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2023 Monitoring Report

on the German Strategy for Adaptation to Climate Change

Report by the Interministerial Working Group on Adaptation to Climate Change

Umwelt Bundesamt

Imprint

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The IMAA (Interministerial Working Group on Adaptation to Climate Change) bears responsibility for the contents of this publication. The IMAA is managed by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Customer Protection (BMUV). The IMAA has representatives from the Federal Foreign Office (AA), Federal Chancellery (BK), Federal Ministry of Finance (BMF), Federal Ministry of the Interior and Community (BMI), Federal Ministry of Labour and Social Affairs (BMAS), Federal Ministry of Education and Research (BMBF), Federal Ministry of Food and Agriculture (BMEL), Federal Ministry of Defence (BMVg), Federal Ministry of Family Affairs, Senior Citizens, Women and Youth (BMFSFJ), Federal Ministry of Health (BMG), Federal Ministry for Digital and Transport (BMDV), Federal Ministry for Housing, Urban Development and Building (BMWSB), Federal Ministry for Economic Affairs and Climate Action (BMWK), Federal Ministry for Economic Cooperation and Development (BMZ). The German Environment Agency (UBA) attends as permanent advisory member.

Note: The federal budget and financial planning period are not prejudiced by the DAS Monitoring Report 2023. Any new measures or processes based on the report are subject to the budgetary reservation. The responsibilities between the federal government and the federal states laid down in the constitution must be taken into account.

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Cluster Urban Development, Spatial Planning, Civil Protection

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READING AID

How the report is structured

The Monitoring Report comprises the following components:

- Development of Germany's climate
- Indicators covering climate change impacts and adaptation
- Appendix: Statements regarding the compilation, contributors, sources, abbreviations

The component entitled **Development of Germany's climate** was compiled by Germany's national meteorological service (DWD). The Report provides an overview of the mean values of changes regarding important climate parameters as well as covering any changes in terms of extremes. Some of the time series date back as far as 1881. This is the first time that this part of the Report includes statements on the developments in respect of the mean values and the extreme values of future temperature and precipitation, strictly speaking, for the short-term (2031–2060) planning horizon, while a differentiation is made between the climate protection scenarios (RCP2.6) and the high emissions scenario (RCP8.5) respectively. More detailed information is available in the **Nationaler Klimareport** (National climate report) published by the DWD.

The relevant action field chapters contained in the **Report component entitled 'Indicators on climate change impacts and adaptation'** present the respective Impact and Response Indicators developed for the purpose of DAS Monitoring, complete with charts and explanatory texts. The chapters are each preceded by an **action-field specific overview**. This overview provides a brief description of the importance of the action field concerned, including a precis of major climate change impacts and adaptation measures, illustrated by means of indicators in the monitoring report. Furthermore, there are references made with regard to gaps in essential data and knowledge gaps, as not all impacts of climate change and adaptation activities relevant to the action field in question can be included in the monitoring report themes, complete with indicator-based illustrations. In addition, the report uses the Response Indicators to address – by means of selected examples – some important political adaptation activities at Federal level.

The action-field specific overview is also used to provide some kind of **bridge to connect with the findings resulting from the Climate Impact and Risk Analysis (KWRA) conducted at Federal level in 2021.** It is important to note that the 2023 DAS Monitoring Report just quotes the findings resulting from the 2021 KWRA in respect of substantial climate change. The Report does not, in fact, add or adopt any new assessments from any third parties. Within the framework of the 2021 KWRA, assessments were indeed made – on the basis of extensive searches in the literature – and in some respects data analyses were assessed by competent experts in government departments, in respect of relevant climate impacts in the near future (2031–2060) and the distant future (2071–2100), under both a strong and a weaker climate change scenario. The relevant risks were graded as low – medium – high, in order to take account of the importance of the climate impacts to be expected for Germany with a view to relevant economic, ecological, social or cultural aspects. Likewise, a differentiation was made between certainty and lack of certainty in respect of the assessments in question. More detailed information can be found in the publications pertaining to the findings of the 2021 KWRA. The **KWRA findings** had a direct influence on how to focus the further and the new development of those indicators for DAS Monitoring on climate impacts for which the KWRA identified a particularly high risk.

The overview is supplemented by the illustration of an action-field specific **effects chain**. In this context, an example is selected to illustrate in what way the climatic changes observed as well as the climate change impacts (impact level) and the adaptation activities (response level) are linked.

The list of contributors in the **Appendix** contains the names of all individuals who made tangible contributions to the further enhancement and updating of the indicators and the preparation of explanatory texts. The Data Sources provide a list of references which are mentioned in the indicator-based parts of the report.

Links provided in the Report

In the part of the report entitled 'Indicators on climate change impacts and adaptation', QR Codes are used to provide access to background documents (in German language) concerning the DAS Monitoring Indicator System. The QR Codes next to the indicator charts provide links to the indicator fact sheets available for each indicator contained in the monitoring system. That is where you will find details such as information on the generation of indicator values, as well as information on data sources and individual contacts and also on any potential limitations to the expressiveness of a particular indicator. Moreover, the fact sheets contain explanations pertaining to the links between climate change and the subject of the indicator. For reasons of data protection, the data fact sheets are not published. Fact sheets are used for the compilation of data and calculations of indicator values; they are also used for the generation of indicator charts and other details in respect of the origin of data and what they refer to.

Furthermore, the documentation pertaining to the DAS Monitoring indicator system comprises the action-field related background documents generated for each action field; these are updated every time the Monitoring Report is updated. Since 2009, the background documents have been used to provide a continuous documentation of the process of developing and revising each action-field specific indicator. This approach should make it fully transparent as to which indication ideas were either discussed, developed to produce tangible indicators or which were rejected. This is also where any perspectives regarding further development are recorded. The background documents also provide clues as to the point in the process when which of the indicators were changed or removed entirely from the indicator set. A QR Code on the relevant first illustrated double page of the individual action-field chapter provides links to the respective background documents. Further details on the background documents and the organisation of the updating process applied in DAS Monitoring and the underlying indicators can be found in the **Organisationshandbuch zum DAS-Monitoring** (Organisation Manual for DAS Monitoring).

There are numerous interfaces and relationships among the indicators used in DAS Monitoring, even those that go beyond the confines of the action fields. The report provides such links in the relevant parts of explanatory texts by referring to the indicators concerned.

In individual cases – especially where figures are quoted – sources are referenced in the explanatory texts. The relevant evidence appears in the 'Appendix' part of the Report, sorted by the parts of the Report and by the action fields concerned. Detailed bibliographies for individual indicators are contained in the indicator fact sheets for each indicator.

Indicator charts

The indicator charts illustrate the time series underlying the indicators. In some cases the charts contain two vertical axes thus facilitating the differentiation between different units or scales. The numbering of the axes and lines is coloured in a way that allows their attribution to the relevant lines or bars of the time series in question.

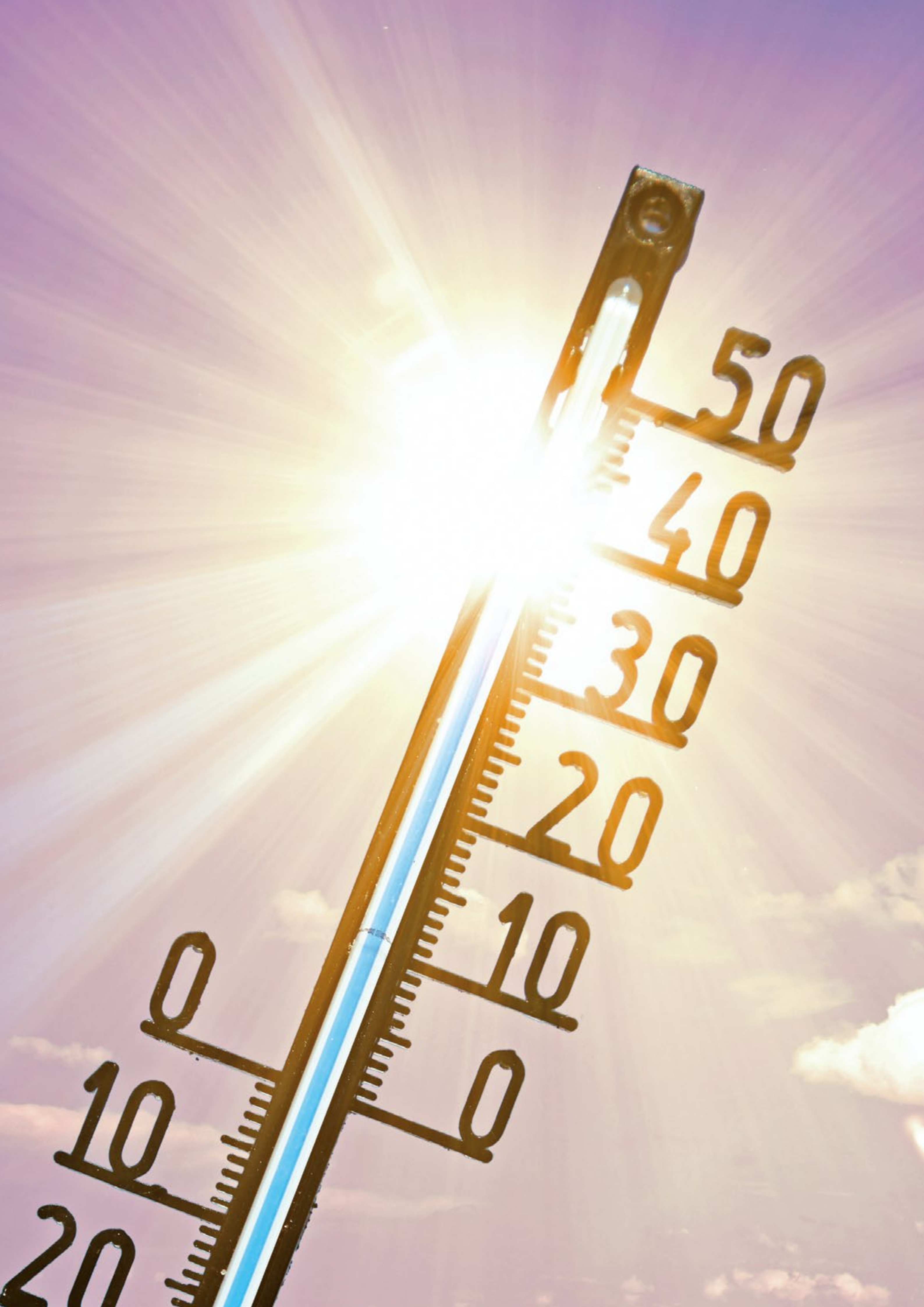
The data sources in the indicator charts are presented in abbreviated form. The relevant detailed evidence is contained in the indicator and data fact sheets.

Findings resulting from trend analysis

In order to facilitate the interpretation and assessment of the development of time series relating to individual indicators, the statistical trend analyses were carried out in accordance with a homogeneous process (cf. p. 15). The **R Code** required for applying the process is in the public domain. The findings from analyses of linear and square trends are documented by means of trend symbols in the keys contained in the indicator charts (see below). In order to ensure clarity of the indicator charts, the use of trend lines has been avoided. Where several time series are illustrated in an indicator, a separate trend analysis was carried out for each of these time series.
In cases where change points were identified in a time series (cf. page 15), these were taken into account in interpreting the data series and mentioned accordingly in the explanatory texts. However, any such change points have not been marked in the indicator chart in question.

Trend description	
	Rising trend
	Falling trend
	Trend with trend reversal: first falling, later rising
	Trend with trend reversal: first rising, later falling
	No trend

Trend appraisal	
	Favourable development
	Unfavourable development
	Appraisal of development impossible


50
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20

Introduction

Process of adaptation to climate change in Germany

Within the framework of the German Strategy for Adaptation to Climate Change (DAS), the Federal government presents the 2023 (third) Monitoring Report on the German Strategy for Adaptation to Climate Change. This report describes the impacts of climate change on the basis of solid scientific data, at the same time as providing the public as well as decision-makers in all sectors of society with information on tangible impacts of climate change. The risks associated with climatic changes affect all sectors of society and all ecosystems which make up the foundations of our life in all aspects of its diverse structures and services. Consequently, the organisation of risk provisioning and adaptation capacities is a task that concerns society as a whole. Curbing global warming and its impacts is a core political challenge for the 21st century worldwide. Meeting this challenge is an essential prerequisite for achieving the objectives set by the 2030 UN Agenda with its focus on sustainable development[I].

In this light, the Federal government has, as early as 2008, under the auspices of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), submitted the first **German Strategy for Adaptation to Climate Change (DAS)** which has been continuously developed further ever since. The overarching objective of DAS is to mitigate the vulnerability of ecosystems and society to the impacts of climate change, at the same time as increasing the resilience and adaptability of these systems. The work on DAS has been carried out within the Federal government under the auspices of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMUV) via the Interministerial Working Group for Adaptation to Climate Change (IMAA) with the cooperation of all Federal ministries and their scientific authorities linked to this Working Group. Furthermore, all work within the DAS framework is carried out in close cooperation with the Länder and municipalities.

Since 2021, the Federal government has been strengthening the political control of climate adaptation by undertaking the following:

- a federal law which establishes a binding legal framework for the adaptation to climate change,
- a precautionary climate adaptation strategy with measurable targets, and
- safeguarding the joint funding of precautionary climate protection and climate adaptation measures at Federal and Länder level.

Since 2008, there has been ongoing development work on a **reporting system** on DAS consisting of various components which are updated at regular intervals: Every four years, the **DAS Monitoring Report** provides updates on climate impacts and adaptation on the basis of measured data. Every six years, a **Climate Impact and Risk Analysis (KWRA)** is carried out analysing future climate risks. **Evaluations of the DAS** are carried out at regular intervals. These are the foundations for further developing the adaptation strategy covered in the DAS **Progress Report** and underpinned by an **Action Plan (APA)**. In the years of 2015[1] and 2020[2] the Federal government presented progress reports accompanied by the 2015 and 2020 action plans.

With the aid of scientific indicators in respect of climate impacts and adaptation, the 2023 Monitoring Report imparts information on the 16 action fields incorporated in DAS (cf. pp. 4–6). The 2021 Climate Impact and Risk Analysis (KWRA) was used to determine the 31 foremost and most urgent requirements for action in Germany in 2021[3]. The 2023 Monitoring Report presents new indicators for some of the most urgent requirements for action, thus facilitating the observation of developments on the basis of measured data. Compared to the first two Monitoring Reports, the structure has been developed further (cf. Reading Aid, p. 7). Each action field is now preceded by an overview of what has been happening with regard to climate change and what has been done already. Furthermore, links are made to the KWRA analysis, and important gaps in respect of data and knowledge are pointed out. The technical foundations of the Monitoring Report are reinforced by cooperation with more than fifty authorities at Federal and Länder level, universities and professional organisations (cf. p. 344 ff.) whose expertise contributes to the technical quality of the indicators and the reliability of the evaluation.

The DAS Monitoring Indicators convey a comprehensive overview of the kind of changes that can be attributed to climate change in Germany, and what kind of adaptation measures have already been implemented. The 2023 Monitoring Report furthermore provides evidence for precautionary efforts that have been made at Federal level in view of the increasing risks. At the same time, the close mutual dependence on achievements in respect of climate protection and progress regarding climate adaptation is also communicated. The only chance to limit and control the impacts of global warming is represented by the intensification of

I United Nations General Assembly Resolution dated 25th September 2015 'Transforming our world: the 2030 UN-Agenda for Sustainable Development' (https://undocs.org.en/A/RES/70/1). Goal 13 stipulates to 'Take urgent action to combat climate change and its impacts', and to 'Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries' efforts in respect of climate protection. At the same time, the precautionary measures taken to adapt to climate change are both important and urgent, in the endeavour to counteract the impacts which have already become inevitable, and to find ways of mitigating any associated ecological, social and economic damage with the greatest possible efficiency.

Where and how do climatic changes manifest themselves in Germany?

The previous DAS Monitoring Report was issued in 2019. Since then, Germany has been confronted repeatedly with heatwaves, droughts, flash floods and flooding events. Even more strongly than in 2019, the impacts of global warming are reflected in the measured data contained in the 2023 Monitoring Report. The temperatures of air, water and soil have continued to rise, thus also increasing the impacts on humans, environment, economy and infrastructures.

Above all, the extreme events are engrained on the collective memory: From 12th until 15th July 2021, the low-pressure front Bernd caused extreme downpours in various parts of Western Europe. In the region encompassing the rivers Ahr and Erft in Rhineland-Palatinate and North Rhine-Westphalia, flash floods and flooding events resulted in disastrous damage and loss, including the loss of more than 180 lives in Germany – most of them in the Ahr valley. Overall, this caused insured material damage to residential property, household effects and business premises totalling 8.1 billion Euros (cf. Indicator BAU-I-5, p. 226). To date, this has been the highest claims expenditure in terms of property insurance involving damage caused by natural hazards. The World Weather Attribution (WWA), an international alliance of individuals involved in scientific activity, researched the extent to which the occurrence of such extreme weather events is related to climate change. They reached the conclusion that the probability – of such extreme rainfall events being due to climate change. has increased by a factor of between 1.2 and 9[4].

The Monitoring Report shows the following: Apart from heavy rain and flooding, there are other extreme events such as heat and drought that descended on Germany with all their measurable impacts. Summers with major heatwaves and highest measured air temperatures to date have been occurring more frequently; for instance, in July 2022, for the first time ever north of the 53rd parallel, at the station of Hamburg-Neuwiedenthal, a temperature in excess of 40 °C was measured[5]. In the years of 2018, 2019, 2020 and latterly in 2022, **periods of great heat** caused, in particular, stress to inhabitants of cities. In Berlin, Frankfurt am Main and Munich, hot days with daily peak temperatures of at least 30 °C and tropical nights with temperatures never dropping below 20 °C, occurred distinctly more frequently than in respect of the nationwide mean. Between 2018 and 2020, some 19,300 individuals died as a result of heat effects in Germany (cf. Indicator GE-I-2, p. 42).

Heatwaves and droughts also led to functional restrictions with regard to infrastructures and waterways. For example, there were **technical obstructions** in goods and passenger transport as well as, in some areas, some massive restrictions to electricity generation in nuclear and coal-fired power plants in Germany and other member countries of the Trans-European Electricity Network. Owing to the high temperature of water sources, on one hand there was insufficient **coolant water** available, while on the other, coal supplies were restricted by low water levels prevailing in waterways used by inland shipping.

The years mentioned above which had remarkably hot summers, were also characterised by low precipitation levels which **regionally led to severe droughts**. As far as the water budget is concerned, massive losses were incurred between 2018 and 2020. Ever since the turn of the millennium, Germany has been losing 2.5 gigatonnes or cubic kilometres of water per year (cf. Indicator WW-I-1, p. 70). In the years of 2019 to 2021, record shortfalls were recorded at gauging stations in terms of long-term lowest groundwater levels. The effects of the drought years have not yet been offset even as late as 2023. Insufficient availability of soil water has led to **yield losses in agriculture**. Owing to drought stress and associated infestations with beetles, there has been a significant increase in crown defoliation. From 2019 onwards, it has become obvious that **dieback rates of trees** has been skyrocketing with regard to all tree species. The extremely dry weather pattern has also been reflected in the forest fire scenario. There were considerably more and – in the north-eastern Länder – **large-scale forest fires**.

Despite the drought – especially during the summer half-year of recent years – there were several, partly extreme flooding events in some regions. On those occasions, the multi-annual mean flood discharge values were exceeded by several multiples at some gauges. In fact, the apparent contradiction between drought and extreme flooding represents a genuine example of cause and effect: On one hand, warmer air absorbs more moisture, thus increasing the risk of **heavy rain**; on the other, it increases the frequency of drought phases. To name just one of the consequences: Desiccated soils are unable to absorb or store the water accumulating in a heavy rainfall, thus leading to rainwater running off the surface which results in river levels rising rapidly and bursting their banks.

The DAS Monitoring Indicator System

Indicators

For the 2023 (third) Monitoring Report, the indicator system dating back to 2019 was reviewed and developed further. As a result of the current update, the DAS Monitoring Indicator system comprises 117 monitoring indicators in total: 67 indicators describe the impacts of climate change (Impact Indicators), 45 describe adaptation measures or activities and conditions supporting the adaptation process (Response Indicators), while another 5 are cross-sectional monitoring indicators

64 Indicators stemming from the 2019 Monitoring Report were updated based on the same methodology. 25 Indicators were revised on the basis of new scientific findings and / or changed baseline data. They are therefore presented in an altered form, although most of these appear under the same indicator title as before. 15 Indicators were deleted from the set, either because the relevant data sources no longer exist or it was possible to replace those indicators by others, or because it is no longer possible to illustrate the subject matter adequately by means of the data available. Most of the deletions (5 indicators each) used to appear in the 'energy industry' and 'tourism industry' action fields respectively. In those cases, there were question marks regarding the previously illustrated close relationships between the circumstances involved and climate change. 4 indicators were assigned a dormant status, as it is still not possible to update the indicators in question compared to their status in the 2015 report, and / or because methodical reviews are imminent. It is expected that these indicators will reappear in the 2027 Monitoring Report (possibly in an altered form). 28 indicators were newly created and make their first appearance in the 2023 Monitoring Report. Innovations are contained in nearly all action fields. The new indicators either replace indicators that have been removed from the set, or they address new themes which had not been examined before within the framework of the monitoring system. These indicators expand the thematic bandwidth and enhance the quality of the illustrations.

As far as the 'water balance and water management' action field is concerned, the work on the review and development of new indicators was carried out in close cooperation with experts at Federal and Länder level within the climate indicator subgroup which is part of the Federal / Länder 'water working group' LAWA. This group – appointed by the Standing Committee on Climate Change (LAWA-AK) – was tasked with bringing about a cross-Länder agreement on indicators which would allow the illustration of climate change impacts on issues pertaining to the water sector. Within the framework of a research project (DASIF) conducted on behalf of the Federal Environment Agency (UBA), three indicators – based on satellite data – were newly developed, to replace previous case-study indicators (see below), thus permitting to make statements on the situation nationwide. Within the framework of a broader UBA project, an indicator on the 'soil' action field was newly developed and incorporated in the new DAS indicator set.

Principally, all monitoring indicators are intended to illustrate, by means of time series, developments across the whole of Germany. In respect of thematic aspects which are not yet sufficiently underpinned by nationwide data to allow the creation of indicators, it was possible in some cases to develop case studies. In the 2023 Monitoring Report, 13 such case studies demonstrate by means of spatially limited data sets, what statements might be generated at the nationwide scale if the relevant data were available. In respect of the 2023 Monitoring Report, it was possible to develop indicators further – which in the 2019 Monitoring Report had been case-study indicators – thus permitting to include them in the current Monitoring Report as indicators of nationwide validity.

Regional differentiations in respect of indicator illustrations are not generally provided for in the nationwide Monitoring Report. However, in some individual cases, nationally averaged statements are difficult to interpret. With the aid of time series for individual wider areas (such as 'north' or 'south') it may be possible to provide more specific statements subject to the availability of relevant data. Map illustrations are a new feature now integrated in the 2023 Monitoring Report. These maps supplement the illustrations pertaining to time-series with regional differentiations for a specific time period.

The deadline for updating the time series in the current, that is to say. the third Monitoring Report was 30th September 2022. It follows that principally, the last-named date in the indicator charts refer to the year 2021. Wherever this seemed either meaningful or necessary, the report texts provide a prospect of developments in 2022.

Handling uncertainties

It is not possible to illustrate all relevant climate impacts and adaptation activities by means of quantitative monitoring indicators. Several processes of data collection are still in their initial stages. However, extended time series will be required before it is possible to interpret any relevant developments. The unavoidable limitations in terms of the availability of data also mean that the number of monitoring indicators used currently in action fields does not necessarily reflect their importance.

In respect of numerous monitoring indicators, it is possible to provide a qualitative description of causal relationships between observable changes in the environment, society or economy on one hand and climate change on the other. However, it is much more difficult to determine their significance, as ecological and societal systems are influenced by multiple factors. When assessing damage to forests, for example, it is necessary, in addition to any impacts of climate change such as seasonal heat or drought periods or severe storms, to take into account other impacts not related to climate change, such as nutrient inputs, acidification and high ozone concentrations which may impact the health of trees. Intense discussions have taken place (and are likely to continue) in the course of the (further) development of the DAS Monitoring indicator system regarding cause-and-effect-relationships, and during the work on adapting indicators to the latest state of the art.

