climate impacts could also be closed.

### Third Recommendation: Evaluate and Further Develop the Methodology

In a dynamic research area such as climate change impact research, it is important that new insights can be integrated into organisations' own methodologies such that the latter still represent the state of the art. This includes the evaluation of an organisation's own methodology, thus opening up the possibility of new research findings. The first vulnerability study performed on behalf of the Federal Environment Agency (Zebisch et al. 2005) had for example the goal of delivering a geographically clear image of Germany's vulnerability in various fields of action. Even if this first study was somewhat restricted in terms of time and resources, it still demonstrates a high methodological consistency with the present Vulnerability Network study. The present study can thus be seen as a systematic development of the 2005 study, which first and foremost represent a development from a purely scientific study to co-production of knowledge, achieved via the establishment of a network of authorities.

### Fourth Recommendation: Regular Repetition of the Vulnerability Analysis

The analysis of vulnerability at a federal level should be reproduced every few years. This has many benefits: firstly, it makes it possible to address the identified research needs in the meantime and to take account of new insights gained from the repeated vulnerability assessment. Secondly, a regularly conducted vulnerability analysis at a federal level would consolidate cooperation between authorities and other stakeholders. At the same time, new partners can be gained who can enrich the study with their knowledge and perspectives. Thirdly, the anchoring of a regular vulnerability analysis into the German Adaptation Strategy (or another similar strategy paper) would, alongside the institutionalisation of the network, create more stability in the field of vulnerability and adaptation at the federal level. This problem area would then be consistently and regularly worked on and thus retain its importance in terms of political events quite independently of political cycles, an appropriate outcome given the importance of this issue.

### Fifth Recommendation: Define Fields of Action Clearly and Prevent Overlaps

The Vulnerability Network's study has shown that the fields of action addressed in a vulnerability analysis must be described as clearly as possible and that they must be prevented from overlapping. This way, work is not repeated and contradictions within the analyses can be avoided in situations where climate impacts can be assigned to several fields of action. It is also possible to simplify the analysis of interactions between fields of action by clearly defining which climate impacts are to be attributed to which field(s) of action. Defining the fields of action it is to be noted that they should not be so wide that climate impacts become imperceptible because of being seen in excessively general terms. Equally so, it is necessary to factor in both the differentiation between fields of action which are affected by climate change and cross-cutting issues which, while they represent an individual vulnerability, can first and foremost contribute to society's adaptation (i.e. to other fields of action).

### Sixth Recommendation: Clear Communication of Findings and Insecurities

Insecurities are always a part of the analysis and evaluation of (future) vulnerabilities. On the one hand, the future can never be predicted with absolute certainty. On the other hand, it is typical that the systems in consideration are so complex that they cannot be transferred over into models in their entirety. Furthermore, every climate change impact or vulnerability study sets out normative decisions and estimations which are constantly affected by affirmative assumptions. It is science's task to reduce insecurities: at the same time, these must be documented and communicated, as only then the findings from a study can be assessed and interpreted properly by the compiler.

### Seventh Recommendation: Engage at an International Level

The processes of and findings from the Vulnerability Network are not only important at a national level; they are also met with great interest internationally. The project has thus already inspired other national vulnerability analyses. It can serve at a European and at other levels as an example and starting point for further developments.