Fuzzy interpretations can also occur in respect of adaptation measures. Numerous measures such as the operation of the heat warning service provided by DWD, have been taken specifically in the interest of climate adaptation. Other measures also contribute to adaptation but that is not their only purpose. For example, nature-oriented measures such as forest transformation or the greening of buildings have multiple positive effects for which they have been planned and implemented in the first place. In any case, these measures also support an effective adaptation process.

In view of the inevitable uncertainties and a degree of fuzziness as discussed above, the intention is to continue reviewing and redeveloping the monitoring indicator system in the course of future updating cycles.

Assessing the developments

DAS Monitoring Indicators are intended to facilitate an assessment of developments that have been observed. The benchmark is the DAS objective to reduce the vulnerability to climate change impacts and to maintain and augment the adaptability of natural and social systems to the inevitable impacts of climate change. The intention is that the political objectives outlined in various action fields can be maintained even when faced with changes in the climatic framework conditions.

The adaptation objectives are currently the subject of a wide-ranging process of discussions. The adaptation targets are currently undergoing a wide-ranging discussion process which aims at the development of quantified targets. The achievement of those targets should be tangibly verifiable by means of indicators, some of which may have to be newly developed. The future development of the DAS Monitoring Indicator system will include the integration of these new indicators. As far as the current monitoring indicators are concerned, there have been no quantified targets set so far, which would make an assessment of the time series possible. The assessment is restricted to the outcomes of a statistical trend analysis and an appraisal examining whether the trend is basically in line with DAS objectives. Nevertheless, a negative or positive appraisal of trends does not seem meaningful in all cases, as the consequences of the changes observed are not always fully known. For example, an earlier flowering of winter rapeseed as a consequence of climate change, indicates that climate change does impact agricultural cultivation. However, the earlier flowering is not in itself necessarily a positive or negative phenomenon as it is part of ecological relationships and dependences. In cases of this kind, the illustration is restricted purely to the outcome of the trend analysis without having been subjected to an appraisal.

In respect of their trend developments, the time series were classified within the framework of statistical trend analysis. Each trend analysis was carried out using the same statistical process for all indicators. The methodology underlying the process applied in respect of the 2019 Monitoring Report was further developed. The analysis was applied to both linear (rising and falling) trends and to trends with trend reversal (square trends) respectively. Trend reversal is useful – especially when observing extended time series – for describing developments which started out as negative trends but, owing to successful adaptation measures, have recently become positive, or vice versa. The analysis of linear trends is carried out for all time series from 7 data points onwards, whilst for square trends, it is carried out from 13 data points onwards. In the process of trend analysis, all data points of the available time series are taken into account. Any data series with insufficient data points or which are based on surveys that are irregular or too far apart temporally are eliminated from analysis. In addition, a statistical change analysis is now carried out additionally for data series with at least 30 data points. This type of analysis checks time series for any significant discontinuities or changes in the development. Basically, all data points of a time series are always entered into the trend analysis. In cases where indicators illustrate time series of different lengths, it follows that the comparison of the trends obtained is limited by this fact. For methodological details regarding trend analysis, please consult the Organisation Manual for DAS Monitoring (Organisationshandbuch zum DAS Monitoring).

Development of Germany's climate

The development of Germany's climate since the end of the 19th century

The climate can be described as the mean condition of the atmosphere, characteristic extreme values and in terms of the frequency distribution of meteorological phenomena such as air temperature, precipitation and wind in a specific location. The climate is the outcome of complex interactions among all components that make up the system of land, atmosphere and oceans. Also part of this system are the biosphere with seasonal changes in vegetation, the hydrosphere, the soil and the cryosphere (ice). The climate can vary in different timescales even without the influence of human activity. This is well-known, for instance, from evidence of glacial periods which repeatedly enveloped major parts of Germany in an icy carapace. However, the assessment of observational data since the mid-19th century indicates progressive global warming which cannot be attributed to natural causes, and nowadays it is considered an established scientific fact that further temperature increases are to be expected. Both in Germany and globally, the mean value of average temperatures on the surface of land and water has steadily increased in the course of recent years. It can be stated that since the 1960s, every decade was warmer than the decade before[6].

According to the analyses carried out by the American federal research organisations NASA and NOAA, the global average temperature is currently around 1.1 °C above the level prevailing at the end of the 19th century[7]. It should be noted that most of the warming occurred in the course of the past 50 years: 21 of the 22 warmest years in global records were recorded in the years since 2001, with 2016 being regarded globally as the warmest year so far, and the years from 2014 to 2022 were, in global terms, the nine warmest years since systematic records began.

For Germany, sufficient data exist from 1881 onwards making it possible to identify climatic changes nationwide. However, this can be said only for the monthly observation of variables such as temperature and precipitation. Relevant, mostly contiguous daily data as well as other measured variables such as sunshine duration are generally not available for the years prior to 1951. While the impact of additional greenhouse gases on the increase of temperature since 1881 is patently obvious, whereas the correlation with changes in the precipitation scenario is more indirect and hence less obvious. This is partly due to changes triggered by general warming in large-scale atmospheric weather patterns. Precipitation is a crucial factor in the availability of water and is virtually of the same major interest as temperature itself.

One consequence of global warming can be seen in major changes to extreme weather events. This includes, for instance, regional shifts resulting in extreme weather events occurring in areas where they had not occurred previously. Likewise, there is an increase – within some regions such as Germany – of extreme weather events including heatwaves, and a decrease in other extreme weather events such as severe frost. The change in extreme thermal events owing to climate change is quite distinct and also scientifically proven, leading to grave consequences for many sectors of society. As far as heavy-rain events and extended drought phases are concerned, statements tend to be more differentiated and less clear-cut.

The subsequent paragraphs are intended to: first provide an overview of the development regarding the mean values of climatic conditions which have prevailed in Germany since 1881, followed by an assessment of changes regarding extreme events and then a look at what our future climate will potentially be like.

Mean values of climate changes

The assessment of mean values for climatic conditions was based on summarising the monthly data available since 1881 regarding seasonal and annual mean values for variables such as temperature and precipitation. Furthermore, the data collected at selective points at meteorological stations were applied scientifically to Germany nationwide.

Temperature

The annual air temperature as an aggregated mean for Germany between 1881 and 2022 was determined statistically to have risen by 1.7 °C (linear regression, cf. Fig. 1). This value is by 0.6 °C higher than the global temperature increase throughout the same period of time. This is not surprising, as the terrestrial regions warm up faster than the marine regions. However, in the course of the past 50 years, the speed of temperature rise has distinctly increased both in Germany and worldwide: Looking at the entire period of 1881 to 2022, temperatures increased every decade by 0.12 °C, and since 1971 the warming rate of 0.38 °C per decade has resulted in making this value three times as high. However, since the 1960s in this country, every decade was distinctly warmer than the previous one, and compared to global warming amounting to roughly 1.1 °C, the past ten years (2013–2022) in Germany were already 2.1 °C warmer than the first decades (1881–1910) since records began (cf. Fig. 2). In other words, nine of the ten warmest years in Germany occurred in the 21st century (cf. Table 1). An annual mean temperature greater than 10 °C had never occurred in Germany prior to 2014. Since that year, a total of five years passed in which such high values occurred.

Year	°C
2022	10,5
2018	10,5
2020	10,4
2014	10,3
2019	10,3
2000	9,9
2007	9,9
2015	9,9
1994	9,7
2002	9,6

Table 1: The ten warmest years so far in Germany since 1881 (data: DWD)

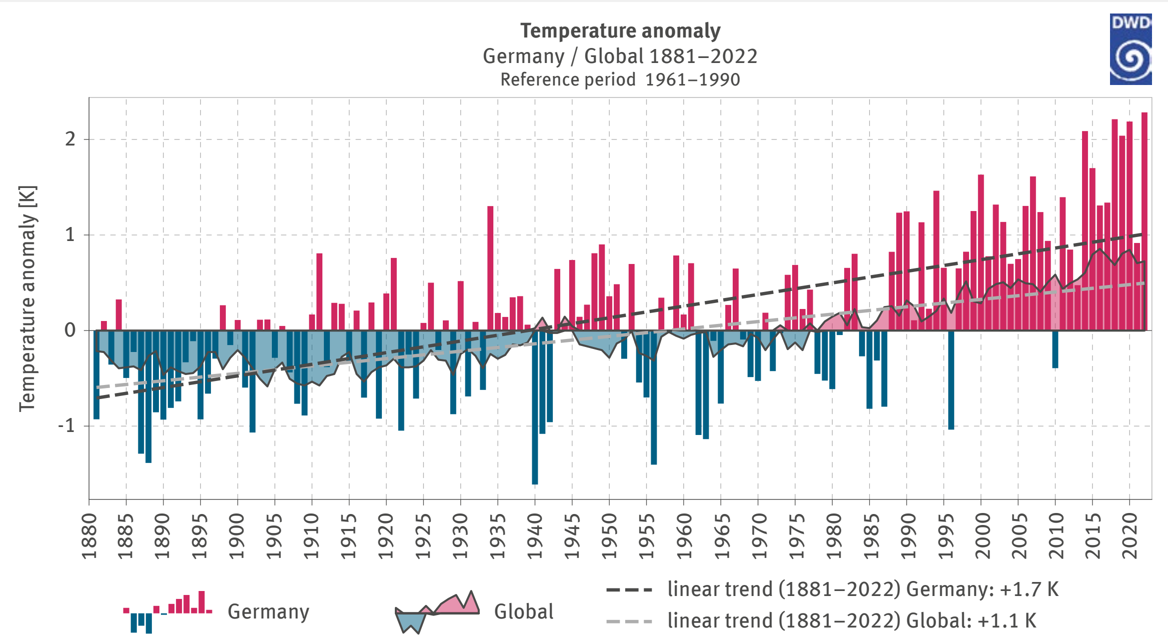


Figure 1: Deviation of annual mean air temperature for Germany and globally from the multi-annual mean 1961–1990 (data: DWD, NOAA)

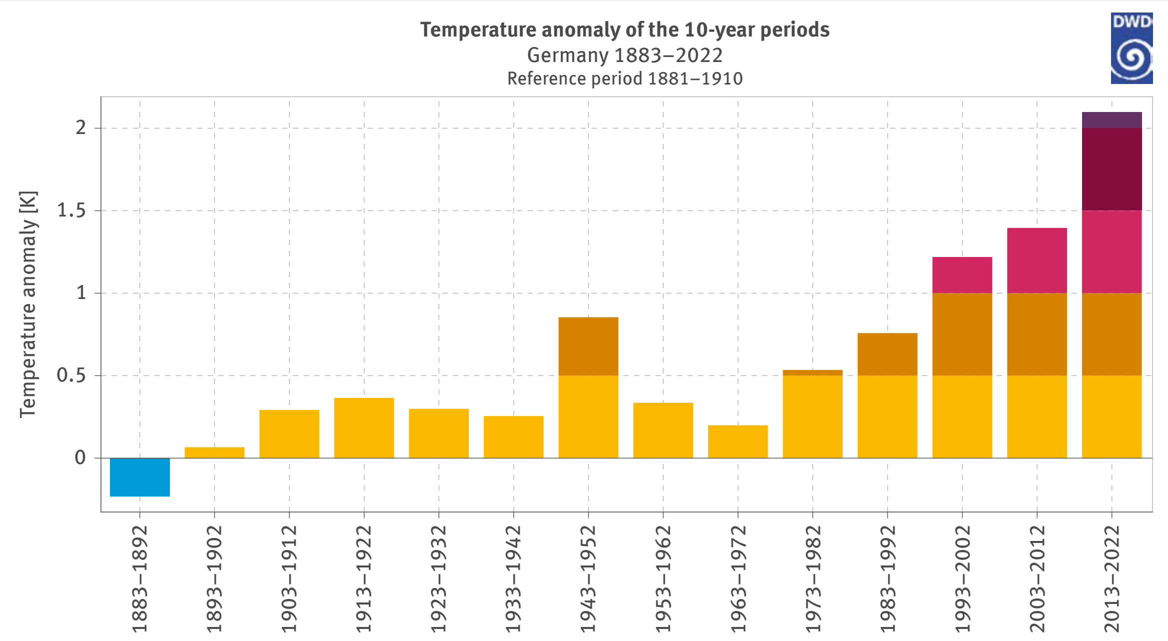


Figure 2: Deviation of 10-year mean air temperatures from the multi-annual mean 1991–1910 (data: DWD)

A close scrutiny of the temporal development shows that the rise in temperature did not take place evenly. In fact, there were phases of warming as well as periods of stagnation, interspersed from time to time with shorter periods during which temperatures tended to decrease slightly. One reason for this uneven progression is the wide range of fluctuations in atmospheric conditions from year to year with regard to, globally speaking, a relatively small region like Germany. Figure 1 demonstrates, in fact, that the variability of temperature in Germany (bars) is much greater than in the case of global temperatures (plane). However, in the course of periods extending over several decades, the so-called decadal climate variability has also played a crucial role. These are periodic fluctuations extending over several years or even a few decades, which are closely linked to ocean circulation – in other words, the sea currents. Depending on ocean circulation, there will be phases from time to time in which the surface temperatures of the sea either warm up or cool down, consequently leading to phases of warming or cooling in the atmosphere. These phases overlie the influence on the climate from external climate drivers. However, apart from natural elements such as solar irradiation and volcanic activity, human influences have to be taken into account, such as changes in land use, air pollution owing to sulphur dioxide output from industrial plant as well as emissions of greenhouse gases such as CO_2. Periods of a greater cooling effect – exerted by ocean circulation on the surface temperature of the sea and consequently on the atmosphere – can therefore lead to a total concealment of the long-term trend, even at times when the total of external climate drivers alone would lead to warming. In phases of weak ocean circulation or in the absence of a cooling effect from ocean circulation, the temperatures observed have been rising.

In Germany the temperature rise observed hitherto seems to have been largely homogeneous throughout the country. Basically, this applies also to the various meteorological seasons. Just in winter (December to February) the value for a surface area mean of 1.9 °C is slightly above the annual mean. For the other seasons the temperature increase of 1.6 to 1.7 °C is the same as for the year as a whole. Roughly the same can be said regarding spatial differences. In this case, the annual mean temperature rise ranges from 1.5 °C to 1.8 °C – bearing in mind that the warming tendency in the western federal states as well as in Bavaria and Thuringia – has so far been somewhat higher, whereas in Brandenburg and Berlin, this tendency is somewhat lower than the mean value for Germany.

Precipitation

In contrast to temperature, there are distinct differences in changes to precipitation in Germany, especially by season but also in spatial terms. Overall, the rainfall mean has remained largely unchanged in summer, whereas particularly in winter, conditions have become significantly more humid. Likewise, the amounts of precipitation have increased at autumn and spring, although this increase is distinctly lower and statistically unproven. Overall, the surface area mean for Germany since 1881 shows an increase in the annual mean precipitation by 7.3 %. However, there are major differences from a spatial point of view. Especially the federal states in the north-west of Germany show distinct increases in wet conditions of almost 16 % in Schleswig-Holstein, whereas precipitation amounts in Mecklenburg-Western Pomerania, Saxony-Anhalt and Thuringia show only a slight increase in the annual mean (less than 10 %). In Saxony, conditions actually became slightly drier during the same period. Spatially the picture is basically similar for the transitional seasons of spring and autumn.

The strongest changes have so far been observed for the winter season. As demonstrated in Figure 3, the surface area mean for average precipitation levels has increased by roughly 48 mm (+26 %) since winter 1881/1882. The spatial distribution of changes is obviously similar to that of temperature at this time of year. In other words, the smallest increases – values of less than 25 % – have so far been recorded in the north-eastern federal states. In the other federal states, rainfall has increased by a greater value than the nationwide average. In the light of these spatially differing variables for warming and increases in precipitation, it can be said that the differences in the degree of continentality of regions, that is to say, the different relationship in terms of the influence of land and sea on the climate at a specific location, show a slightly rising tendency in the course of the 20th century. With regard to the summer months, there has been hardly any change so far. While it is true that the precipitation mean at that time of year has decreased by roughly 11 mm since 1881, it must also be said that the overall minimal decrease, which is within the range of natural variability, does not allow any conclusions even regarding tendency (cf. Fig 4).

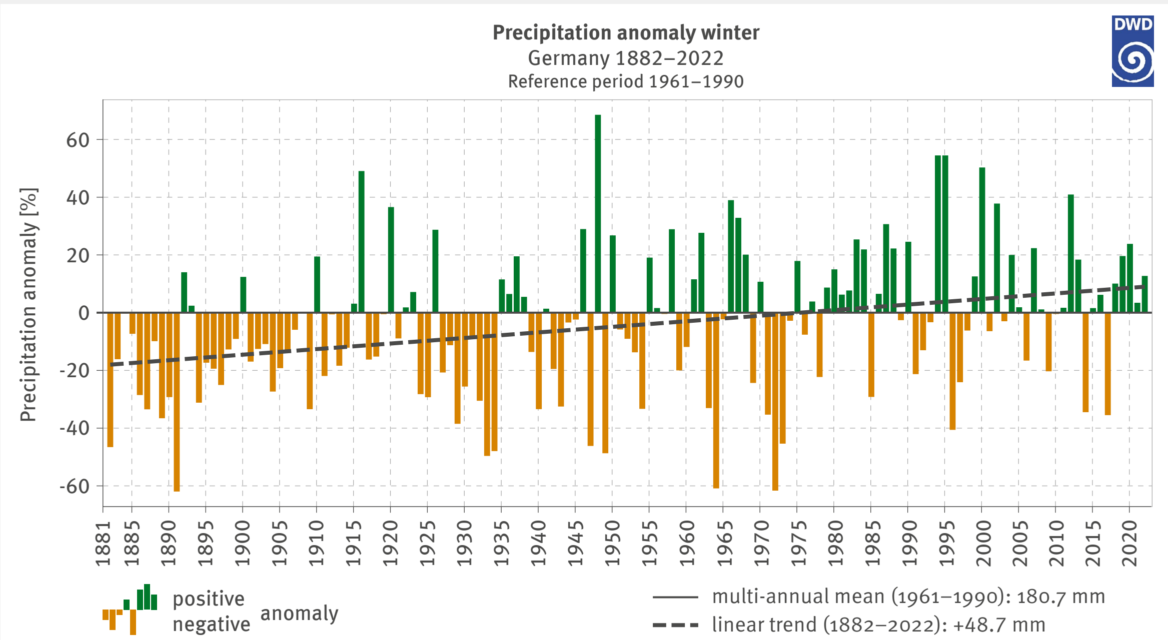


Figure 3: Percentual deviation of winter precipitation (December, January, February) from the multi-annual mean of winter precipitation totals 1961–1990 (data: DWD)

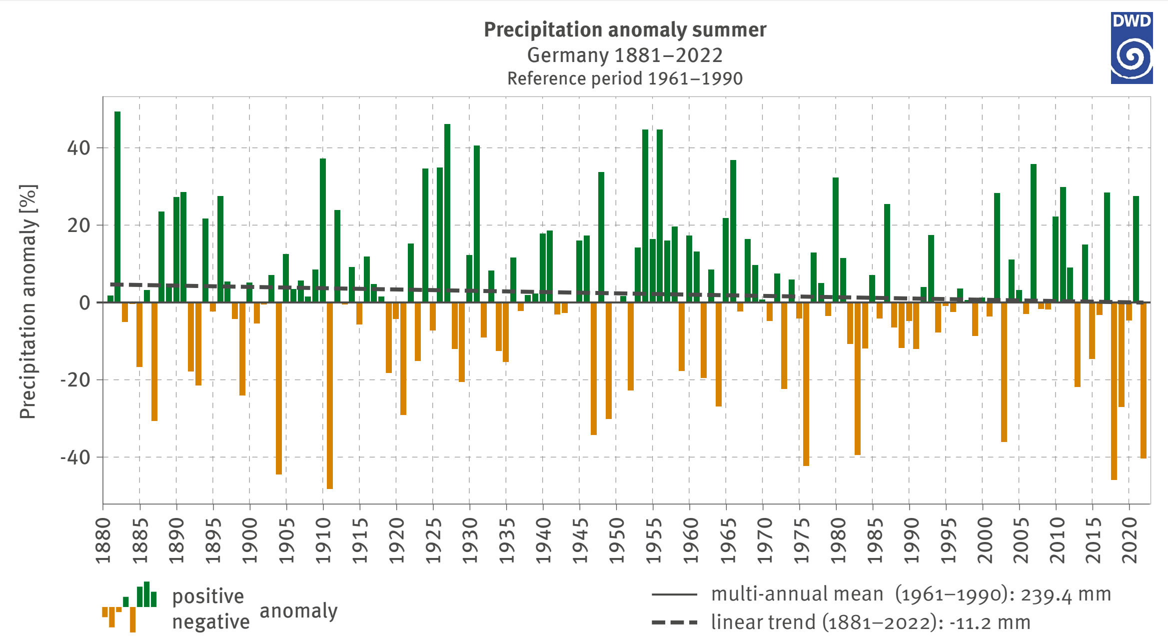


Figure 4: Percentual deviation of summer precipitation (June, July, August) based on the multi-annual mean of summer precipitation totals for 1961–1990 (data source: DWD)

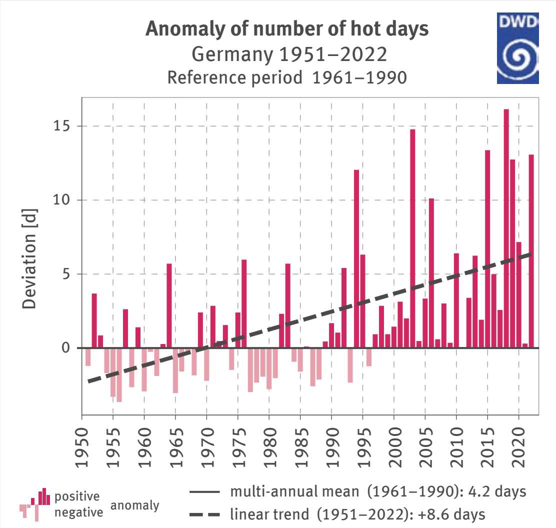
Changes regarding extremes

As the term implies, extreme situations are rare as they deviate strongly from usual situations. Consequently, statistical analyses are less resilient than assessments of mean conditions. So-called once-in-a-century events (in other words, extreme events which statistically occur once in 100 years) for instance, have to be determined on the basis of series of measurements which typically extend to little more than a hundred years. A relatively easy and very descriptive method of determining changes in extreme events are so-called climatological indicators on which threshold values are recorded; these are termed threshold value events. This is, in fact, an assessment of days on which, for instance, the maximum temperature exceeds a specific threshold value, as for example the number of hot days with a maximum temperature of at least 30 °C. Apart from such threshold values, it is possible to utilise other indicators which can also be used for recording persistent extreme climate events such as heat or drought periods. The subsequent paragraphs present and discuss various indicators for the analysis of changes in extreme events regarding temperature and precipitation levels.

Statistically backed statements are already available today regarding changes in the frequency of cases where threshold values have been exceeded in terms of temperature; as indicated by the data, heat periods have become more frequent and more intensive throughout Germany since 1951. It is more difficult, however, to make reliable statements regarding trends of heavy precipitation events. On one hand, such events entail a high variability in terms of space and time, while on the other, especially during the summer months, convective events – the development of showers and thunderstorms – are considered relevant in cases where they occur within the space of an hour or less. Although it is possible to observe tendencies towards a greater frequency of heavy precipitation events in the course of the past 65 years, it has so far not been possible, owing to the lack of available data, to make any statistically backed climatological statements on changes in heavy precipitation events.

Temperature extremes

For the analysis of temperature extremes, the amount of hot days as well as ice days (days with a maximum temperature of < 0 °C) were examined. Furthermore, the most intensive annual 14-day heat period with a daily



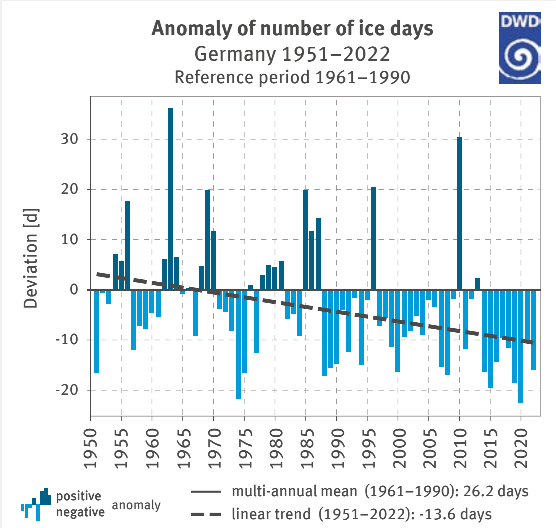


Figure 5: Deviation of the number of hot days (left) and ice days (right) from the multi-annual mean 1961–1990 (data: DWD)

maximum of at least 30 °C air temperature for the period 1950–2022 was assessed for eight German cities.

Since 1951 there has been an increase in the number of hot days in Germany from a mean of approximately three days annually to a current mean of approximately ten days annually (cf. Fig. 5 left). Prior to 1994, more than ten hot days were never recorded in Germany before. The years with the greatest number of hot days were 2018, 2003, 2015, 2022 and 2019. The increase in hot days is backed up by statistics, notwithstanding great variability of this index from year to year. By comparison, the considerable decrease in the mean of ice days from roughly 27 days to currently approximately 18 days annually is statistically significant (cf. Fig. 5 right).

The temporal development of surface area mean values contained in temperature indicators is clearly reflected in their spatial development (cf. Fig. 6). Likewise, the major spatial differences between individual German regions are clearly visible.

In the period of 1953 to 1962 the mean of hot days amounted in many areas to between zero and four days

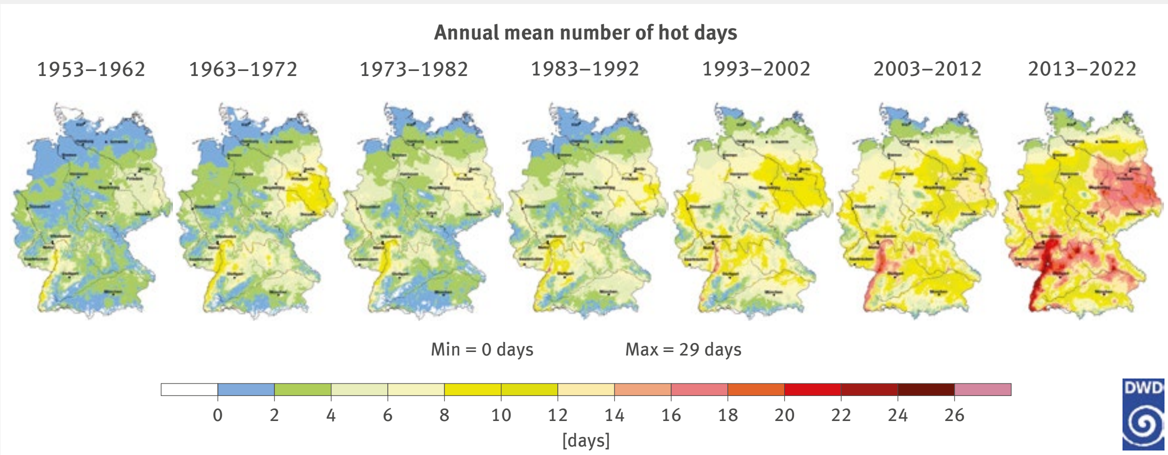


Figure 6: Mean annual number of hot days (data: DWD)

annually. Just along the Rhine trough and in north-east Germany south of Berlin between four and eight such days occurred, while in parts of the southern Rhine trough up to ten such days occurred (cf. Fig. 6). Up until the decade of 2003–2012, the number of hot days increased on average by up to 18 days annually. The extreme north of Schleswig-Holstein was the only area where that decade again showed fewer than two hot days annually. In the course of the past ten years the number of hot days, especially in eastern Germany, has again increased markedly. Consequently, the multi-annual mean in large areas of the south and east shows more than ten such days annually.

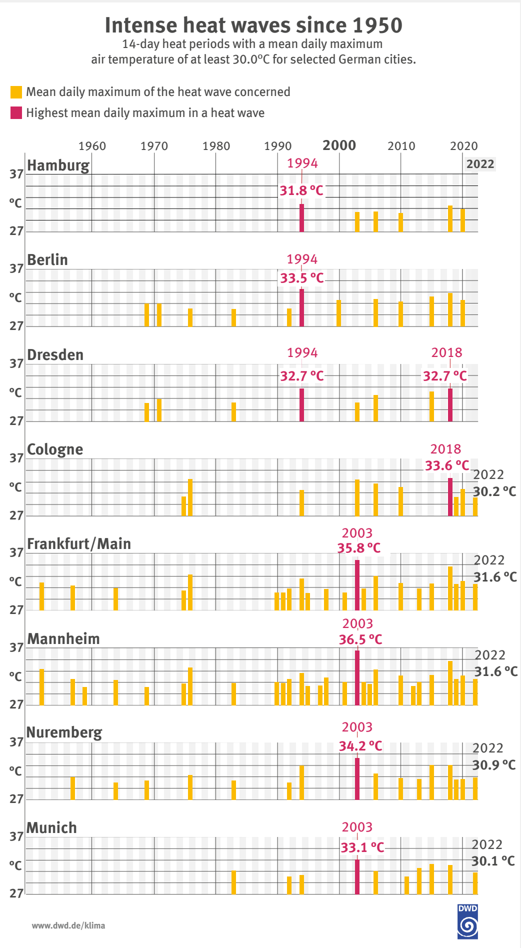


Figure 7: Mean value of the warmest 14-day period per annum for eight German cities (the height of a bar indicates the 14-day mean calculated, while the red bar indicates the year with the most intensive heat period so far) (data: DWD)

Figure 7 shows the most intensive annual 14-days heat period for several German cities, with a daily maximum air temperature mean of at least 30 °C for the period 1950–2022. Regarding the cities examined, it is clear to see that both the frequency and intensity of intensive heat periods show a rising tendency from north to south. Generally speaking, the mean of the highest daily maximum temperature in heat periods in northern cities lies below 33 °C; this value is often exceeded in the southern cities. There are fewer recordings for Munich than is typical for the south, because the recording station is located at a relatively high altitude (515 metres). Furthermore, it can be seen that such extreme heatwaves have occurred more frequently since the 1990s; for instance, Hamburg never experienced such events between 1950 and 1993, whereas six extreme heatwaves have occurred there since 1994.

Precipitation extremes

Relatively warm air is able to absorb more water vapour than relatively cold air. This is why principally, warming with consistent relative air humidity are expected to coincide with greater precipitation. Besides, it can be assumed that, especially on the so-called convective scale, the development of showers and thunderstorms, an intensification of processes leading to the development of clouds and precipitation can be expected as a result of changes in meteorological conditions. Heavy precipitation events occurring under such conditions would then even increase disproportionately compared to the increased content of water vapour in the air. The term heavy rain is used for major amounts of precipitation falling in a relatively short time. In this case, precipitation events typically result from convective clouds (such as cumulonimbus clouds). Heavy rain can lead to a fast rise in water levels and flooding which is often accompanied by soil erosion. The three warning levels employed by the DWD for different durations are illustrated in Table 2.

It must be borne in mind, however, that several other factors and processes play an essential role in the development of precipitation, thus leading to regional differences. Presumably, heavy rain events do not occur in all places to the same extent.

In analysing heavy rain events on the basis of conditions prevailing at gauging stations, a differentiation is often made between daily precipitation totals and shorter intervals down to durations of 5 minutes. However, many investigations are limited to a minimal temporal resolution of 60 minutes. The frequency of heavy-precipitation events lasting 24 hours (cf. also Table 2) has not changed much in

	Heavy rain		Persistent rain	
Duration	**1 hour**	**6 hours**	**24 hours**	**48 hours**
Extraordinary weather	15 bis 25 l/m²	20 bis 35 l/m²	30 bis 50 l/m²	40 bis 60 l/m²
Tempest	25 bis 40 l/m²	35 bis 60 l/m²	50 bis 80 l/m²	60 bis 90 l/m²
Extremely severe weather	› 40 l/m²	› 60 l/m²	› 80 l/m²	› 90 l/m²

Table 2: DWD warning levels for various duration levels of heavy and persistent rain.

Germany over the past 70 years, although a minor increase was observed for the entire calendar year and most of the meteorological seasons. Owing to the overall infrequent occurrence of such events and their great variability from year to year, these trends cannot be considered statistically significant which means that they are not really meaningful.

In contrast, there are relatively few findings available for heavy precipitation of short durations occurring predominantly in summer in Central Europe. Admittedly, there are some indications for an increase in the intensity of convective events as temperatures rise. However, there is a distinct requirement for further research regarding this timescale. Trend analyses of heavy precipitation are principally hampered by the fact that not all particularly intensive precipitation events of limited spatial extent are necessarily captured by meteorological stations. In fact, sometimes they occur in the space between these stations and therefore elude recording. It is true that, in addition, there are radar data available for the past roughly 20 years for contiguous areas, but such timescales are currently too short to permit making any robust trend statements.

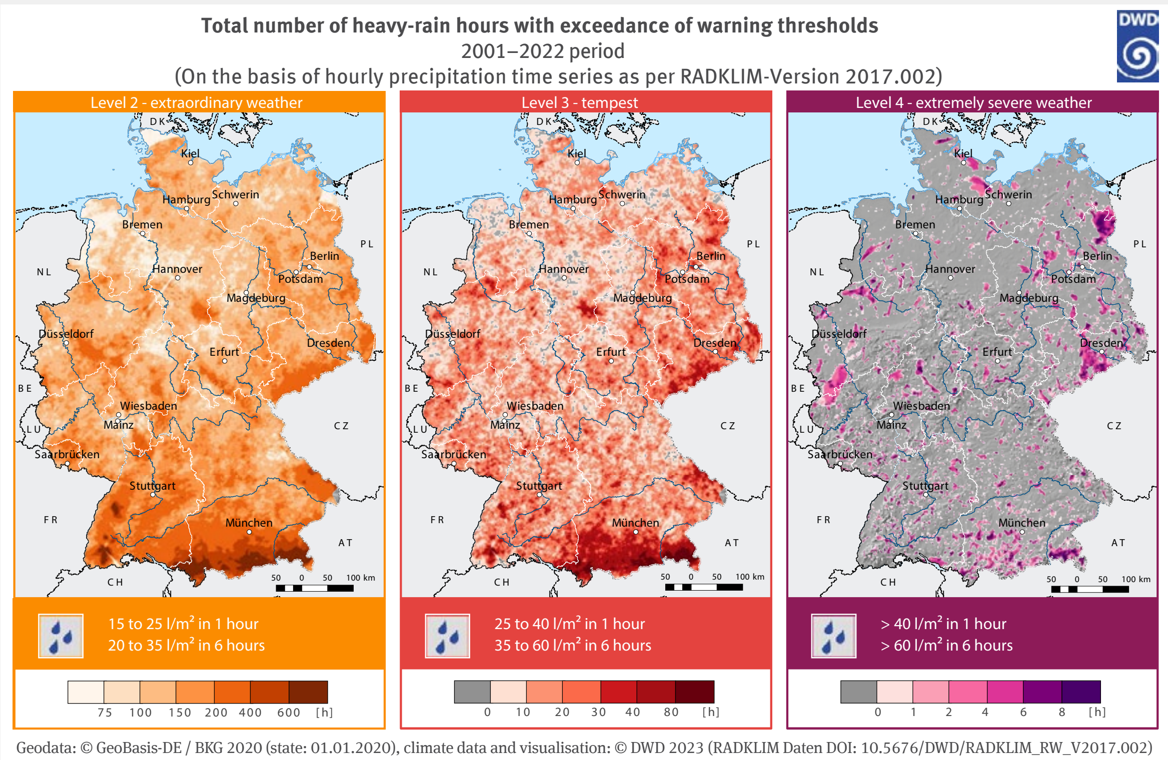


Figure 8: Total of precipitation hours within a period from 2001 to 2022, during which the DWD's warning thresholds were exceeded (source: DWD)
(The database is founded on the quantified precipitation analyses of data collected by the Wetterradarverbund (association of weather radar stations in Germany), as well as from the automated ombrometer and from any associated measuring network partnerships operated by individual states of Germany.)

Radar data have made it possible to capture and enumerate the occurrence of heavy-rain events for contiguous areas. Figure 8 shows that the hours of heavy precipitation of particularly high intensity amounting to more than 25 mm/h in 6 hours, or more than 35 mm per 6 hours, respectively, in Germany (cf. Fig. 8, middle) are distinctly more evenly distributed than the total hours of moderately heavy rain (cf. Fig. 8, left) where the spatial distribution is strongly linked to Germany's topography. This demonstrates clearly that spatially extremely small-scale heavy-rain events of short duration and with high damage potential can occur anywhere and affect anyone in Germany; in other words, these conditions constitute a hazard which is not limited to the southern federal states of Germany only. In fact, a temporal extension of this kind of heavy rain analysis will in a few years from now allow a robust trend analysis for the related frequency of events where threshold values are exceeded.

On the basis of a time series of radar data collected for 22 years, heavy-rain events were catalogued in the CatRaRE (Catalogue of Radar-based heavy Rainfall Events) and listed under 11 different duration levels varying between 1 and 72 hours. In addition to variables such as duration level, point of occurrence and precipitation intensity which can be determined on the basis of radar data alone, CatRaRE also contains demographic and geographical information on the events concerned. Figure 9 indicates the frequency distribution of precipitation events in Germany for the years 2001 to 2022 for the 11 duration levels. This, too, demonstrates that the number of events varies strongly from year to year between 554 events in 2001 and 2,304 in 2018. Initially it seems surprising that the greatest number of heavy-rain events occur in 2018 considering that the mean value for 2018 indicates that this was a comparatively dry year. However, 2018 also was an extraordinarily warm year. This validates the assumption that, in particular, relatively warm years can have a greater frequency of extreme convective precipitation events, because the duration levels of 1 to 6 hours alone account for more than 2,000 events in 2018. Although the time series of 22 years is still too short to allow a resilient statement on climate trend, it is nevertheless possible to identify a slight increase in the number of heavy-rain events in the period examined.

Extreme drought

In recent years drought has become a topic that is very much in focus. Apart from the issue of changes in heavy-precipitation events it is crucial, especially in summer, to examine to what extent warming is accompanied by additional soil dehydration. Agriculture is particularly

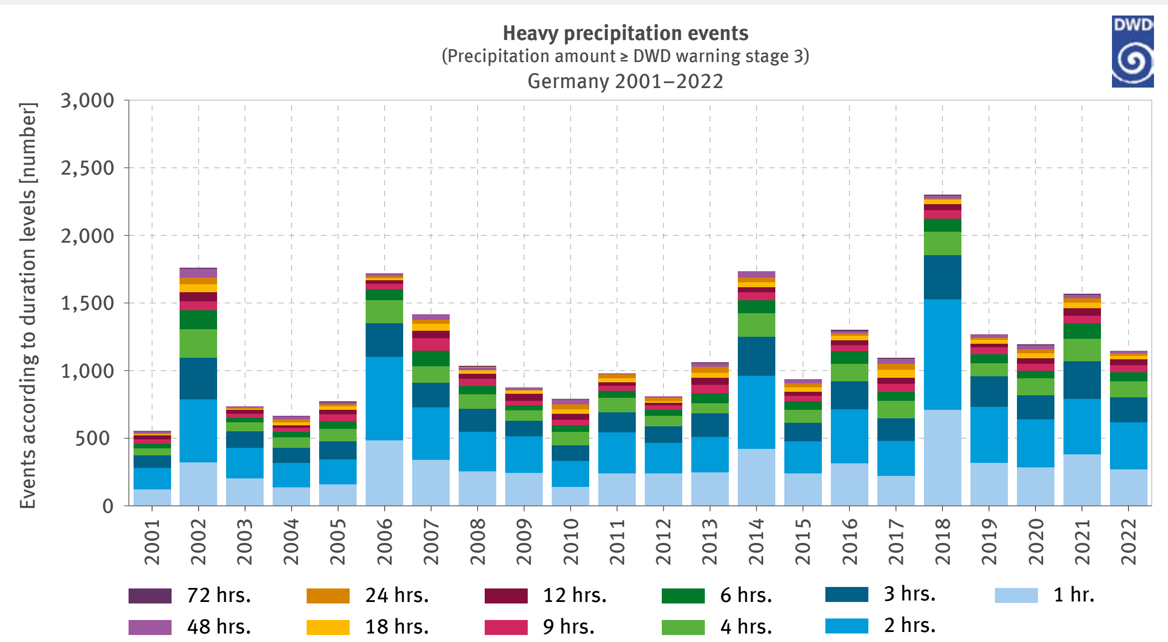


Figure 9: Annual number of heavy-precipitation events differentiated by duration levels (based on radar measurements taken by DWD)

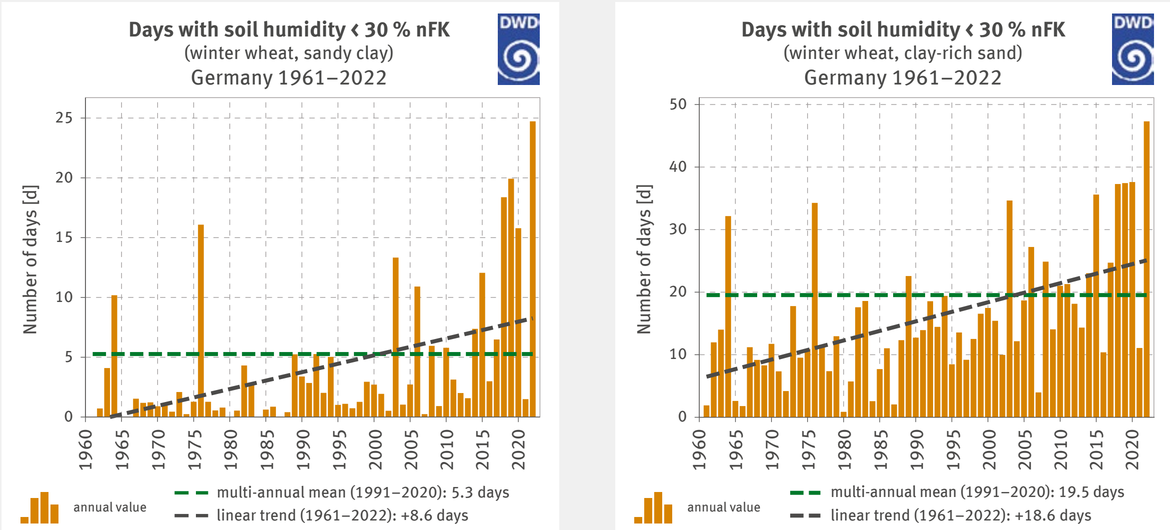


Figure 10: Annual number of days with soil humidity values below 30 % nFK for winter wheat on heavy soil (sandy clay, left) or light soil (clay-rich sand, right) (data: DWD)

vulnerable to drought, but other infrastructures such as water management and energy supply are also affected. In agriculture the term drought always refers to the condition of plants which – owing to lack of water resources in the soil – either have to limit their photosynthesising activity or, in extreme cases, have to die. Inadequate availability of water in the soil can be caused either by the absence or lack of precipitation and by high evaporation rates of plants; these rates are higher in dry and warm weather than under cold and humid conditions.

An ideal indicator for the degree of water supply available to plants is the soil humidity which is expressed as a percentage of usable field capacity (% nFK). The usable field capacity (nFK) is a relative measurement for the amount of soil water available for absorption by plants. If soil humidity drops to less than 30 % up to 40 percent nFK, this will distinctly reduce the photosynthetic performance thus leading to reduced plant growth. The longer a plant remains in this condition, the more severely it can be damaged. It was therefore considered essential to examine the number of days on which the critical soil humidity values of 30 % nFK for the cultivation of winter wheat were not reached. The examination focused on the main growth period of winter wheat, which will typically last from March until July or August. Furthermore, the type of soil also has a major influence on soil humidity. Heavy soil (such as sandy clay) is able to store more water for plants than light soil (such as clay-rich sand); that is why the former is able to bridge longer periods of drought than the latter.

As shown in Figure 10 the mean number of days with soil humidity values of less than 30 % nFK has increased significantly in Germany since 1961, both for heavy soil (left) and for light soil (right). Owing to the lower water storage capacity of light soil, the number of days on which the critical threshold value is not reached is generally greater for light soil than for heavy soil. However, for the development of or the damage to plants, the duration of such days with an nFK value of less than 30 % plays an important role. Furthermore, it must be remembered that extended droughts during the main growth period affect the development of plants and yields significantly – more than, for instance, a brief drought just before harvest.

Widespread areas in eastern Germany and the Rhine-Main area are particularly affected by increasingly dry soil (cf. Fig. 11).

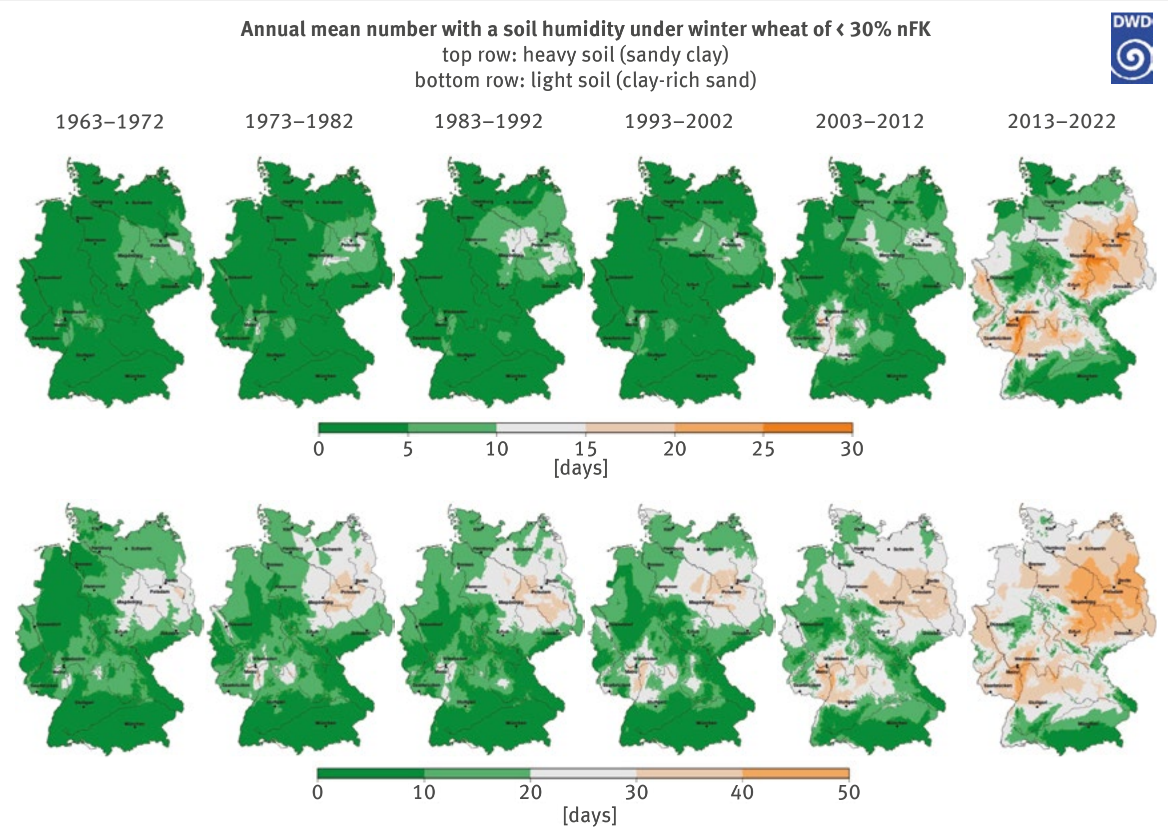


Figure 11: Annual mean number of days with a soil humidity of less than 30 % nFK for winter wheat on heavy soil (top: sandy clay) and light soil (bottom: clay-rich sand). NB Please note the different scales underlying the two illustrations.

Future developments

Any statements on the future development of meteorological parameters are made on the basis of climate projections. The potential climate change is calculated by a global climate model based on a scenario. Two scenarios are examined in this report. The 'Climate protection scenario' (RCP 2.6) is based on assumptions in line with the global 2-degrees upper limit. The aim is to achieve a situation where in 2100 the world will be subject to global warming of no more than 2 °C compared to the pre-industrial level. The 'High emissions scenario' (RCP 8.5) describes a world in which energy supply is essentially based on the burning of carbon-rich fossil fuel reserves. Compared to today, the emission of greenhouse gases will increase further steadily by 2100 in line with the radiative force.

It would be incorrect to equate a climate projection to a climate forecast. In fact, it is a 'what if' calculation based on the scenario selected. Climate projections are useful for trying to categorise different scenarios within a bandwidth of potential developments while taking into account different climate protection measures.

Global climate projections are used as drivers for regional climate projections. The analyses shown are based on the outcomes of 32 regional climate projections covering a period from 1971 to 2100 (climate ensemble). The regional climate projections used constitute the DWD Reference Ensemble which was 'regionalised' within the framework of research into a theme entitled 'Climate change and adaptation' by the experts network of the Federal Ministry for Digital and Transport (BMDV); it was bias-adjusted (in other words, adjusted for a reduction in systematic errors) and applied to a 5 kilometre grid[8]. The assessments listed below are all based on this ensemble. In order to calculate the difference between the present and the future state, two 30-year periods were used, and a mean value was calculated for each period. The years from 1971 to 2000 covered in the model calculations were used as reference period for the climate examined. Furthermore, in order to optimise categorisation, Figure 12 (right-hand side) shows – in respect of temperature – the change in relation to the early industrial period of 1881 to 1910. Two periods were analysed in terms of the future: The short-term planning horizon describes the mean value of the years from 2031 to 2060. The years from 2071 to 2100 are used as a basis for the long-term planning horizon. Future changes are stated in terms of a bandwidth. The description of the bandwidth is based on the values of the 15th and 85th percentile contained in extant datasets. This approach makes it possible to eliminate any outliers at either end of the ensembles from climate projections.

Temperature – mean values and extremes in the future

The temperature change that has been reached already – between the early industrialisation period and the reference period of 1971 to 2000 – amounts to 0.8 °C. In Germany, a further temperature increase is to be expected.

For the short-term planning horizon (2031–2060) the increase amounts to 0.8 to 1.5 °C approximately in the climate protection scenario and to 1.5 to 2.3 °C in the high emissions scenario (cf. Fig. 12). So far, the development has not been very dependent on the emissions scenario. The warming process is more pronounced in the south of Germany. The temperature development for the long-term planning horizon (2071–2100) is characterised strongly by the scenario selected. Based on the climate protection scenario, an increase by 0.9 to 1.6 °C is to be expected. There are hardly any regional differences. Under the conditions of the high emissions scenario, warming amounts to 3.0 to 4.7 °C approximately. The warming process is more pronounced in the south of Germany. The extent of warming is similar in the various seasons, except for spring when it is less pronounced.

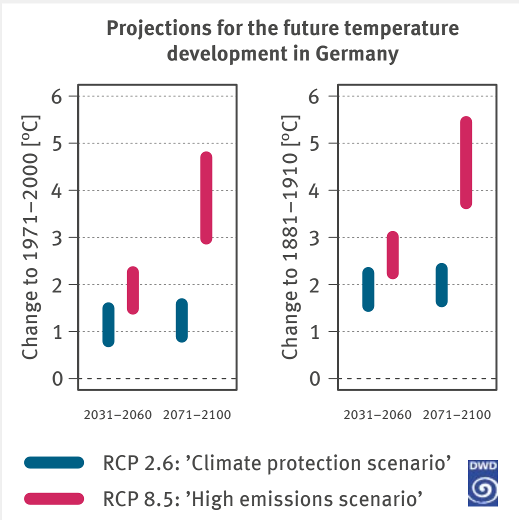


Figure 12: Range of the change signal in extant climate projections for the annual mean temperature.

The future increase in temperature entails a distinctive change in temperature extremes. Extreme conditions linked to low temperatures are decreasing markedly, whereas those linked to warmth are increasing strongly. This development also increases the frequency of heat-waves. The climate projections suggest a distinct change in all indicators, especially in terms of the high emissions scenario and the long-term planning horizon. In most regions, a distinct increase is expected in terms of summer days, hot days and tropical nights. As far as the mean value for Germany is concerned, regarding the short-term planning horizon, the high emissions scenario suggests between 5 and 10 additional hot days annually, and regarding the long-term horizon, between 14 and 28 days. In future, tropical nights will occur also in regions where they have not occurred before. In particular for the high emissions scenario, a distinct increase in frequency and an expansion to new areas are to be expected. As far as the mean value for Germany is concerned, in this scenario, for the short-term planning horizon, an increase by up to 3 tropical nights annually is to be expected, compared to the long-term planning horizon where an increase by 5 to 16 tropical nights is to be expected. In the Upper Rhine Rift Valley and in urban agglomerations, the greatest increase in tropical nights is to be expected. By contrast, the number of frost and ice days – as in the past few decades – will decrease further in all regions. Especially in the river valleys of Ruhr and Rhine, ice days will occur only very rarely. However, less drastic changes are to be expected for the short-term planning horizon and for the climate protection scenario.

Precipitation – mean values and extremes in the future

For the short-term planning horizon 2031–2060, there is no distinct change projected with regard to the annual precipitation total. For the annual mean precipitation a change by ±0 % to +6 % was calculated regarding the climate protection scenario and by -1 % to +9 % for the high emissions scenario (cf. Fig. 13). The difference between the two scenarios is minor, while the change is roughly the same for the entire Federal Republic. In principle, it must be said that a modelled change of less than 10 % is not distinguishable from natural climate variability. This threshold value applies equally to all subsequent values. For the long-term planning horizon of 2071–2100 in Germany, with regard to the high emissions scenario, a change in the annual mean precipitation is to be expected in the range of ±0 % to +16 %. The change is expected to be about the same in all parts of the Federal Republic.

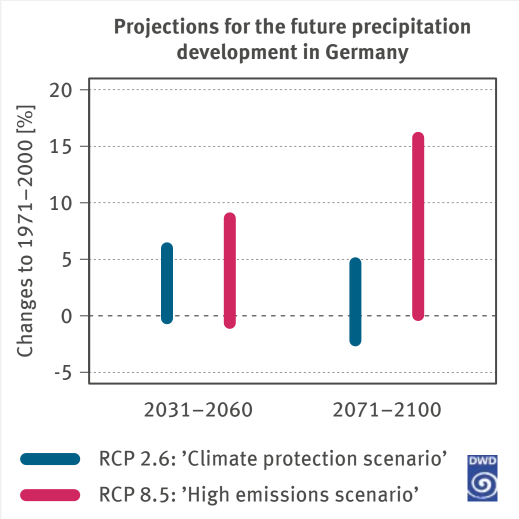


Figure 13: Spectrum of the change signal in extant climate projections for the annual precipitation total

For the short-term planning horizon 2031–2060, using the climate protection scenario for winter, the increases calculated amount to between +3 % and 11 % compared to between +2 % and 23 % in the high emissions scenario. It is not possible to make a resilient statement regarding the trend direction for summer and autumn. The range of outcomes for summer lies between -6 % and +3 % (climate protection scenario) and between -7 % and +7 % (high emissions scenario). In autumn the range lies between -4 % and +5 % (climate protection scenario) and between -7 % and +10 % (high emissions scenario). In spring there are changes indicated for this planning horizon in the mean precipitation total – assuming a climate protection scenario ranging from +3 % to +12 %. On the basis of the high emissions scenario, an increase between +6 % and +14 % was calculated.

In spring, the change on the basis of the long-term planning horizon (2071–2100) can – depending on the type of scenario – amount to +0 % to +11 % (climate protection scenario) or +3 % to +22 % (high emissions scenario), whilst in autumn the comparable values are -3 % to +7 % (climate protection scenario) or -7 % to +18 % (high emissions scenario). In winter the change can lie between +7 % and +33 % (high emissions scenario) and between -3 % and +13 % (climate protection scenario). For the summer within this planning horizon, values ranging from a very small change in the climate protection scenario (-6 % to +3 %) were calculated, while a potential decrease in precipitation was calculated for the high emissions scenario with values ranging from -14 % to +6 %. In the individual regions, summer is also characterised by wide-ranging outcomes which appear not sufficiently resilient.

As far as the change in the number of days with precipitation of at least 20 mm per day is concerned, an increase is expected for all regions, both within the short-term and the long-term horizon. For the alpine region only, some models project a decrease in the number of days. In this context, the most distinctive increase is projected for spring and winter. In the short-term planning horizon, the difference between the individual climate scenarios is rather minor, whereas in the long-term planning horizon, the difference is more pronounced in winter, spring and autumn. A less pronounced increase is projected for the days with precipitation of 30 mm and more. However, in the case of heavy-rain events, the range within the ensemble is very extensive in some cases, thus making the outcomes lack in resilience. Regional differences regarding the change in the annual mean total of precipitation are not very pronounced.

For the projection period the assumption is that for the whole year, dependent on the bandwidth of the climate model ensemble and the climate scenario, changes ranging from a minor decrease up to a moderate increase in dry days can be expected. However, as far as the individual seasons are concerned, projections are more differentiated. While there is no appreciable change in respect of dry days within the short or the long-term planning horizon regarding the climate protection scenario in winter and spring, there is a moderate increase expected for summer and autumn, although there are no major differences between the short or long-term horizons, Within the high emissions scenario there are no projections for major change either, as far as winter and spring are concerned. However, especially in summer, a distinct increase in dry days is projected for the distant future although this is projected to be more moderate in the autumn season.

Indicators of climate change impacts and adaptation

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Human health

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

The World Health Organisation (WHO) describes climate change as the 'single biggest health threat facing humanity': In many countries in the global south, climate change exacerbates the problems already caused by hunger and inadequate access to clean drinking water. However, climate change impacts are also on the increase in Germany where, owing to demographic change, they present our ageing society with problems.

This is why in 2022, the task force entitled Health Climate Pact (Klimapakt Gesundheit) published a joint declaration regarding its joint responsibility to counter the health impacts of climate change and to advance the public health system by improving health care in terms of climate adaptation, climate protection and sustainability.[9]

DAS Monitoring –what is happening due to climate change

Extreme weather and weather patterns have an immediate effect on health. Ever since the 1980s, there has been an increasing trend towards heat extremes (cf. Indicator GE-I-1, p. 40). In extreme cases, heatwaves can cause mortality. In Germany alone, for example, it is estimated that between the years of 2018 and 2020, 19,300 individuals died from heat effects (cf. Indicator GE-I-2, p. 42). In the past three decades, a slight decrease in the effect of high temperatures on mortality figures has been recorded.

Apart from heat-related health impairments, it is important to mention also pollen allergies, skin cancer caused by UV radiation as well as cardio-vascular and respiratory illnesses caused by air pollutants; all these health conditions have been linked to (non-infectious) illnesses which are regarded as associated with climate change. Nowadays, allergies are among the most frequent chronic diseases in Germany. Among these, pollen allergies play a particularly important role. Climatic changes influence the pollen season and the intensity of pollen burdens. Apart from grass pollen, various types of birch pollen are top of the 'hit list' as the cause of sensitisation among Germany's population. As far as birches are concerned, some intensive research has been carried out studying the links to climate change. Especially in eastern Germany, the pollen concentration has been rising since records began in 1995 (cf. Indicator GE-I-3, p. 44). So far, the pollen concentration of the introduced highly allergenic Annual Ragweed (Ambrosia artemisifolia, see Indicator GE-I-4, p. 46) does not indicate any trend. However, the peak values identified repeatedly in eastern Germany are alarming; among other causes, these are attributed to long-distance transport from neighbouring south-eastern countries and/or to regional plant populations.

As far as cases of UV radiation (cf. Indicator GE-I-8, p. 54) and air pollutants are concerned – the latter is linked in particular to near-ground ozone (cf. Indicator GE-I-9, p. 56); the relationships with climate change are complex and not yet fully understood. Nevertheless, in both cases, the changed radiation scenarios and/or the changed radiation intensity are important factors. The health risk caused by UV radiation increases as a function of increased irradiation. Photochemical ozone generation is boosted in particular during prolonged periods of sunny weather. With this in mind, both of these themes have now been incorporated in the Monitoring Report for the first time.

Infectious diseases, too, are brought into context with climate change. As far as animal pathogen vectors such as mosquitoes, ticks or rodents are concerned, their living conditions can potentially improve under changed climatic conditions. This also holds true for the pathogens themselves, thus increasing the infection risks arising for humans and animals. The Asian Tiger mosquito is one example of a vector that is able to transmit hazardous pathogens. Owing to warmer weather patterns, this species is increasingly widening its distribution range and is able to hibernate, thus establishing populations (cf. Indicator GE-I-5, p. 48).

Analogous to the Indicator entitled 'Contamination of bathing water by cyanobacteria burdens' describes hazards concerning bathing in lakes (cf. Indicator GE-I-6, p. 50), the Monitoring Report now also presents an indicator covering health hazards to bathers in the sea in respect of vibrios (cf. Indicator GE-I-7, p. 52). Especially in years with prolonged heatwaves, the extent of such loads becomes unusually high, thus distinctly increasing the risks to bathers.

Future climate risks – outcomes of KWRA

According to the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7), the findings demonstrate that the impacts on health are even now causing high risks. In the run-up to the middle of this century, high risks are expected also in terms of health impacts from air-borne allergens and UV burdens. In addition, in the run-up to the end of this century, a high risk of respiratory problems owing to air pollution is expected, although this estimate is subject to low certainty.

The 2021 KWRA also analysed the impacts on the public health service. A high risk is expected to arise also in this sector by the end of the century. This means that presumably, but with low certainty, the health service will be facing a distinctly increased need for adaptation.

For the middle of this century, the risk of (a continued) spread of vector organisms – as well as potentially harmful microorganisms and algae – is assessed as medium (in a reference grid comprising the levels low – medium – high. This risk might lead to an increase in the incidence of certain vector-related) infectious diseases.

Likewise, the risk of increases in the number of injuries and mortalities resulting from extreme events is assessed as medium, albeit this assessment is subject to low certainty.

Where do we have gaps in data and knowledge?

In the 2023 Monitoring Report, the spectrum of the 'Human Health' action field was considerably widened by adding to the themes illustrated. Nevertheless, there are still difficulties in achieving a comprehensive reflection of the actual degree in which human beings are affected. The heat mortalities cover only the most extreme impacts of heatwaves whilst lack of data makes it impossible to quantify those illnesses that are a much more frequent outcome of heatwaves. With regard to other non-infectious and infectious diseases, it is difficult, to indicate any direct causal relationships with climate change impacts. Moreover, it is impossible to attribute the available data in a causal way. Hence, the focus of the Monitoring Indicators is on describing the potential risks at the impact level.

Despite the addition of new themes, it has not been possible to address several relevant climate risks in the context of DAS Monitoring, as there are certain gaps in research and also owing to the lack of data sources suitable for the development of indicators. However, there is also need for improving the datasets underpinning the themes addressed. In that context, the heat protection plan published in July 2023 by the Federal Ministry for Health (BMG) aims at improving the evidence for health impacts from heatwaves. In this context, the focus is on heat-related mortality and morbidity. Furthermore, there is a lack regarding the systematic and nationwide collection of data on the occurrence and spreading of vectors such as mosquitoes and ticks and the level of their infection with pathogens.

The issue to be researched is, as before, the question in what way and to what extent climate change will influence the quality of drinking water and foodstuffs in future. Work is also currently underway on the theme of fungal infections and in what way they are influenced by climate change[10]. Another focus of current research concerns the relationships between climate change and an increase in the resistance to antibiotics.

Climate change and the disasters ensuing from its impacts, which now occur with greater frequency and/or intensity, are not just putting physical health (including injuries) at risk; they can also entail various kinds of mental stress and disorders. However, the relationships of climate change and mental disorders have not yet been researched sufficiently to permit the presentation of concrete facts and figures in the current report.

Not least, climate change can entail high costs and new technical and organisational requirements to be covered by the public health service, as for instance, in terms of health care professionals, hospitals, emergency services or health insurance funds. These areas, too, require further research.

What's being done – some examples

At the core of adaptation efforts in health-related areas are the nationwide networking of stakeholder groups, setting appropriate political frameworks, supporting the municipalities, as well as monitoring and transferring scientific findings to practical applications. Furthermore, Federal government has a strong commitment to the tasks of communication and raising public awareness, with the objective to motivate and empower citizens, in particular, any vulnerable groups such as the elderly or persons with existing medical conditions, thus enabling them to protect their own health.

Since 2021, the Federal Centre for Health Education (BZgA) has used the internet portal entitled 'internetportal klima-mensch-gesundheit.de' to provide information in respect of the impacts of climate change on human health. Citizens will also find quality-tested recommendations on appropriate behaviour and action for their own protection from heat and UV radiation on that website. The UBA provides information – in some cases jointly with the DWD – especially on themes such as heat[11] as well as air and water pollution. The Federal Office for Radiation Protection (BfS) provides information on UV radiation, its impacts, and in what way these are influenced by climate change, as well as potential protective measures. Apps and targeted newsletters have gained increasing importance; these provide information on risks (cf. Indicator GE-R-1, p. 58) and in addition, individually tailored recommendations for action (cf. Indicator GE-R-3, p. 60). The intensive public relations (PR) work has already made an impact. For example, there are distinct signs showing that the population's awareness regarding the potential for heat affecting human health and wellbeing has increased (cf. Indicator GE-R-2, p. 59).

Monitoring and the systematic, continuous surveillance of the health problems scenario are essential tools in facilitating current and future health risks. With its focus on climate monitoring and weather observation as well as climate projections, the DWD makes vital contributions to achieving this objective. The BfS coordinates the monitoring of UV radiation, while the UBA collects data on air quality and combines these data with data collected by the Länder. In addition, the UBA examines climate change impacts also in terms of ticks, rodents and mosquitoes as well as the infectious pathogens transmitted by them. In doing so, the UBA provides a model for a nationwide hantavirus prognosis, at the same time as working on measures for the sustainable management of vectors. Since 2023, the Robert Koch Institute (RKI) has been monitoring – every week in summer – the heat-related survivability; the RKI is responsible for implementing the reporting system in line with the Protection against Infections Act (IfSG) and has been advancing the surveillance of non-infectious diseases and health-related risk profiles. The Friedrich-Loeffler Institute (FLI) is active in the field of monitoring vector organisms; jointly with the Leibniz Centre for Agricultural Landscape Research (ZALF), it has been maintaining the 'Mückenatlas' (mosquito atlas) (cf. Indicator GE-R-4, page 62).

In its progress report 'Klimawandel und Gesundheit' (Climate change and health) published in 2023, the RKI has provided a comprehensive scientific overview of the health impacts of climate change as well as suggesting opportunities for counteracting those impacts. This report has coalesced contributions from a major number of (public) authorities, universities and research institutions[12]

Apart from communication activities and raising public awareness, there is also a need for the support of health services. For this purpose, the BMUV launched the funding programme 'Climate adaptation in social institutions' (Klimaanpassung in sozialen Einrichtungen) in 2020. It provides support for social institutions for the purpose of protecting themselves from climate change impacts such as heat, heavy rain or flooding. Although the programme was initially scheduled to run until 2023, its duration has now been extended beyond 2023 to 2026 on account of the enormous resonance it has encountered. An overview of further funding opportunities for health services in respect of climate adaptation, climate protection and resources efficiency in Germany was compiled on behalf of the BMG[13].

Great need for action is seen at all levels, from Federal government down to municipalities. The generation of heat action plans has a high priority; the purpose of these plans is to prevent heat and UV-related impacts as well as medical complaints, and to reduce mortalities. The joint Federal/Länder government ad hoc working group entitled 'Health-related adaptation to the impacts of climate change' which is managed by the BMUV developed recommendations in 2017 – under the leadership of the UBA – for the design of municipal heat action plans. In March 2022, the BMUV initiated an emergency programme for climate adaptation developed for municipalities, which is also used for funding the development and implementation of heat action plans. In addition, and as requested by the Länder and leading municipal organisations, the Centre for Climate Adaptation (ZKA) founded – on behalf of the BMUV – an advisory programme for heat action plans. The Heat Service Portal [HitzeService-Portal (hitzeservice.de)] created on behalf of the BMG, is a platform to be used by municipalities for the planning and implementation of heat protection measures enabling these authorities to obtain tangible information and support.

Climate changes relevant to the action field

Photo: © deberarr / stock.adobe.com

Heat

The distinct increase in the mean annual temperature also entailed an increase in the frequency of temperature extremes. For example, the frequency of hot days with a maximum temperature of at least 30 °C has increased throughout Germany. Moreover, extraordinary heatwaves have occurred more frequently since the 1990s. In the context of the current monitoring report, heatwaves are to be understood as 14-day heat periods with a mean daily maximum air temperature of at least 30.0 °C. The examination of eight German cities revealed that 24 % of the heatwaves identified occurred in the period of 1961 to 1990, compared to 76 % which occurred in the period of 32 subsequent years (cf. Figure 7, p. 24)

Impacts of climate change

Photo: © Satjawat / stock.adobe.com

GE-I-2 Heat-related mortalities

Heatwaves affect human beings in different ways. Above all, the group comprising the elderly and people living alone, is regularly affected by mortalities at significant scales during intensive and prolonged heat events. It is estimated that in the years from 2018 to 2020 alone, 19,300 individuals succumbed to extreme heat. This figure exceeds the number of mortalities due to severe storm disasters.

Adaptations – activities and results

Photo: © Maren Winter / stock.adobe.com

GE-R-1 Heat warning service

The heat warning service established by the DWD informs the population and facilities such as hospitals via the heat newsletter, the health weather app (GesundheitsWetter-App) and the 'www.hitzewarnungen.de' website on imminent weather patterns hazardous to health. These information sources can help institutions to take preventative measures in good time as well as enabling the population to respond by taking measures for self-protection.

GE-R-2 Public awareness of health problems caused by heatwaves

In recent years, intensive PR work has contributed to raising public awareness regarding the impacts of heatwaves. This may also be one of the reasons why especially in recent years, there has not been an increase in mortalities, despite greater frequency and intensity of heat events.

Photo: © MiguelAngel / stock.adobe.com

Heat stress on the rise

Apart from the increasing average temperature, climate change will presumably also entail more health problems related to stressful heat events such as more frequent, more intensive and more persistent heatwaves. High temperatures impose burdens on health. Most affected are the elderly and individuals with chronic diseases such as cardio-vascular of respiratory diseases.

Looking back it is possible to discern a trend towards increasing numbers of 'hot days' (with a daily maximum temperature of 30 °C or more) and of 'tropical nights' with a temperature minimum of 20 °C or more since the 1970s. Contrary to hot days, tropical nights have so far occurred relatively seldom in our climes. It can be stated, however, that years with distinctive heatwaves have also regularly led to the development of tropical nights. Tropical nights are of particular relevance to health, as in those nights, especially after very hot days, the chance of getting a good night's rest is rather limited.

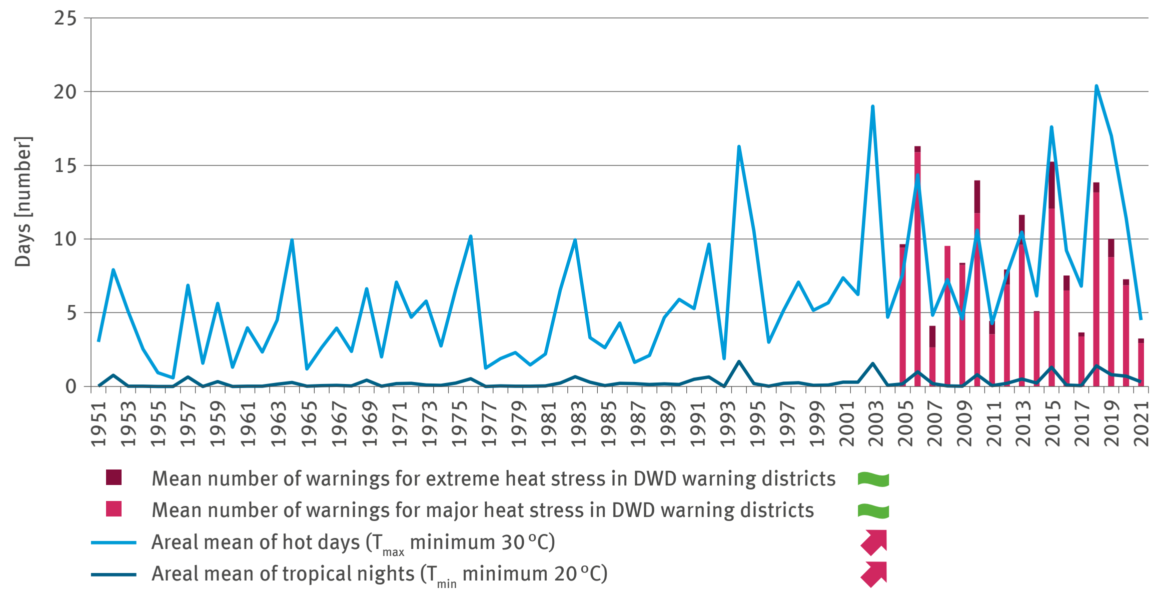
As far as tropical nights are concerned, it has to be borne in mind when interpreting the time series that the area mean for Germany underrates the actual stress, especially in urban areas, where most of the tropical nights occur. In the DWD climate measuring network, there are distinctly fewer urban measuring stations than background measuring stations. The latter indicate the mean for tropical nights at a lower level.

In 2005, the DWD launched a heat warning system. Since then, the criteria for heat warnings have been continuously developed further. Currently warning stage 1 is announced when at least 'major heat stress' is forecast (subject to regional adaptation in the course of summer) of approximately 32 to 38 °C 'perceived temperature' when, as a result, interior rooms do not cool down adequately at night. Warning stage 2 comes into force when the threshold value for extreme heat stress amounting to 38 °C 'perceived temperature' is exceeded, even when interior rooms cool down sufficiently at night (cf. Indicator GE-R-1, p. 58).

Ever since the heat warning system came into operation, there have been weather-dependent fluctuations in the

GE-I-1: Heat stress

Apart from the increase in annual mean temperature, there has also been a trend towards rising heat extremes, especially since the 1980s. The number of hot days and tropical nights has increased significantly. As far as heat warnings are concerned – issued by the DWD since 2005 – there is so far no clear trend discernible. However, the nationwide mean indicates that there has been no year without any heat warnings.

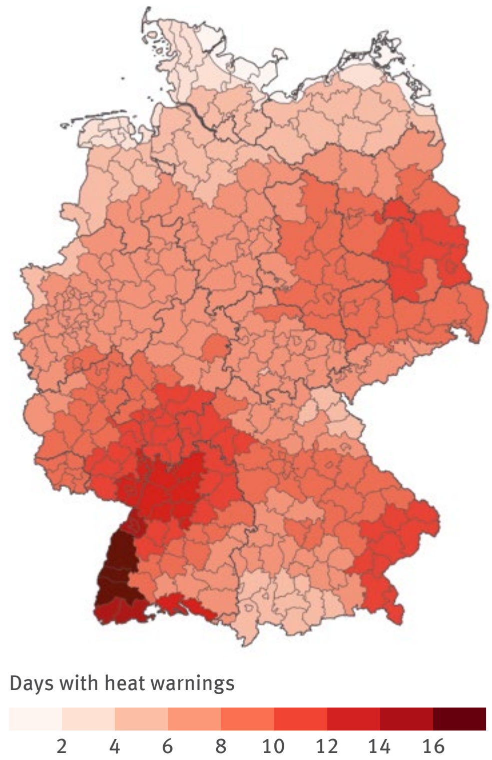


Data source: DWD (Open-Data-Server)

annual mean number of heat warnings in the so-called warning districts which follow the general outlines of administrative districts. An exceptionally high number (for the area mean) of heat warnings were issued on more than ten hot days in 2006, 2010, 2013, 2015 and 2018. Compared to the time series of hot days, there are years in which the number of heat warning days is higher than that of hot days, as against years in which the opposite applies. The 'perceived temperature' – relevant in terms of heat warnings – is determined with due consideration of a typical human being's temperature perception. Air humidity can play an essential role in this context. By contrast, hot days are based solely on air temperature data. The summer of 2018 was characterised by the highest number of hot days to date, but also by extreme drought. Owing to the fact that 'dry heat' is less stressful to health, fewer heat warning days were recorded than in 2015. On the other hand, the summer heatwaves in 2015 were accompanied by higher humidity. From June to mid-July and from the end of July onwards, the weather pattern prevailing at the time led to the influx of subtropical and humid hot air masses from the Mid-Atlantic and North-West Africa into Central Europe. From the middle to the end of July, a high-pressure system over the Azores dictated the sultry weather. In 2015, this situation resulted in the highest number of heat warnings in relation to extreme heat issued to date.

The spatially differentiated illustration of the mean number of heat warnings in the years from 2017 to 2021 demonstrates that there are major regional differences in the extent of stress. As expected, most affected are individual warning districts along the Upper Rhine from Baden-Württemberg in the south, and to Bingen in Rhineland-Palatinate. The Upper Rhine Rift Valley between the mountain ranges of the Black Forest and the Vosges acts like a heat storage basin; this area received an additional influx of warmth from the French part of the Rhône valley which is partly subject to Mediterranean influences. Further high values were recorded in the north-western parts of Baden-Württemberg such as the Neckar-Odenwald district, Heilbronn and Ludwigsburg, which are subject to the warm air emanating from the equally favoured Neckar valley.

Hot days and tropical nights as well as heat warnings indicate weather patterns that are apt to cause health burdens. However, they do not permit drawing any inferences as to how many individuals are actually affected by related health problems (cf. Indicator GE-I-2, p. 59).



Data source: Technical data: DWD (Historische Hitzewarnungen in Deutschland, Version v001, 2022)
Geodata: Geobasis-DE/BKG 2021

Days with heat warnings in DWD warning districts – mean of the years 2017–2021

The south-west along the Upper Rhine Rift Valley is Germany's heat hotspot. As indicated by the latest 5-year mean, heat warnings were issued here on 12 to more than 16 days.

Heatwaves can be fatal

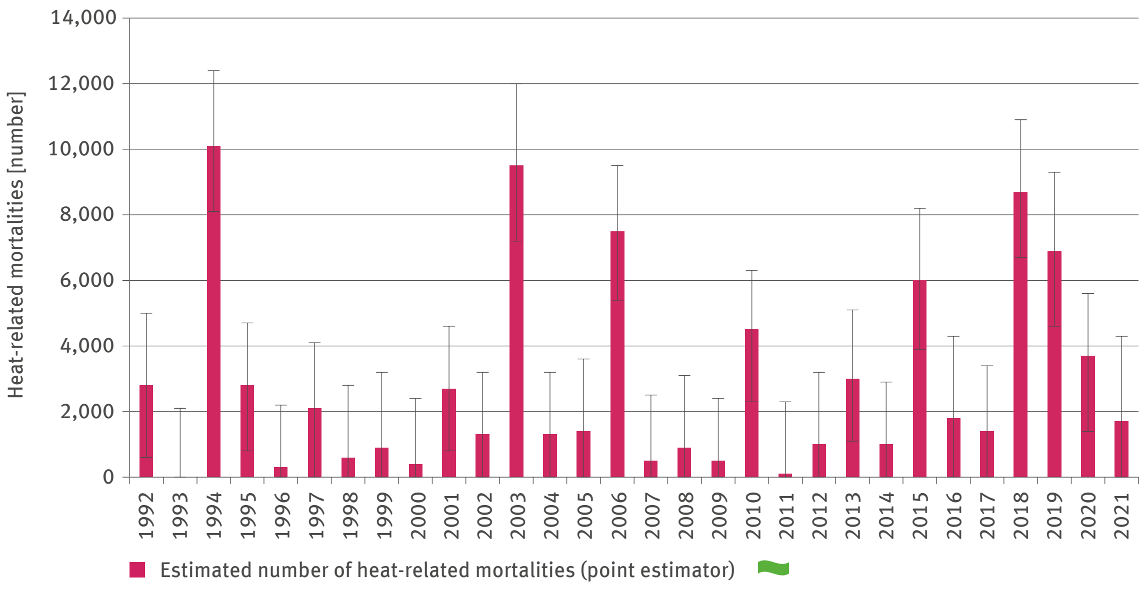
As a result of sweating, heat stress can cause the body to lose a relatively great amount of fluid and electrolytes. This fluid loss can lead to dehydration (lack of water in the body) and may also entail diminished viscosity of the blood. These phenomena increase the risk of thromboses and other cardio-vascular conditions. When thermoregulation (the mechanism of the human body for maintaining a constant body temperature of approx. 37 °C) is restricted, this can bring about disorders in the human water and electrolyte balance which may result in life-threatening impairments of the cardio-vascular system. Groups of individuals particularly at risk include very elderly and sick people, small children and individuals living alone, who cannot ensure – or can only in a limited way ensure – that their body has adequate fluid balance. In extreme cases, heat or rather overheating, can lead to the death of the individual concerned.

Environmental factors also have an influence on health threats from heat. There is evidence from studies that in densely built-up urban areas, where heat islands develop (cf. Indicator BAU-I-2, p. 221) and where increased values of dust from fine particles and ozone concentrations (cf. Indicator GE-I-9, p. 56) occur, health risks will increase.

In mortality statistics, mortalities related to heat effects are typically attributed to other causes of death (for instance conditions of the cardio-vascular system). If the amount of mortalities exceeds the seasonally typical and thus expected values, this is taken as an indication that there are extraordinary events involved. The number of heat-related mortalities – in the model underlying the indicator – is estimated as the difference between the modelled mortality and a hypothetical mortality regime. The latter would occur, if the mean weekly temperature (calculated from all hourly values within one week) were not to rise above a fixed temperature threshold, above which the temperature would have a significant effect on mortality. Subject to the age group and region examined, this value would be around 20 °C. Within a range of between 10 °C and 20 °C of a weekly mean temperature, mortality is relatively constant, whereas at a weekly mean temperature of more than 20 °C, it rises distinctly.

GE-I-2: Heat-related mortalities

2018 to 2020 were the first three years in quick succession with an extraordinarily high amount of heat-related mortalities. Nevertheless, the number of mortalities in the year of 2018 with its persistent searing heatwave was lower than the 'summer of the century' in 2003. This may have been an effect resulting from preventative measures.



Data source: RKI (own calculations)

In weeks with a mean temperature of more than 20 °C there will typically be at least one entire hot day[14]. Furthermore, the model – which has been developed since the publication of the previous monitoring report – takes into account that also any preceding hot weeks can influence mortality. This is why the mean temperatures of up to three preceding weeks are taken into account. This approach allows identifying any delayed heat effects thus making it possible to convey a clearer picture of the progress of mortality in Germany.

The age group of 85-year old people is most affected by heat-related mortalities in Germany. The analysis of heat-related mortality demonstrates that there are sex-specific differences regarding the number of heat-related mortalities. This is due to the fact that the group comprising people of great age consists of distinctly more women than men. Nevertheless, mortality in all age groups is slightly higher for men than women. This means that within the age groups studied, men succumb to heat impacts more frequently than women. However, overall, more women die from heat-related causes, simply because heat-related mortalities occur most frequently in the group comprising people of great age, as it contains significantly more women.

As expected, the time series for heat-related mortalities indicates distinct fluctuations from year to year. This is due to the fact that stronger or weaker heat periods occur in different years in different frequencies and intensities. 2018 was a year characterised throughout Germany by one of the longest heat periods which extended from the whole of July to the whole of August. Moreover, very high weekly mean temperatures were measured during this heat period[15]. Although some very high temperatures were measured also in 2019, there were repeatedly weeks with lower temperatures interspersed between heat periods. In 2020 the comparatively long heatwave was less hot than in the record summer of 2018, and 2021 was in general a much cooler year.

In the past three decades, a slight decrease in the effect of high temperatures on mortality figures has been observed. To put it briefly: Despite the raised temperatures and the extreme heatwaves, there were – also in summer 2018 – fewer heat-related mortalities than in summer 2003. Presumably, this is because people in Germany have since learned how to cope better with recurring heat periods. Adaptation measures taken by the public health services are likely to have contributed to this positive development. In 2003, the heatwave in Germany hit a relatively ill-prepared country. By comparison, the heat warning service was in operation by 2018 (cf. Indicator GE-R-1, p. 58), und vorsorgende Maßnahmen waren in vielen stationären Pflegeeinrichtungen etabliert.

For the elderly, and particularly for people of great age, heat constitutes a major threat to their health. (Photo: © Satjawat / stock.adobe.com)

Notwithstanding all adaptation measures taken, it has to be said that heat continues to be a serious threat to human health in Germany. It is estimated that in the years from 2018 to 2020 alone, 19,300 individuals succumbed to extreme heat. The focus on potential heat victims will therefore have to be further sharpened, and that means paying particular attention to this issue when drawing up municipal heat action plans.

Pollen burdens on the rise

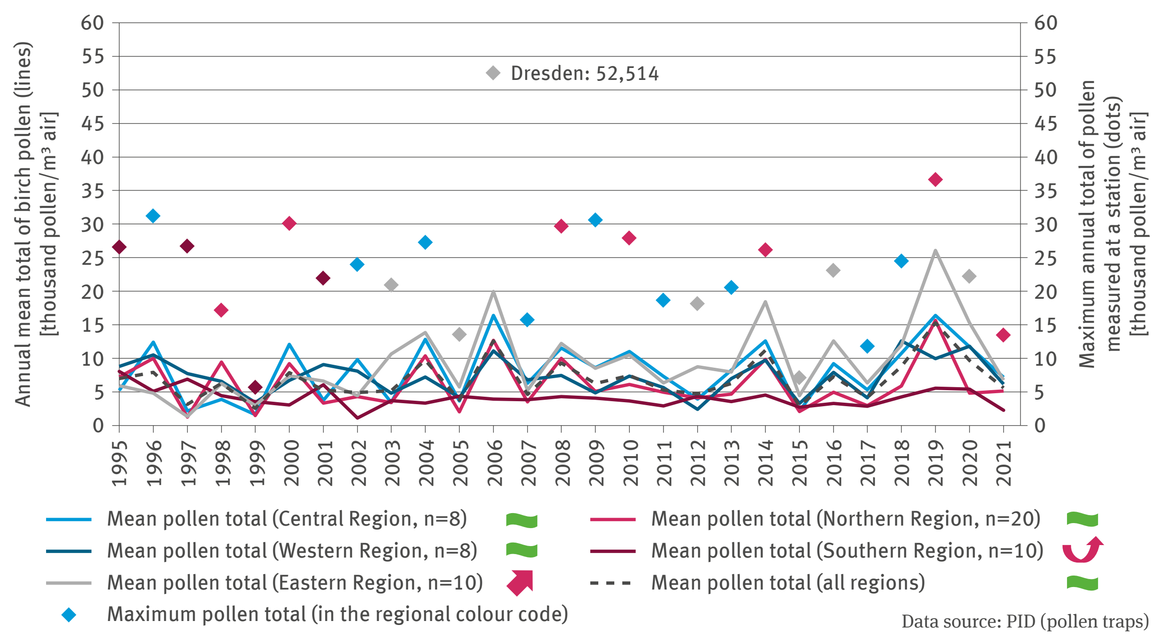
Nowadays, allergies are among the most frequent chronic health problems in Germany. Roughly 15 % of adults have been diagnosed at least once in their life with hayfever (allergic rhinitis) whilst 9 % had a medical diagnosis of asthma bronchiale[16]. In the age group of children and juveniles 11 % have been diagnosed at least once in their life with hayfever whilst 6 % had a medical diagnosis of asthma[17]. Even higher than the number of people with this condition is the number of people who have been sensitised. In other words, once having made contact with the allergen, their body is more prone to respond with symptoms.

Allergenic types of pollen are the foremost trigger of hayfever. Notably, the occurrence of pollen is heavily dependent on the weather pattern or the climate. Higher temperatures, especially when combined with drought, and an extended vegetation period favour longer periods when pollen are air-borne as well as higher pollen concentrations. It is also conceivable that the allergenicity of pollen may increase as a function of temperature rise. Furthermore, there have been discussions on the possibility that an increasing frequency and intensity of extreme weather events might bring the phenomenon of 'thunderstorm asthma'[18] to the fore, thus giving it significance in clinical terms. A prerequisite for this would be a high concentration of pollen or spores in the air. Changes in the weather, such as precipitation, an increase in air humidity or lightning activity can lead to the fragmentation of pollen, thus producing smaller allergenic particles which can penetrate more deeply into the respiratory tract. Strong down-draughts transport these particles in direction of the ground, thus often leading to a sudden rise in the allergen concentration at breathing height. In people suffering from pollen allergies, this can cause severe symptoms.

In Germany, the pollen of hazel, alder, birch and ash trees as well as sweet grasses such as rye, mugwort and annual ragweed have particular relevance in terms of allergies. These are eight types of pollen to which the adult population of Germany is most frequently sensitised[19]. Apart from grass pollen, birch pollen is top of the 'hit list' as the cause of sensitisation. During the birch pollen season which – at the earliest – begins at the end of March, very high pollen concentrations can occur.

GE-I-3: Birch pollen burdens

Apart from grass pollen, birch pollen is the foremost trigger of pollen allergies in Germany. A warm and dry spring is a major factor in increasing pollen concentrations. The highest pollen count was measured between 2006 and 2021 in the eastern, central and northern regions. This is where birches are more widely distributed than in the south of Germany. In the east and south of the country, pollen counts increased significantly.



Data source: PID (pollen traps)

Scientific evidence has been found for close relationships between the occurrence of birch pollen burdens and climate change: Increased warmth and drought in spring lead to higher birch pollen counts. Pollen measurements conducted by the Foundation of German Pollen Information Service (PID), especially in 2019 and 2020 have demonstrated this. In 2019 the mean spring temperatures were distinctly higher by 1.3 °C and in 2020 by 2.5 °C than the long-term annual average in the period from 1961 to 1990. At the same time, precipitation – especially in the north-east of Germany – remained below average: lack of precipitation favours the distribution of pollen, thus remaining in the ambient air for a long time. In parts of Uckermark and Vorpommern less than 70 litres of rain fell locally per square meter in 2019. In spring 2020 precipitation reached only some 50 % of its multi-annual average. This was one of the six most precipitation-poor years since weather records began in 1881. Likewise, in 2020 the east of Germany recorded one of the highest precipitation deficits[20].

In Germany, the birch tree is one of the foremost triggers of pollen allergies. (Photo: © lochstampfer / stock.adobe.com)

The indicator is based on data from 56 pollen traps distributed throughout Germany within the PID measuring-network. Not all stations provide data in every year, as the regular operation of pollen traps cannot always be guaranteed. Occasionally there are locations which are abandoned after years of taking measurements, and then again others which are newly installed. Owing to these dynamics prevailing within the Messnetz, it is necessary to calculate for every year the mean across all available measuring stations.

As far as the whole of Germany is concerned, the time series has to date not indicated a statistically significant trend. It is important to realise that the developments have to be considered in a regionally differentiated manner. As to be expected, the birch pollen count is particularly high in those regions where birches are very widely distributed. The silver birch and also the weeping birch – the most important arboreal types of birch in Europe – are particularly widely distributed owing to their relatively low need of nutrients and water as well as their resilience to extreme weather conditions, with a distribution range from Scandinavia to southern Italy and from France as far as Russia. Nevertheless, the birch is primarily a boreal tree which, along with spruce, pine and aspen, can form climax forest communities in northerly regions. In southern Germany however, the silver birch is a pioneer tree species which, owing to the fact that it rapidly loses its growing strength, is therefore often eclipsed by other tree species in natural woodlands, thus sooner or later disappearing from forest stands. Nevertheless, it can happen that high pollen counts occur in connection with birch stands in some locations in the south and west of Germany. As a result, the maximum concentrations measured tend to alternate between stations and regions year by year. As shown by specific research on the development of the birch pollen season by means of pollen measurements in Munich, the days with particularly high concentrations (of more than 100 pollen per cubic metre) have become more frequent. This is important in clinical terms.[21]

In central, eastern and northern Germany, the concentration of birch pollen will at first increase with rising temperatures. In eastern Germany, the time series shows already now a significantly rising trend. However, according to model calculations for Bavaria, it is to be expected that in 40 years' time, there will be distinctly less trouble from silver birch pollen affecting hayfever sufferers in the tree's present main distribution region, as presumably by then, silver birches will find it too warm and too dry in that region. Their optimum temperature for photosynthesis is below 20 °C. By contrast, in regions at higher altitudes where temperatures will be milder then, the birch might extend its distribution range, thus leading to higher pollen counts.[22]

Moreover, the proliferation of birch trees will, in the near future, also be connected with increasing calamities in the forest. In areas where forest stands suffer widescale destruction owing to storm, heat or pathogens (cf. Indicator FW-I-5, p. 180), pioneer tree species such as birch are able to take a hold, thus – at least temporarily – affecting the characteristics of a forest or woodland.

Introduced ragweed is highly allergenic

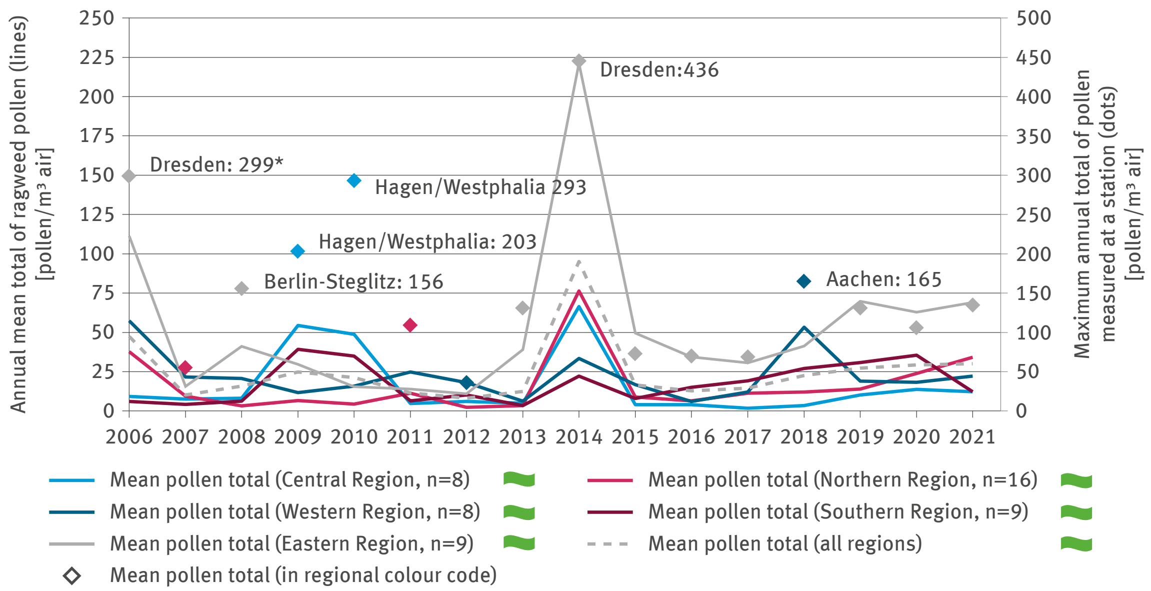
Apart from the indigenous allergenic plants, in view of the increasingly warm weather patterns, other plant species will become relevant as allergen producers – species that hitherto did not occur in Germany or occurred only here and there. For example, annual ragweed (Ambrosia artemisifolia) which emanates from North America – known as ragweed – has an extraordinarily high allergenic potential. Ragweed used to occur relatively seldom and inconsistently in Germany. Its occurrence did not start to increase until the beginning of the 1990s. Nowadays annual ragweed occurs in all Länder, and especially in eastern Germany, where it has started to form extensive, well established localised populations containing thousands of plants. This plant thrives in gardens, on uncultivated or fallow ground, in arable fields and cut-flower fields, in agricultural set-aside areas, on building sites and on road and path verges. Causes for the spreading of this species may be, for instance, the contamination with seed from wildlife food or cut-flower plots, and bird food containing ragweed seed material. Other causes might be the transportation of soil from affected areas in connection with building projects as well as the adhesion of seeds to agricultural machinery or mowers used on road verges. In order to counteract the proliferation of this species, via products such as birdfood, maximum content values were stipulated in an EU Directive in 2011 restricting the unwanted addition of ragweed to feedstuffs.

The fact that ragweed is able to spread and establish itself in Germany is, however, to a relevant extent, also attributed to climate change, because the annual plant can only achieve the seed maturity required for dispersal where the prevailing climate is warm or moderate with mild autumn months. Similar concerns exist with regard to the proliferation and establishment of other thermophilic plants with highly allergenic pollen, such as the Pellitory-of-the-wall *(Parietaria officinalis or P. judaica)* or the olive tree *(Olea europaea)*.

In sensitised individuals, even minor ragweed pollen concentrations can provoke allergenic symptoms and can trigger asthma in up to a quarter of allergy sufferers [23]. Besides, there are reports of rare skin reactions after skin contact with the flower head or other components of this

GE-I-4: Ragweed pollen burden

The spreading and establishment of ragweed is presumably favoured by climate change. However, so far the results of pollen measurements do not indicate any significant trends. However, there were key loads where – owing to long-haul transportation and / or local plant populations – pollen concentrations were distinctly higher than the corresponding regional mean. The relevant maximum annual totals occurred predominantly in the eastern region.



* Sites recording maximum annual pollen total ≥ 150

Data source: PID (pollen traps)

type of plant. Another important aspect of the establishment of ragweed is the fact that, once the plant is established, the period in which its pollen can be airborne is extended well into October[24], as this is a late-flowering plant. The temporal extension of the period in which pollen is air-borne also extends the duration of the time in which affected individuals will suffer from related complaints. This adds to the stress for people who are prone to suffering from allergies.

In Germany, ragweed pollen – the same way as pollen from indigenous plants – are captured mostly in pollen traps within the PID measuring network. The time series illustrated here is based on nationwide surveys of 50 PID stations. As in the case of birch pollen (cf. Indicator GE-I-4, p. 46) not all stations supply data every year, which is why the mean values are calculated on the basis of pollen-trap numbers which change from year to year.

Currently, the pollen concentration of ragweed is relatively low in Germany; the mean value across all measurements so far amounts to approximately 25 pollen per cubic metre of air annually. By comparison: For birch, the comparable value is 6,800 pollen per cubic metre air annually. However, in some years, values can arise at some stations which are 20 times higher than the mean value mentioned above. The stations which have reported peak values for those individual years are distinctly higher in the eastern part of Germany. These high pollen concentrations can – to some relevant extent – also be attributed to long-distance transportation from affected neighbouring countries. The peak value so far amounting to 436 pollen per cubic metre air annually was measured in Dresden in 2014.

So far there are no statistically significant trends. The same is true for all regions. In eastern Germany the regional mean values are typically higher than those of other regions, owing to influences described above which emanate from eastern neighbouring countries. The region in the area of Drebkau in south-eastern Brandenburg stands out owing to its special scenario: It can be described as a regional ragweed hotspot which is not illustrated here in terms of the pollen data shown. The nationwide high concentrations of ragweed pollen in 2014 were caused by persistent wind dispersal of pollen from the Hungarian basin during the plant's flowering period, which was due to weather conditions with a south-easterly flow. This kind of south-east wind is one of rather infrequent weather phenomena. Ragweed is particularly wide-spread in Hungary and other neighbouring countries, especially in Slovakia, Romania, Serbia, Bosnia-Herzegovina and Croatia. The so-called 'long-haul flights' of pollen may emanate from those countries.

The ragweed plant is thermophilic and in the past produced only a few scattered populations in Germany. Its pollen is highly allergenic. (Photo: © Aleksandr Lesik / stock.adobe.com)

The pollen total measured does not permit any robust conclusions as to the risk of the population actually coming into contact with these pollen or in respect of developing sensitisation or allergic reactions. Nevertheless, for precautionary reasons, every effort should be made – subject to the rules of proportionality – to curb the further spread of various ragweed species in Germany.
As far as any direct ragweed control and the elimination of ragweed populations is concerned, there are primarily mechanical options available. The most efficient method is to uproot the one-year old plant in June when it is easily recognised and it is easy to tell it apart from other plant species, and when it is not yet dispersing any pollen.
If this type of manual control is not possible, it will be necessary to resort to mowing between June and September, at least four times at intervals, in order to weaken the plant to such an extent that it is no longer able to produce any shoots.

Dangerous Tiger Mosquitoes are spreading

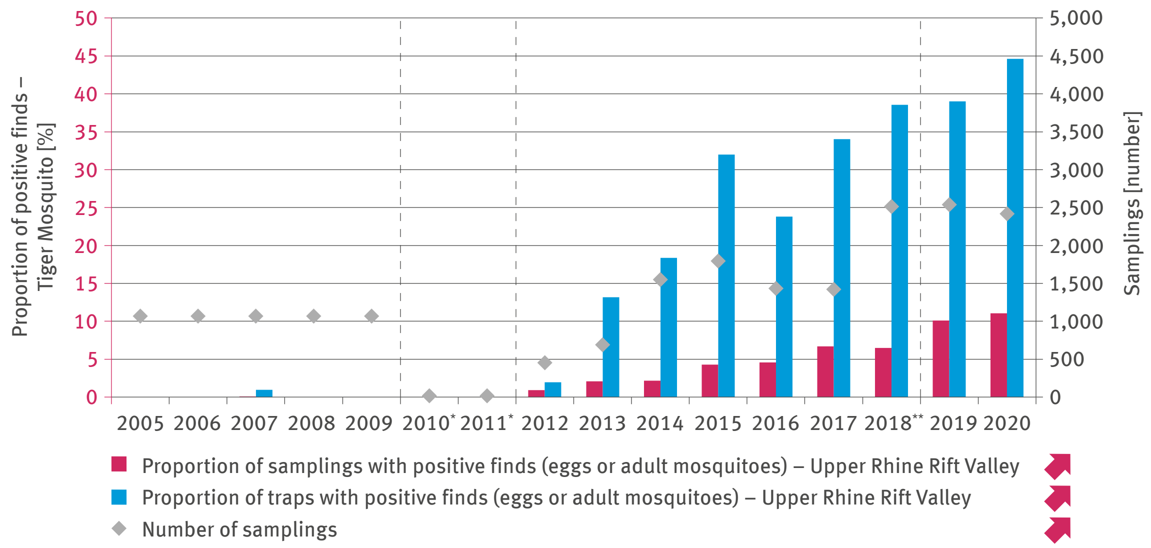
Worldwide we are confronted with new and recurring fomites (infection agents) which in many cases can be transmitted between animals and humans; owing to their increasing global mobility they are able to spread rapidly. Both long-term climatic changes (temperature, precipitation) and the increase in extreme weather conditions play important roles in this process. In vector-transmitted infectious diseases such as West Nile Fever, malaria, dengue, leishmaniosis, zika, chikungunya or tick-borne encephalitis (FSME) there is the risk that in Germany the changed climatic conditions will enhance favourable conditions for animal vectors such as mosquitoes or ticks as well as pathogens, thus increasing the risk of infection in respect of humans and animals. For example, in recent years there have been cases in central eastern Germany where humans were infected by the autochthonous West Nile Virus (WNV) which is transmitted by indigenous mosquitoes *(Culex)*.

The mechanisms of absorption, development and reproduction of pathogens in vectors, and the transmission to animals and humans remain to be clarified in the majority of cases. Changed climatic conditions can influence this interaction of pathogens and vectors in various situations. Changed climatic conditions can lead to changes, for instance, in the reproduction rate of animal vector organisms, their lifespan, their behaviour or their population density[25]. Besides, short winters may result in the animals being active for longer in the course of the year, thus reproducing faster and producing more generations. Their efficiency in transmitting pathogens can also be affected. This can cause vector species previously not indigenous to Germany – introduced from warmer countries – to become established here and disperse widely.

The exploration of relationships between climate change on one hand, and the spreading of vectors / pathogens on the other, is still in its infancy. The recording of most infectious diseases associated with vectors is already being carried out systematically – in most respects on a nationwide basis – and covered by regulations laid down in the German Infection Protection Act (for instance. compulsory registration). However, there is nonetheless still a shortage of data collected systematically and continuously on the occurrence and distribution of vector species

GE-I-5: Pathogen vectors – case study

Warmer climatic conditions can favour the establishment and spread of the Asian Tiger Mosquito Aeoles albopictus in Germany. This increases the risk that the bite from a mosquito can lead to the transmission and subsequent spreading of dangerous viral diseases by pathogens introduced to Germany by infected persons arriving from abroad. The finds of eggs and mosquitoes in traps in the area of the Upper Rhine area have increased distinctly over the past 15 years.



* No data available for 2010 or 2011; from 2012 onwards, sampling was continued using different types of traps
** From 2018 onwards changed monitoring programme with some relocated trap sites

Data source: KABS (mosquito monitoring)

and their infection with pathogens. The illustration of the indicator is therefore limited to the example of one specific vector, namely the Asian Tiger Mosquito *(Aedes albopictus)*, a mosquito species that was originally introduced from Southeast Asia. This species is considered a highly efficient vector which can transmit more than 20 different viruses.

The Tiger Mosquito which emanates from a species variant successfully adapted to non-tropical conditions in the USA, has meanwhile achieved wide distribution in southern Europe and also in parts of Central Europe. In recent years there have been frequent finds of eggs, larvae and adult individuals of this species in Germany. According to the current state of knowledge, the introduction takes place by means of vehicular traffic from the south (for instance from Italy). In areas where the Tiger Mosquito comes upon favourable conditions, it is able to establish colonies, and those populations can then also become the source of further passive (anthropogenic) introductions elsewhere. Of particular benefit to the establishment of the Tiger Mosquito is its invasion of areas where the immediate environment offers adequate breeding sites, blood hosts and safe havens such as allotment garden environments and housing zones with a high proportion of garden space.

In respect of the chikungunya virus it has been possible to show already that transmission by *Aedes albopictus* is, also in Germany, less limited by external temperatures than (especially) by an inadequate occurrence of mosquitoes[26]. For the zika virus, laboratory tests have shown that the vector competence of *Aedes albopictus* is distinctly boosted by temperatures of 27 °C as against lower temperatures of 18 °C[27]. In fact, the establishment of these mosquitoes has created the basic prerequisites for this pathogen to spread more widely in Germany too, provided it is introduced by infected individuals.

The region of the Upper Rhine plain in Germany is favoured by warm climatic conditions. This region also plays a major role as an important entrance point to Germany for thermophilic species via vehicular traffic from neighbouring countries, including Switzerland and Italy. Since 2005, there have been ongoing records of the occurrence of Tiger Mosquitoes in the Upper Rhine area, starting with the first record in 2007. This finding resulted from examining 105 traps where evidence was found in terms of five Tiger Mosquito eggs in one of more than one thousand samples. After a break in monitoring in 2010 and 2011, followed by the installation of new types of traps in 2012, findings were again positive: a total of eight individuals were trapped which means that one percent of all trap samplings was positive. From 2012 onwards, the

It is true that the risk of mosquitoes transmitting dangerous viruses is still relatively small in Germany. Nevertheless, monitoring and local control play an important role. (Photo: © noppharat / stock.adobe.com)

number of samplings was expanded, leading to annually approximately 1,500 samplings in the Upper Rhine area from 2014 onwards. As early as 2013, 13 % of all traps and more than 2 % of all samplings resulted in evidence of eggs or adult mosquitoes. Subsequent years produced further increases in the number of positive finds. As early as 2014 approximately in 18 % of traps, and in 2017 approximately in 34 % of traps along the A5 and A6 motorways, evidence was found for *Aedes albopictus*. By the end of 2021, there were already well-established populations in 14 rural districts and in district-free towns along the river Rhine and in Fürth (Bavaria) as well as Jena (Thuringia)[28]. In fact, the establishment of these mosquitoes has created the basic prerequisites for this pathogen to spread more widely in Germany too, provided it is introduced by infected individuals.

Since 2021, there have been no further resources available for monitoring work in the Upper Rhine area. It is true that the ZALF and the FLI continue to collect data on the distribution of mosquitoes for the 'Mückenatlas' (mosquito atlas) (cf. Indicator GE-R-4, p. 62) while also conducting geographical campaigns for data collection by means of placing traps alternately in different locations. However, these surveys are not yet sufficiently standardised for establishing a time series.

Cyanobacteria – impairment of recreational bathing waters

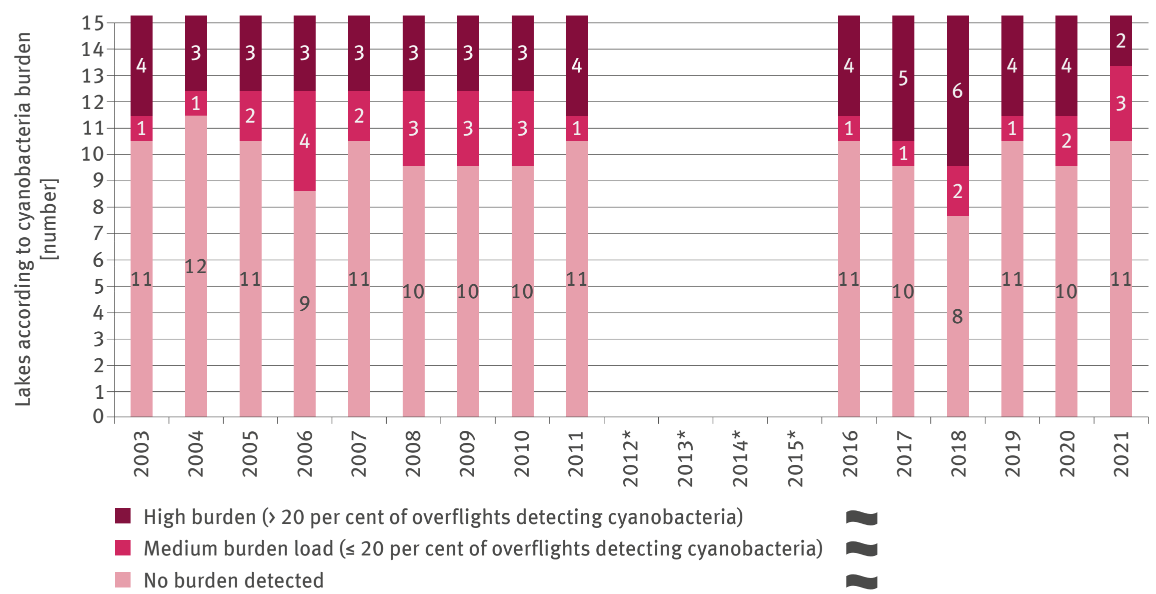
If temperatures rise in future summers, the desire of humans to take a cooling bath in lakes, rivers or the sea will increase. At the same time however, climate change can affect the quality of recreational bathing waters. A much discussed health risk in connection with climate change is the contamination of recreational waters with cyanobacteria, commonly known as blue-green algae.

Increased concentrations of plant nutrients – especially total phosphorus – in standing water or in slow-flowing watercourses, are the main cause of mass developments of cyanobacteria, the so-called algal bloom. In waters only moderately contaminated with nutrients, cyanobacteria have to compete for available nutrients with both higher water plants and with other phytoplankton, thus rarely achieving dominance. Furthermore, some cyanobacteria are favoured by a stable thermal layering of waters which develops especially at high temperatures and stable weather conditions. Stable layering also leads to the deposition of some cyanobacteria at the surface thus potentially resulting in further localised accumulations of cyanobacteria. Owing to these relationships, climate change has been under discussion as one of the causes of increased health risks from cyanobacteria.

The absorption of major quantities of cyanotoxins – the toxic substances contained in cyanobacteria (nerve gases and liver toxins) – can lead to serious impairments of the liver, kidneys and nerves during bathing in the wild, and it can also lead to bathing accidents ('near-drowning'). The risk is particularly high for young children and children of primary-school age who are apt to swallow relatively large amounts of water inadvertently when playing in a shallow-water area. However, in the case of unspecific symptoms such as irritations of the skin and mucous membranes, allergic reactions or stomach, bowel and respiratory illnesses which have been observed to occur increasingly owing to bathing in waters rich in blue-green algae, it is more likely that these symptoms have been caused by other pathogenic bacteria or substances. Cyanobacteria are found within the framework of bathing water inspections and the European Water Framework Directive (WRRL), although they are not always recorded quantitatively or in sufficient frequencies. Moreover, the flowering

GE-I-6: Contamination of bathing waters by cyanobacteria burdens

Subject to weather conditions during the bathing season, health risks can develop in bathing waters owing to high concentrations of cyanobacteria. Based on satellite images, the analyses of data from up to 16 lakes distributed over different natural spaces demonstrate that there are distinctly no trends discernible in the time series which is rather short and gappy so far. However, in very warm summers the proportion of lakes with major burdens can be higher than average.



*no suitable satellites in operation

Data source: CAU Kiel, Brockmann Consult GmbH (analysis of satellite data) of cyanobacteria within a lake can be marked by very different characteristics, because the cyanobacteria can drift to different locations within the water body or move up and down in the water column in the course of a day. It therefore depends on a number of factors, whether the occurrence of cyanobacteria by means of measurements taken in situ, (typically) on a monthly basis, is indeed captured. This is why methods of remote sensing are better suited to the detection and recording of cyanobacteria blossoms. There are satellites which are capable of measuring the reflexion of the pigment phycocyanin responsible for photosynthesis in cyanobacteria. This process also permits the detection of cyanobacteria drifting below the water surface and – provided there are no clouds in the sky – to collect data very frequently (in a cycle of one to three days, as required for the size of the water). The relevant analysis of satellite data can be validated by individual surveys carried out in situ.

For the years from 2003 to 2011 and from 2016 onwards, suitable satellites were available. In the years between, there were no satellites active that were equipped with the requisite satellite sensors. The indicator is underpinned by data covering four lakes in the area of the Alps and associated foothills, three lakes in the central uplands region and eight lakes in the North German Plain. Lake Constance was covered in two ways (upper part and lower part). Work is ongoing to expand the selection of lakes. The overflights during the relevant months between July and September were assessed in respect of the occurrence of cyanobacteria. As a requirement for such occurrences, it was stipulated that positive cyanomarkers (phycocyanin) are found in at least 30 % of correctly captured pixels (grid cells). If in a maximum of 20 % of all valid overflights occurrences of cyanobacteria are recorded, this is taken as a medium burden; if the value exceeds 20 % of all valid overflights, that is taken as a high burden for the year in question.

There is no distinct trend discernible for the time series to date. However, owing to the four-year data gap, the trend analysis is of limited information value. Fluctuations in the cyanobacteria burden between the years can be attributed, for instance, to weather patterns and thus to associated stratification regimes in the lakes in question. If stratification sets in earlier in the year – owing to higher spring temperatures – this can in turn result in cyanobacteria developing higher biomass maxima earlier in summer (cf. Indicator WW-I-9, p. 86). Compared to other species of phytoplankton, cyanobacteria species grow slowly and therefore benefit particularly from persistent high water temperatures. However, warm years are not stringently associated with stable stratification. For example, in the hot summer of 2003, the summer stratification was distinctly less stable than in 2006 – a year in which the months of May, June, July as well as the entire autumn were much warmer than average, thus leading to stable stratifications which forced the development of cyanobacteria. The year of 2018, too, stands out distinctly from the time series. In early April, the weather turned within a few days from winter to summer thus resulting in rapid warming of water temperatures. May and June remained warm too, and in July and August followed the longest and most intense heat period to date. These conditions were extremely favourable for the development of cyanobacteria and entailed that in half of the lakes surveyed, medium and high burdens were recorded. It must be noted, however, that apart from the temperature increase, the nutrient content of the lakes also played a crucial role. As long as the nutrient concentration in a water body amounts to less than 30 µg (microgram) total phosphate per litre, the growth of cyanobacteria is distinctly limited. In water bodies, phosphorus is considered a growth-inhibiting factor. Any efforts to reduce the nutrient inputs into lakes – thus achieving an associated mitigation of the cyanobacteria burden – might be frustrated by a prolonged and more stable stratification, as long as the phosphorus concentrations do not fall below the threshold mentioned above.

The advice is not to bathe in water contaminated with cyanobacteria. (Photo: © mivod / stock.adobe.com)

Vibrios on the coast – health risk to bathers

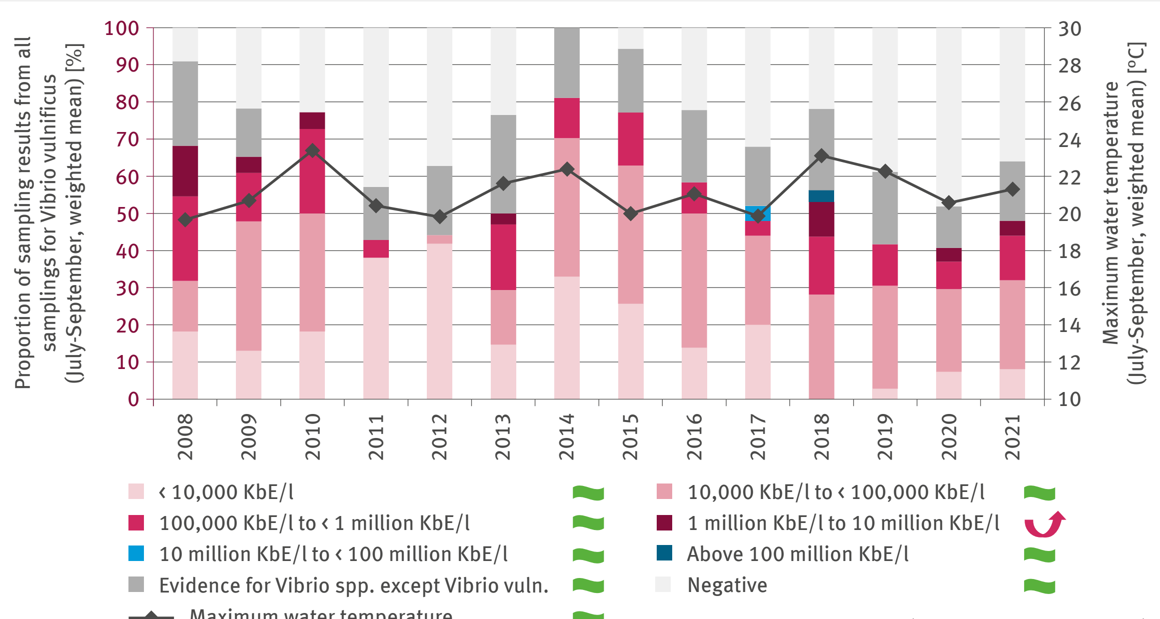
Local residents are not the only people who appreciate the German coast for its high leisure and recreation value: Coastal areas are among the most popular regions for holidays and rehabilitation purposes in Germany. Especially in the summer months when air and water temperatures reach their maximum levels, numerous visitors and patients frequent many rehabilitation centres. Air temperatures rising as a result of climate change leads to the North Sea and the Baltic Sea getting warmer (cf. Indicator KM-I-1, p. 100), thus making the coast even more attractive to bathers (cf. Indicator TOU-I-1, p. 278).

On the other hand, a higher water temperature also favours the growth and the increase of specific aquatic microorganisms. Among the beneficiaries are species of the bacteria genus *Vibrio*. The warmer, moderately salty, brackish and seawater areas on the North Sea coast and especially on the Baltic Sea coast provide ideal habitats for bacteria, known colloquially as vibrios. In high concentrations, vibrios can pose health risks: Given certain conditions, some of more than a hundred vibrio species can cause infections in humans. As far as the Baltic Sea is concerned, these species include *Vibrio fluvialis, Vibrio parahaemolyticus, Vibrio alginolyticus* and *Vibrio vulnificus*[29].

It is mostly through open wounds that vibrios enter the human body. They are less frequently absorbed through inadvertent swallowing of infested water or the ingestion of contaminated shellfish or fish. Subject to the type of pathogen, an infection can present in different ways. Apart from causing diarrhoea and stomach aches, the infection can damage a person's health, for instance through body tissue dying (necroses) and in severe cases to an infection of the blood flow (sepsis), sometimes even leading to a person's death. The infection risk increases as a function of the increase in vibrio concentrations in the water. However, the absorption of vibrios does not always trigger an infection. The underlying health condition of a person also influences the risk and severity of the infection. The chronically sick, immune-deficient and elderly people are particularly at risk. In 2018 and 2019 there were eight mortalities among these groups of people, that were associated with vibrios[30].

GE-I-7: Health hazards from vibrios – case study

Higher water temperatures resulting from climate change drive biological processes in water bodies, favouring, for instance, the growth and reproduction of infectious vibrio species belonging to the bacteria genus of *vibrio*. The findings from water samples taken in the Baltic Sea demonstrate the strong influence of maximum water temperature on the bacteria concentration of *Vibrio vulnificus*.



Data source: LAGuS (water quality measurements)

In order to keep an eye on the infection risk, the authority with competence for health and social matters (Landesamt für Gesundheit und Soziales) in Mecklenburg-Western Pomerania has been collecting data since 2008 on the summer concentrations of various vibrio species occurring in the Baltic Sea. Sampling is conducted on a random basis in most bathing locations along the coastline. However, the vibrio concentration measured is just an approximate value compared to the actual conditions prevailing in the Baltic Sea. The sample contains a small amount of water, a small proportion of which is pipetted and examined for pathogens. Given that the bacteria are not distributed evenly throughout the water body – occurring instead in clusters – a precise analysis of the bacteria concentration is not possible. Nevertheless, the findings permit the categorisation of the infection risk faced by bathers. In cases where a heightened infection risk exists, warnings are issued in due course.

The connection between rising water temperatures and the development and reproduction activity or the bacteria concentration is particularly evident in respect of *Vibrio vulnificus*. This species of bacteria generally tolerates a broad spectrum of water temperatures. Evidence typically becomes available above a water temperature of 10 °C minimum. The growth of the organisms is usually limited at these temperatures. It is not until the water becomes warmer, typically from about 18 °C, that the bacteria begin to reproduce more vigorously. The optimum water temperatures for growth are between 20 °C and roughly 30 °C. If the water temperature reverts to a level below this range, the vibrios often remain active for some considerable time. Once the water temperature drops to less than 10 °C, the bacteria die or – as presumed by scientists – they partly survive in an inactive state in the sediment layer of the water body[31]. As with other Vibrio species, an infection caused by Vibrio vulnificus can be life-threatening.

If temperatures rise fast early in the year or they become particularly high in the course of the year, the bacteria can be accounted for earlier and in higher concentrations. In 2020, for example – owing to a summer heatwave with an extremely high number of sunshine hours on the coast of Mecklenburg-Western Pomerania – roughly 77 % of all samples provided evidence for the existence of Vibrio vulnificus in the Baltic Sea. Moreover, the bacteria reached concentrations of between 1 million and just under 10 million colony-forming units per litre (KbE/l). The term colony-forming unit denotes individual or agglomerated microorganisms which – after reproduction – form a colony in a nutrient medium. The size of this agglomeration indicates the number or concentration of bacteria. The proportion of positive samples was higher only in 2014 which was another extremely warm year. The highest concentration detected so far – amounting to more than 100 million KbE/l – was recorded in the record heat year of 2018 when a stable high pressure bridge extending from the Azores to the Barents Sea maintained high water temperatures from May until well into August.

Vibrio-bacteria are favoured by high water temperatures. They can be transmitted to the human body via open wounds. (Photo: © LoloStock / stock.adobe.com)

The development and reproduction of *Vibrio vulnificus* is not bound up with the water temperature alone. Other influential factors entail, for example, that – just like in the years of 2008 and 2009 – there can be numerous individual pieces of evidence showing the occurrence of increased bacteria concentrations even in less warm water. The salt content of water plays a controlling part in these scenarios. The influence of salt content is not yet fully understood. However, according to current findings, the salinity of the Baltic Sea amounting to between 0.5 to 2.5 % is in line with the tolerance spectrum of Vibrio vulnificus. In the years of 2008, 2009 and 2014 the salt content was slightly higher at the point of sampling than in the other years of the time series, which means it was possibly closer to the ideal value for *Vibrio vulnificus*. Distinctly higher content values up to 3 % and higher have been recorded in only a few cases in the Skagerrak. The salt content in the North Sea is typically even higher, which is why bacteria are accounted for less frequently and in lower concentrations than in the Baltic Sea.

UV radiation

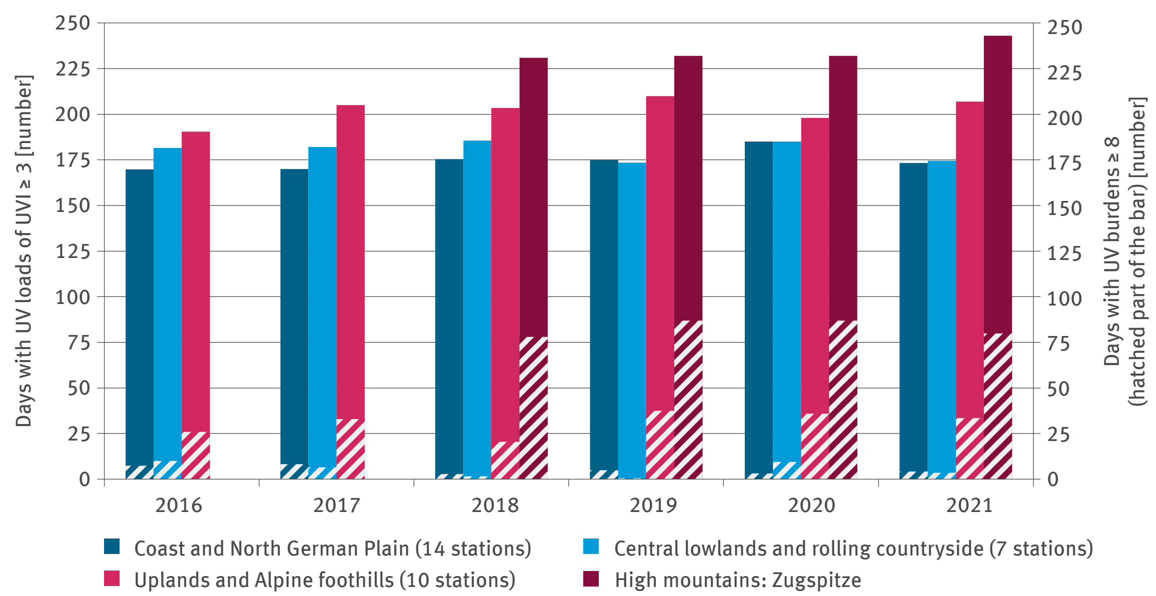
UV radiation is the energy-richest part of optical radiation and cannot be seen by the human eye. In healthy humans, UV radiation initiates the important vitamin D production by the body. At the same time, however, it can lead to serious medical conditions which may manifest either directly or at some later stage in life, both in the eyes and in the skin[32]. UV radiation damages the genetic material. It is the main cause of skin cancer and has been assigned by the IARC (International Agency for Research on Cancer) to the highest risk category, Group 1, as 'carcinogenic to humans'[33]. UV-related cancerous conditions constitute a major stress on the health of the person affected, and they inflict high expenditure on the public health service[34]. In Germany the incidence of light skin cancer (both in terms of basal cell and squamous cell carcinoma) quadrupled in respect of men over the past 30 years, whilst it quintupled in respect of women. With regard to malignant melanoma, the incidence has increased approximately fourfold since the 1970s[35] According to extrapolations from data collected by the Hautkrebsregister (Skin Cancer Registry) of Schleswig-Holstein, currently every year some 300,000 people are newly diagnosed with skin cancer in Germany[36].

UV-related damage to health can basically afflict anyone. In particular children are affected, as their skin and eyes are more sensitive to UV radiation than adults. Likewise people who work outdoors, thus being exposed more long-term, are subject to a high risk. At any age, sunburn will increase the risk of malignant melanoma roughly twofold – in childhood even two- to threefold. Damage caused by UV radiation will cumulate over a lifetime[37].

Although the depletion of the stratospheric ozone layer arising from anthropogenic influences increases the UV irradiation close to the ground, it is of less importance for UV burdens in Germany. Nevertheless, the recovery of the ozone layer seems to be delayed on account of several influential factors. For the northern hemisphere, a return to ozone column values as experienced in 1980 is to be expected approximately by 2035[38]. Furthermore, so-called 'low ozone events' can occur which can cause unexpectedly high UV irradiation strengths lasting for just a

GE-I-8: Index – case study

UV radiation is the main cause of skin cancer. It is a disease to which annually more than 300,000 new people in Germany fall prey. Even at stations in lowland areas, almost for half the year, irradiation strengths (UVI ≥3) are reached which can cause sunburn for which sun protection is recommended. UV irradiation strength varies with latitude, altitude and the current weather scenario, especially cloud cover.



Data source: BfS (UV monitoring network) few days. The origin of this phenomenon may be sought year-round in dynamic processes in the atmosphere and, especially in spring, in the wintry ozone depletion above the arctic[39]. Low-ozone events in spring are particularly relevant in terms of health, as the human skin is still especially sensitive to UV radiation at that time of year. At the end of March / early April in 2020, for example, the UV index in southern Germany (Munich) increased from 3 to 6, owing to such a low-ozone event combined with the weather pattern prevailing at the time[40]. A study has indicated that the frequency of low-ozone events in spring has decreased over the past two decades[41]. At the same time, this study demonstrates that spring seems to be the season which is most affected by low-ozone events. As far as the development of low ozone events in the northern hemisphere in the future progress of the 21st century is concerned, no uniform findings have yet emerged from this study[42].

In Germany the number of sunshine hours has changed in the course of recent decades. Until the 1980s, in Germany and the entire northern hemisphere, a continuous decrease in sunshine hours (1951–1980 by roughly 11 %, linear trend) was recorded[43]. The reason for this so-called 'global dimming' effect is attributed to the increasing contamination of the atmosphere with industrial gas emissions and the associated formation of clouds[44]. Approximately since the middle of the 1980s, the aerosol concentration has decreased in Germany, thanks to the successful implementation of air pollution control measures [45], followed by an increasing number of annual sunshine hours (1981–2022 by roughly 19 %). This 'global brightening' effect is essentially due to a successful international air pollution control policy rather than representing a direct impact of climate change[46]. The basic relationship between a change in radiation intensity and climate change is currently an important focal point of research. For example, data collected in the period of 1996 to 2017 at four European stations show that long-term changes in UV radiation depend, above all, on changes in aerosols, cloud cover and surface reflexion capacity (albedo)[47].

The intensity of UV radiation is indicated in terms of the UV index (UVI) – a worldwide homogeneous standard for the daily peak value expected to be measured at ground level (30-minute mean) of the UV irradiation strength capable of causing sunburn[48].The higher the UVI, the higher the UV irradiation strength and the faster sunburn can develop on unprotected skin.

The case study presented in this report is based on the values measured at measuring stations which are part of the UV measuring network. Taking the latitude into account (the UV Index increases from north to south) as well as the altitude (the UV Index is higher in mountains than in lowland areas), the stations have been assigned to four natural spaces. The illustration shows all days with UV values of 3 and more, given that from UV Index 3 upwards, it is already recommended to take measures for sun protection. Given that for a UV Index of 8, the recommendations for taking sun protection have been stepped up further, the days with UVI values equal to or higher than 8 are illustrated. For every station, the days with the relevant values for each year are totalled, and then the mean is calculated across the stations in the natural space concerned.

High UV radiation intensity can cause health-threatening sunburn. (Photo: © New Africa / stock.adobe.com)

There are distinct regional differences. In lowland areas, almost for half the year, irradiation strengths are reached for which sun protection is recommended. In the uplands, the foothills of the Alps and in the high mountains, this applies to 200 days and more annually. The period in question does not yet permit any statements on trend. There is a need for further research into the climate-change related changes in influential factors affecting UV radiation close to ground level.

Ozone burden caused repeatedly by weather patterns

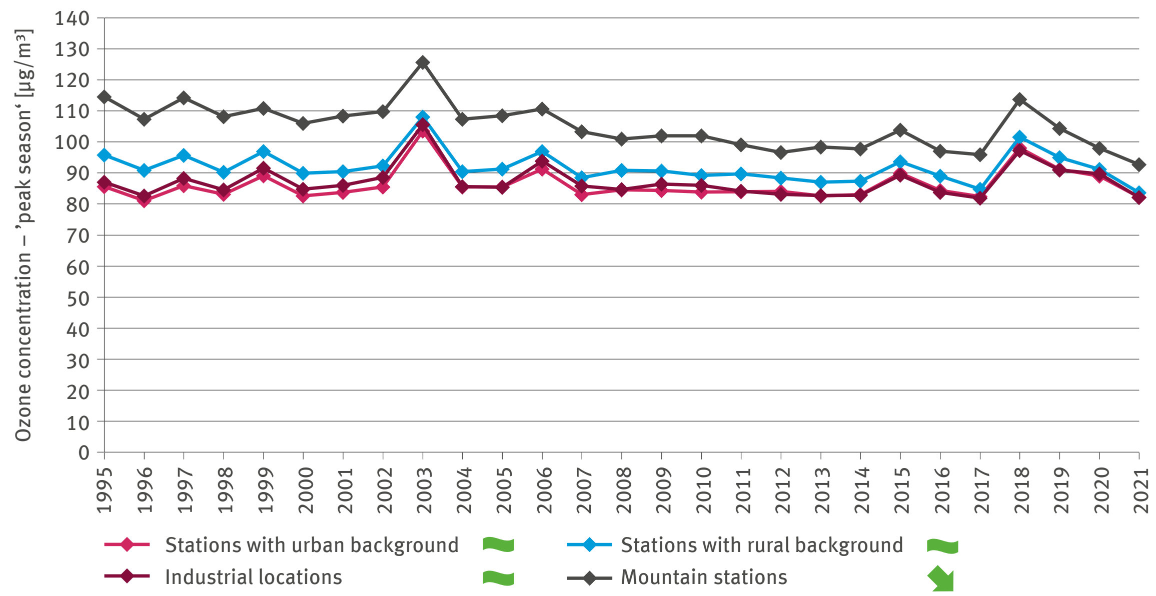
According to scientific research, there is an increasing amount of evidence pointing to the influence of weather conditions on the increase in diseases and mortalities related to conditions of the respiratory tract. Apart from temperature, it is air humidity which is of particular relevance in respect of illnesses affecting the respiratory tract, as dry air dries up the mucous membranes and facilitates virus infections. However, high air humidity can also make breathing difficult, and it can increase the number of allergens such as dust mites and moulds in the air. Likewise, wind, air pressure and thunderstorms can cause respiratory complaints. There is also reliable evidence now for the influence of weather patterns on heart disease.

The relationships are more complex between meteorological factors and air-hygienic components and their impacts on human health. Interaction takes place between temperature, air humidity, air pressure and air pollutants such as nitrogen oxide, ozone and particulate matter. Owing to changed mixing processes in the troposphere, in other words, the lowest layer of the earth's atmosphere, and photo-chemical reactions, there is a potential for the frequency of high air pollutant burdens increasing. Furthermore, high air temperatures increase the impact of air pollutants. Proteins adhering to particulate matter are transported more deeply into the respiratory tract. Likewise, ozone and nitrogen oxides increase the allergenicity of pollen (cf. Indicator GE-I-3, p. 44).

The indicator focuses on the ozone as an air pollutant, given that weather-pattern related factors are of particular significance to the formation of ozone. Ozone occurring near the ground will not be released at once; in fact it is formed only as a result of intensive sun irradiation on account of complex photo-chemical processes produced by precursors – mostly nitrogen oxides and volatile organic compounds. This entails that ozone concentrations are likely to increase more in rural areas than in conurbations. Especially for the volatile organic compounds, vapours from deciduous and coniferous trees are relevant; biogenic nitrogen oxides emanate mostly from over-fertilised soils. The emissions from precursor substances have decreased since 1995; this has led to a distinct

GE-I-9: Ozone burden

Ozone forms from nitrogen dioxide and volatile organic compounds at high temperature and sun irradiation. The emissions from those substances decreased distinctly since 1995; this led to a decline in peak concentrations of ozone. However, at the same time, there was less ozone depletion caused by nitrogen monoxide, thus largely leading to ozone concentrations stagnating during the peak season. In 2003 and 2018, extreme weather conditions led to high ozone burdens.



Data source: UBA (based on measuring networks of the federal states and of the federal level) decline in peak concentrations of ozone. However, owing to a reduction in the titration effect (ozone depletion by nitrogen monoxide) this was associated with an increase in medium-high ozone concentrations.

High ozone concentrations are injurious to human health. They can reduce the functionality of lungs, cause inflammatory reactions in the respiratory tract as well as breathing difficulties. These impacts can become serious during physical exertion and intensified breathing. Sensitive individuals or those with pre-existing complaints such as asthmatic persons are particularly vulnerable. They are advised to avoid physical exertions outdoors while ozone levels are high. Given the fact that ozone is highly reactive, it is reasonable to assume that ozone might be carcinogenic.

In cases where the ozone values reach or exceed an hourly mean of 180 µg/m³ air, the population is informed accordingly and provided with behavioural recommendations; an hourly mean of 240 µg/m³ triggers warning messages. Furthermore, a target value has been set for the purpose of health protection. The maximum daily 8-hour value of 120 µg/m³ must not be exceeded on more than 25 days per calendar year. The mean of the days is calculated across three years. The WHO published new recommendations for air quality in 2021. These recommendations have supplemented the 8-hour value applied so far by a value for the so-called 'ozone peak season', thus facilitating the illustration of the long-term effect. The 'ozone peak season' is defined as the phase of six consecutive months with the highest ozone concentrations. For the DAS Monitoring Indicator, this season was fixed at April to September, as in Germany increased ozone concentrations near the ground occur mainly during that time. Beyond this half-year period, the mean of the daily maximum 8-hour values has been calculated. According to the WHO, the critical threshold value is set at a concentration of 60 µg/m³.

The Länder and the UBA measure ozone concentrations within a nationwide measuring network comprising more than 260 stations. The measuring stations are divided into the categories 'urban background', 'rural background', 'industrial background' and 'mountain background', as these are characterised by different preconditions for ozone formation. At the mountain stations – stations at altitudes from 900 metres above sea level – and at rural stations, the ozone concentrations measured are typically higher than at urban stations. This is due to the fact that the concentrations of nitrogen oxide contained in exhaust gases emitted by car exhausts are lower in rural areas. Nitrogen monoxide reacts with ozone and leads to ozone depletion, especially during the night. In fact, ozone precursor substances are transported by wind beyond urban areas, thus contributing to the formation of ozone at some distance from their actual source. The concentration values measured at industrial stations are comparable to those from urban stations.

In hot conditions and with strong irradiation from the sun, the resulting ozone level can be hazardous to human health. (Photo: © Lightspruch / stock.adobe.com)

The concentrations measured during the 'ozone peak season' have remained almost unchanged since 1995 whilst they even decreased in the case of the mountain stations. This is due to the fact that the emissions from the ozone precursor substances were regressive. However, the time series indicates fluctuations from year to year which can be attributed, above all, to specific weather patterns occurring in summer. For example, the 'ozone summer' of 2003, during a particularly long period of sunny summer weather with above-average temperatures and long sunshine periods, allowed the formation of high ozone concentrations. Quite the opposite happened in the summer of 2018, indicating new high temperature records, especially in July and August. Although the mean concentration values were increased, high peak concentration values were few and far between. This demonstrates that despite regressive concentrations of the ozone precursor substances, extreme weather patterns can still lead to distinctly increased ozone concentrations. With higher temperatures and more intensive sun irradiation, climate change drives the formation of ozone near the ground, which can potentially lead to recurring stresses on health owing to excessive ozone concentrations.

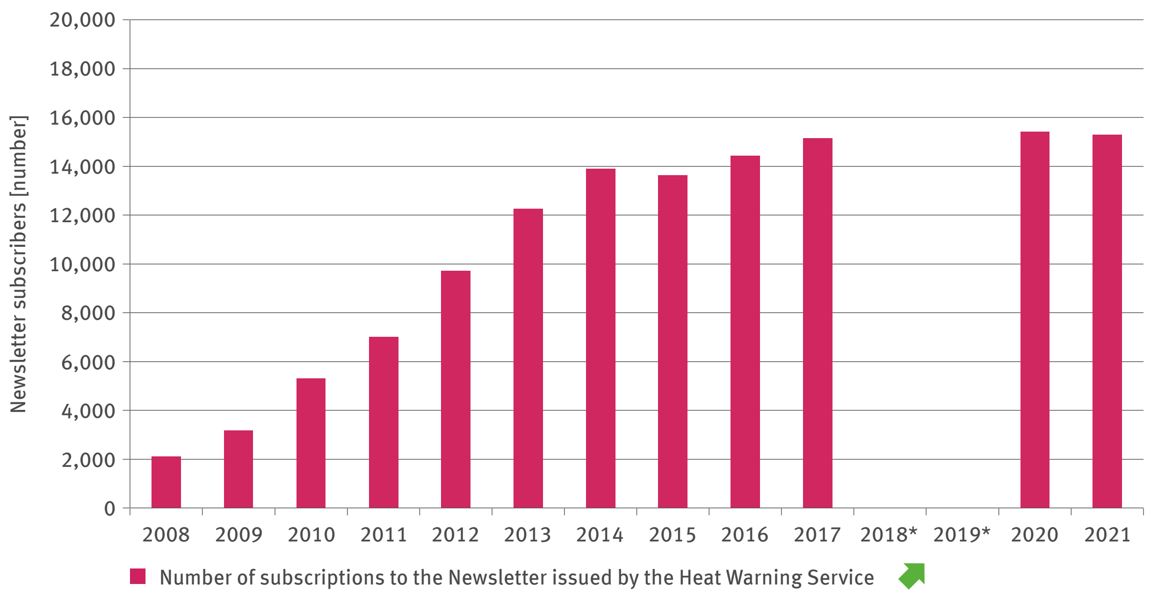
Heat warnings support preventative measures

The high number of heat-related mortalities and hospital stays in the hot summer of 2003 (cf. Indicator GE-I-2, p. 42) demonstrated that we have to prepare for such health-threatening events in a more targeted way. In order to enable, in particular, health facilities such as hospitals and individuals with solitary lifestyles to prepare for imminent heatwaves and to take timely precautionary and protective measures, the DWD introduced a heat warning system in 2005. With differentiation between warning districts, heat warnings are issued on a daily basis for the current and the next day, as soon as the 'perceived temperature' reaches the threshold value defined, and as indicated by other factors such as thermal situations in towns and cities (cf. Indicator GE-I-1, p. 40).

Heat warnings are issued in various ways: via the internet or via subscription to the 'Newsletter Hitzewarnungen' (heat warnings) (www.hitzewarnungen.de); since July 2013 also via smartphone apps and via apps associated with disaster warnings (NINA, Katwarn). Alongside the institutions of the health service, private individuals now also make use of the newsletter. The number of subscriptions was rising continuously in past years, but latterly came to a standstill in 2020 and 2021. There are no numbers available for the years 2018 or 2019, as the conditions for data storage changed since the introduction of the General Data Protection Regulation (DSGVO) in 2018, thus making it necessary to establish a new system. The stagnation of newsletter subscriptions is presumably due to the growing use of apps which are more in accord with current usage behaviour. The heat warning app introduced in 2015 was switched off in 2020, as the more broadly themed DWD GesundheitsWetter-App came into operation at the end of May 2020. This app informs the public health service, vulnerable people and at-risk-groups as well as the general public on topical, weather-related health hazards. In concrete terms, the app contains official UV and heat warnings as well as information on the 'perceived temperature', pollen forecasts as well as the hazard indices of weather sensitivity. Besides, the DWD WarnWetter-App also provides information on heat warnings. However, it is generally more complex, targeting a different user group. Another reason

GE-R-1: Heat warning service

The DWD 'Newsletter Hitzewarnungen' (NL heat warnings) provides information at times when 'starke' (major) or 'extreme Wärmebelastung' (extreme heat stress) is to be expected for the current or the next day. In the course of previous years, the number of subscribers (facilities such as hospitals as well as private individuals) to the newsletter increased steadily. However, latterly this development came to a standstill, as the use of warning apps became increasingly popular.



*No data

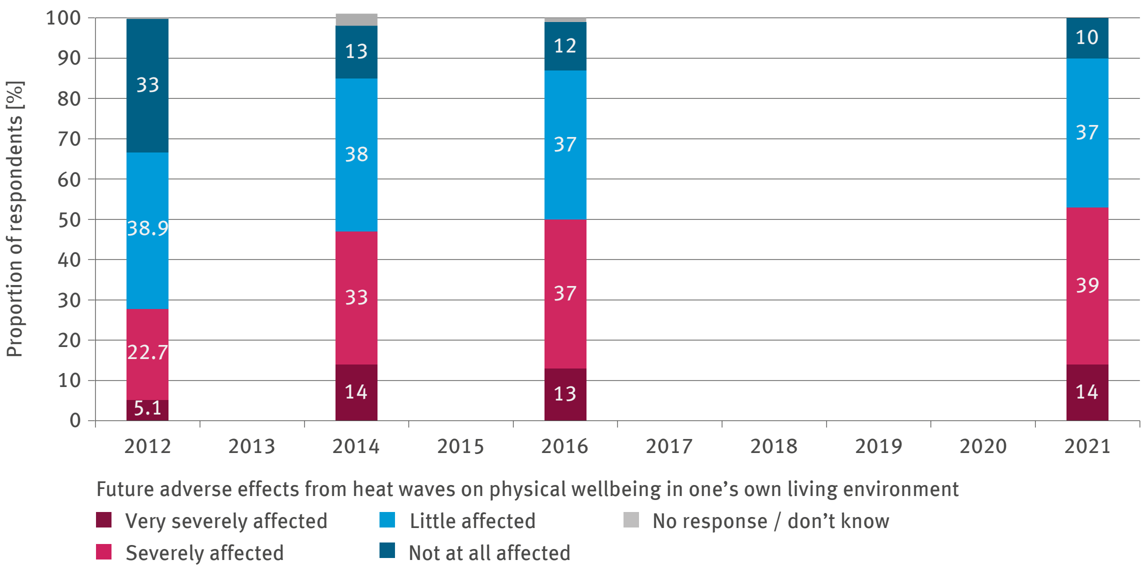
Data source: DWD (heat warning service, records of newsletter subscribers and warnings issued) for the 2020 / 2021 stagnation might be that the Covid-19 pandemic eclipsed most other health concerns.

It is reasonable to assume that it is due to more intensive PR activities regarding heat impacts and the more vigorous communication of risks, both by authorities and by medical doctors, that the public's awareness of health impairments arising from heat periods has increased in recent years. This is indicated by the findings from the representative population survey entitled 'Environmental awareness in Germany' which is carried out at regular intervals on behalf of the UBA and the Federal Environment Ministry[49]. The proportion of respondents who subjectively expect for their own future that heatwaves would have either very severe or severe effects on their own physical wellbeing or their health, has increased since the first survey was conducted in 2012. Although the increase was less pronounced latterly than in the early years of the survey, in 2021 already 53 % of respondents stated that they expected to be either severely or very severely affected by the future development. By 2021 only 10% considered themselves not affected in any way, whereas in the first survey as much as 33 % of respondents had expected not to be affected. For the first time in 2021 the data were collected within the framework of a special survey on environmental awareness which will in future be conducted only every four years. Another reason for the increased awareness of heat-related hazards is assumed to be that – especially over the past ten years – there were several occasions on which record temperatures and heatwaves were experienced. This made the impacts of climate change very real for the life experience of individuals.

However, in order to be really effective, heat warnings have to be followed up by concrete actions and the adaptation of behaviours. This includes the prevention of major physical exertions, drinking enough fluids, ensuring proper electrolyte balance as well as taking measures to ensure both the active and passive cooling of rooms. Residential homes for the care of the elderly and people with disabilities as well as care homes, are inhabited by people who are not necessarily able to take such measures unaided. The care and attendance workers will therefore have to provide active support. It has so far not been examined systematically nationwide as to which actions are actually triggered by heat warnings.

GE-R-2: Public awareness of health problems caused by heatwaves

There has been an increase in the awareness of health hazards connected with great and persistent heat. In 2021 already 53 % of respondents stated that in terms of their own health, they expected to be affected in future either severely or very severely. Only every tenth respondent stated that they did not expect to be affected in future.



Data source: BMUB/BMUV & UBA (study ‚Umweltbewusstsein in Deutschland', for 2021: additional survey in the framework of the study ‚Umweltbewusstsein in Deutschland 2020')

People with pollen allergies need information

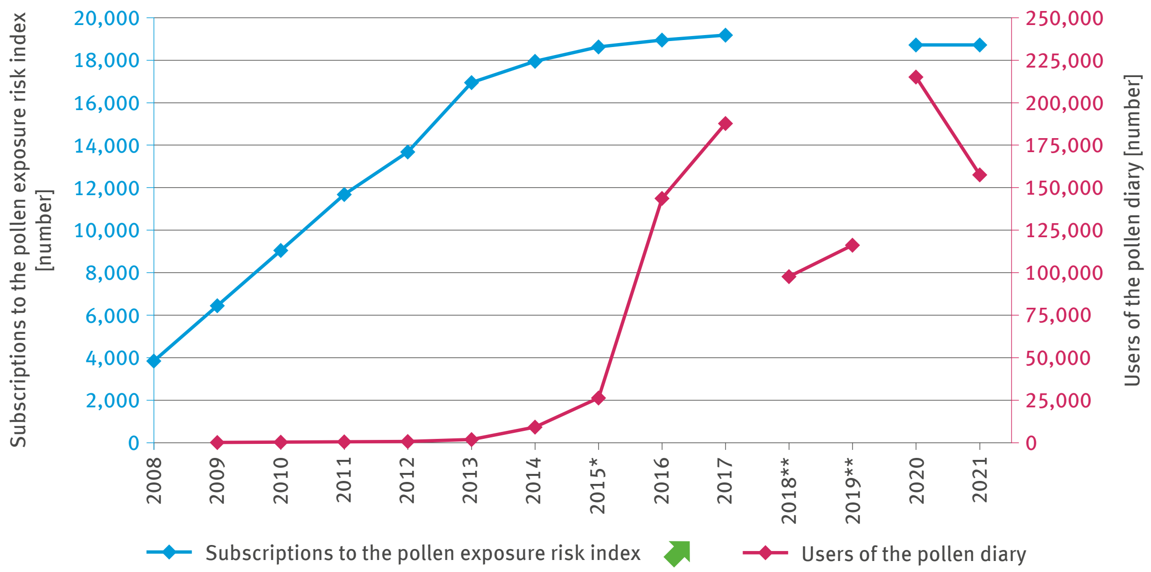
'Hay fever' is the colloquial, as well as trivialising term for a condition which is induced largely by allergenic pollen. However, hay fever is by no means harmless; it can be accompanied by major losses in quality of life and serious health impairments. Especially in cases where the allergic inflammation of nose and eyes extends to the bronchia, this can lead to chronic breathing difficulties (allergic asthma) and irreversible restructuring processes in the bronchia and lungs. One in three hay-fever sufferers will develop, in the course of their life, asthma that is associated with the pollen season but which can later become asthma that prevails all-year round.

Coming into contact with allergenic pollen in the environment is in many cases unavoidable or difficult to control. It is therefore absolutely essential to give allergy sufferers a chance to better understand the nature of their condition and of any underlying causes, thus enabling them to develop avoidance strategies. The following applies: the more allergy sufferers understand their condition, the less they suffer. In order to provide better and prophylactic information for people with pollen allergies, the DWD operates a pollen exposure risk index and the PID provides weekly pollen forecasts for Germany. During the season when pollen is airborne, this index provides information on the probable intensities of pollen burdens regarding the eight allergologically most important types of pollen (hazel, alder, ash, birch, sweet grasses, rye, mugwort and ragweed) expected to prevail during the current day and the two subsequent days. The weekly pollen forecast provides information on the eight types of pollen mentioned above and a number of other allergologically relevant pollen for the period of a week[50]. The up-to-date nature of these forecasts enables people who suffer from pollen allergies to arrange for targeted prophylactic actions in terms of adapting their behaviour and obtaining appropriate medication. Information on the stress risk expected can be downloaded direct via the internet on the respective websites operated by the DWD and the PID. Alternatively, there is an option to subscribe to a newsletter from either of these institutions.

As in the case of heat warnings (cf. Indicator GE-R-1, p. 58) there are no data on the DWD Newsletter

GE-R-3: Information on pollen

There is an increase in the use of available information contained in the pollen exposure risk index and in the use of the service of the pollen diary or smartphone apps which facilitate a personalised documentation of hayfever symptoms and the medication used. The number of newsletters distributed and also the use of the services offered by the PID and Techniker Krankenkasse ('Husteblume' app) have been increasing significantly.



* Up to 2014 Pollen App only, from 2015 onwards summarised for Pollen-App and Husteblume
** No data for the Husteblume app

Data source: DWD (pollen exposure risk index), PID (pollen diary) subscriptions available for the years of 2018 and 2019 owing to the fact that the regulations in connection with the DSGVO (Datenschutz-Grundverordnung / General Data Protection Regulation) had not yet been issued at that time. In the years of 2020 and 2021 the subscription numbers stagnated. Presumably – similar to the situation with regard to heat warning newsletters – this is due to the growing use of apps which are more in accord with current usage behaviour. The pollen exposure risk index was incorporated in the DWD GesundheitsWetter-App which has been available since May 2020.

In addition to the pollen exposure risk index, the Medizinische Universität Wien / Austria in cooperation with the PID has since 2009 been developing further services offered for the support of allergy sufferers. The Online-Pollentagebuch (online pollen diary) was made available first. This enables people with hayfever to make connections between their current problems in eyes, nose and bronchia as well as their current medication, and the values of pollen activity in the location where they happen to be at any particular time (even if they happen to be staying in another European country). The daily records entered into the internet-based pollen diary helps allergy sufferers to compare – quickly and on their own – the intensity of their condition and the degree of current exposure to air-borne pollen. This enables them to see which type of pollen triggers what kinds of symptoms. In addition, the users of this diary are provided with an individual assessment of their pollen season. The pollen diary can also serve a patient's GP or medical specialist as a useful aid in making a diagnosis and planning a therapy. In line with technological advances, a pollen app ('Pollen App 7.3.1'[51]) was developed for smartphones in 2013. This app makes it possible to record the individual symptoms and their severity, at the same time as providing individual forecasts regarding likely medical complaints for the subsequent two days.

Since 2015 the Techniker Krankenkasse in cooperation with the PID has offered an app entitled 'Husteblume' (a pun on a children's name for the seed heads of dandelions[52]. The contents of this app are identical with Pollen App 7.3.1. The Husteblume, in addition to the pollen exposure forecast and the recording of symptoms, also provides generic therapy tips. For the 2019 pollen season, the app was revised and expanded to include several new functions. The number of users who – via the Pollen 7.3.1 app and / or the Husteblume app – make entries into their pollen diary at various intervals during the year, has increased enormously since 2015. There are no data available for 2018 or 2019 regarding the Husteblume app which is the reason why the user numbers for those years appear to be distinctly lower. In 2021 almost 158,000 users made entries regarding their medical complaints in respect of nose, eyes and bronchia and the medication taken to alleviate those complaints. The significant decline in numbers for 2021 is to a large extent due to the impacts of the Covid-19 pandemic. Health topics other than allergies focused the public's attention, and possibly the wearing of masks helped to reduce contacts with pollen allergens. It might also have been the case that – owing to the weather pattern – the pollen count at least of birch was distinctly lower in 2021 than in the previous dry and hot years (cf. Indicator GE-I-3, p. 44). In 2022 the figures were distinctly higher again.

The pollen forecast and daily entries into the internet pollen diary facilitate a targeted prophylactic approach.
(Photo: © Александра Вишнева / stock.adobe.com)

The large amount of data arising every year thanks to both apps being used by a great number of users, makes it possible to analyse the type and intensity of allergenic symptoms in Germany's 'hayfever population'[53]. Particularly welcome for the purpose of statistical analysis are the data from users who enter information into the app for at least five consecutive days. However, this differentiation is of no consequence in terms of the Indicator. An evaluation of the 'Husteblume' app shows that 56 % of users felt better informed about their allergy; while 34 % stated that they have been coping better with their allergy since using the app. 27 % of users report that the app has improved their quality of life[54] Every eleventh user even states that their allergy has improved in general. The usage of the app over a year or during the pollen-relevant months – as stated in the study – showed that behavioural changes seem to be feasible, as the users of the Husteblume app sought medical assistance 7 % (mean) less frequently.

Mosquito atlas – Citizens get involved

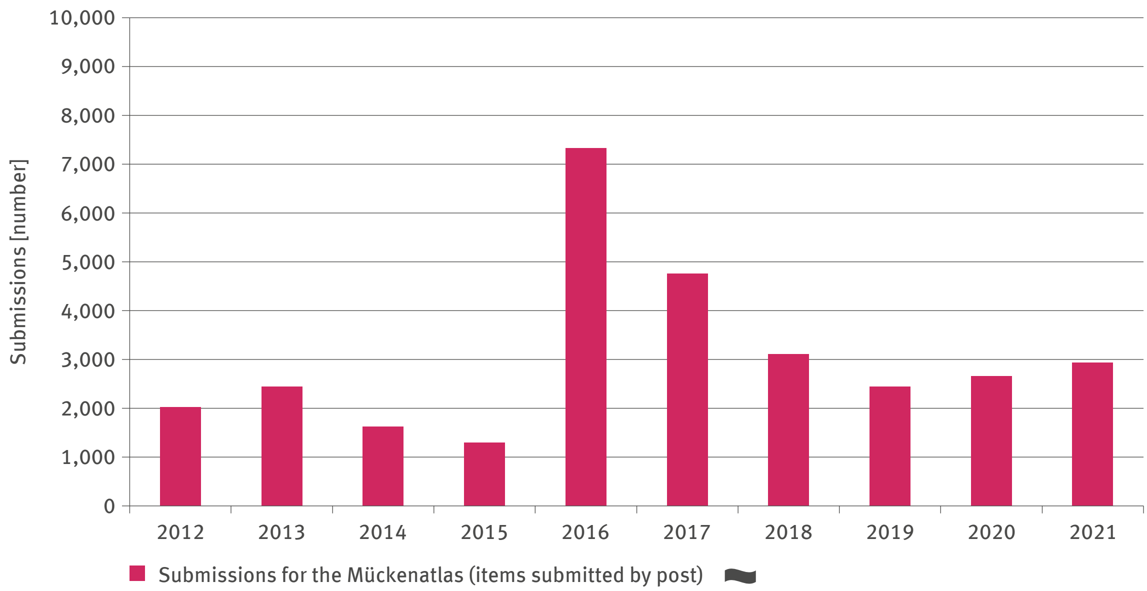
The spreading of mosquito species which can transmit pathogens hazardous to humans is a relevant health risk. Apart from autochthonous cases of West Nile Fever, there has been no evidence yet of infections such as dengue, zika or chikungunya transmitted by mosquito bites and contracted in Germany. Nevertheless, this hazard is increasing, given the spread of mosquitoes which can act as vectors for these pathogens (cf. Indicator GE-I-5, p. 48), and the concurrent presence of these pathogens which can be introduced, for instance, by travellers returning from abroad. The collection of data and information on the spread of mosquitoes is an important basic prerequisite to be met in order to facilitate preventative measures. Apart from controlling these insects – as is being done, for instance, in the Upper Rhine area – this includes especially raising awareness among the population in order to enable people to take individual protective measures. The main issue must be to prevent getting bitten, and to be able to give any medical specialist correct information in case of an infection.

On account of limited resources it is not feasible to carry out any systematic nationwide mosquito monitoring using traps baited with attractants. This is why the ZALF and the FLI launched a Citizen Science Project in 2012 – the ‘Mückenatlas’ (Mosquito Atlas)[55]. Citizen Science is a participatory approach to science, in which interested amateurs – often in cooperation with full-time researchers – contribute to progress in the field of scientific findings. Such cooperations create win-win situations: Researchers obtain data collected across a wide area, while the participating citizens gain confidence and experience in handling topical issues and complex problems as well as the satisfaction to get actively involved and make constructive contributions to a worthwhile project. Especially in areas such as the health service, where personal provision plays a major role, such approaches are valuable.

As far as the Mückenatlas is concerned, citizens can post mosquitoes to researchers by surface mail, who will identify the relevant species scientifically and conduct assessments regarding their spread or distribution range.

GE-R-4: Submissions for the Mückenatlas

Since 2012 interested citizens have been able to submit captured mosquitoes for inclusion in the Mückenatlas. The data are used for the purpose of analysing the spread of mosquito species in Germany. At the same time this ‘tool’ raises the public’s awareness of the issues concerned. In 2016 vigorous press activity in Germany led to keen attention to the zika epidemic in Latin America at the time of the Olympic Games.



Data source: FLI, ZALF (Mückenatlas)

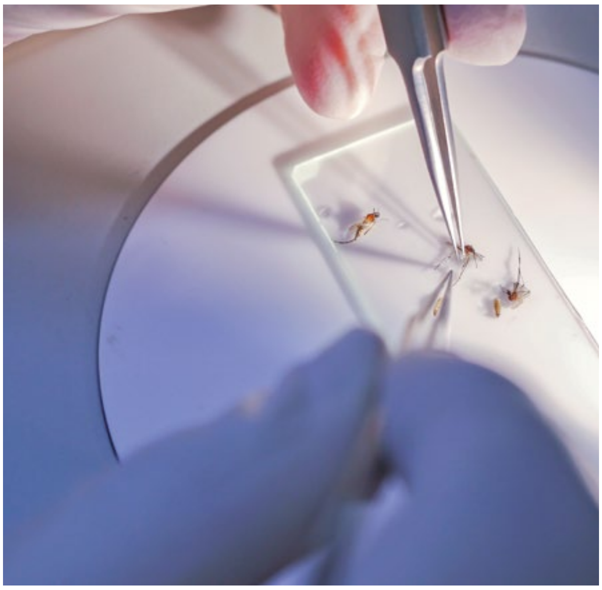
Compared to a systematic scientific monitoring process regarding the spread of mosquitoes, the Citizen Science approach has its pros and cons. The focus of the captures made by means of the Citizen Science approach in a person's every-day environment limits the representativity of the finds and entails that the finds can only reflect a section of the actual distribution. Almost two thirds of the insects submitted have to date been caught in rather urban environments such as sports fields. By comparison, rural areas are under-represented. Distorted outcomes can also be due to citizens limiting their search to unusual types of mosquitoes which is why those make up the bulk of submissions received by researchers. Relevant advantages of this approach are that captures are distributed more widely in terms of space and that in some cases, the insects are caught on private property which might not be as accessible to researchers.

Although Citizen Science cannot on its own monitor Germany's entire mosquito population, the 'Mückenatlas' is an important component supplementing the monitoring process with the aid of specialised traps baited with attractants.

The indicator illustrates the number of items submitted by post. This means that each item posted is counted as an addition to the Mückenatlas, regardless of how many mosquitoes are contained in the item submitted. Most participants send only one or just a few mosquitoes per submission. However, there are also submissions which contain mosquitoes collected throughout an entire year – some by means of using private traps – and these are posted as one item.

The time series covering the postal mosquito submissions demonstrates that the population is already sensitive to the themes and issues involved in the introduction and spread of non-native mosquitoes. According to the opinion of ZALF and FLI experts, the distinct leap in submissions in 2016 can be attributed distinctly to the zika epidemic in Latin America in 2015 and 2016 which attracted a lot of attention also in Europe. The coincidence of this development with the 2016 Summer Olympics held in Brazil gave rise to intensive press activities on the issues which obviously entailed that the public kept a very close eye on the occurrence of potentially hazardous mosquitoes also in Germany. This was reflected in an unusually high number of submissions.

In Europe, the zika virus had been unknown to that date. Above all, this virus is transmitted by the yellow-fever mosquito (*Aedes aegypti*), but also through other species of the genus Aedes, such as the Asian Tiger mosquito (*Aedes albopictus*). In adult humans infected, the zika virus often just produces influenza-like symptoms. However, in the unborn foetus whose pregnant mother was infected, the virus can bring about severe impairments (skull deformation) as well as disabilities. As stated by the WHO, it was estimated that 1.5 million zika cases occurred in Brazil in the period from October 2015 to July 2016. In the whole of Europe, warning messages were issued for the sake of pregnant women.



The scientific identification of the mosquitoes submitted for the 'Mückenatlas' improved the data foundation. (Photo: © moxumbic / stock.adobe.com)

Probably, the time series covering the submissions for the Mückenatlas will continue to be influenced by such events as well as similar events either in Germany or at a global scale. Nevertheless, it can be said that the indicator fulfils its purpose, either despite or because of this scenario: The subject of the spread of mosquitoes and hazardous pathogens needs to be paid more attention, in order to facilitate more active measures.

Photo: © grafxart / stock.adobe.com

Water balance and water management

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

In the natural water cycle, water moves continuously in its liquid, gaseous or frozen state through land, sea and the earth's atmosphere. As a result of climate change, increased temperatures fuel this cycle, accelerating and intensifying the processes of evaporation. Any increase of water content in the atmosphere raises the likelihood of precipitation. Precipitation patterns are changing. Changes in the water cycle that have been observed already, have strong impacts on ecosystems, economy and society. This is because not just all living organisms – humans included – but nearly all economic processes are dependent on the availability of water, in some cases on high-quality water.

Water management encompasses the entirety of measures for regulating the water balance, for abstracting and distributing drinking water and for the management of various kinds of waste water. Climate change is one of the greatest challenges to the water management. It is primarily the incidence of extreme weather events which makes planning difficult. Given that the climate change impacts on water and groundwater are on the increase, the requirements for protecting and improving the resilience of these water sources to climate change impacts are increasing too. At the same time, the demand for the utilisation of water keeps rising. The experience of drought periods in the summer months of recent years shows that various regions in Germany are already now witnessing conflicts in respect of the utilisation of water.

DAS Monitoring –what is happening due to climate change

Previously, it was possible in Germany to assume that water would always be available in sufficient quantities. It was only the reliable supply of high water quality that has always been in focus. As demonstrated already by the 2019 DAS Monitoring Report, the development of groundwater levels requires greater attention. As indicated by data collected in the drought years of 2018 to 2020, the trend towards diminishing groundwater levels and reduced spring flows has continued. The development in northern Germany is of particular concern (cf. Indicator WW-I-2, p. 72). In the drought years, all over Germany record shortfalls were determined in respect of the long-term lowest groundwater levels recorded at gauging stations. Comparable trends have also been observed with regard to water levels in lakes, which – especially in the North German Plain – are closely linked with groundwater levels. Between 2018 and 2020 massive water losses were recorded in some cases (cf. Indicator WW-I-7, p. 82).

Precipitation deficits and high evaporation rates occurring in summer are also noticeable in the discharge rates of watercourses: The mean water discharge rates in the summer half-year have been decreasing significantly since 1961 (cf. Indicator WW-I-3, p. 74), while the number of low-water level days in the summer half-year – in other words, days on which the level of the mean low-water discharge (MNQ1960-1991) has not been attained – is increasing (cf. Indicator WW-I-6, p. 80). Evidence for decreases in the availability of water is also found in satellite gravimetric data. In Germany, the terrestrially stored water has diminished significantly in the course of the past 20 years (cf. Indicator WW-I-1, p. 70).

A dearth of water on one hand is contrasted with a surfeit of water on the other. Increased frequency of heavy rainfalls – sometimes even extreme and persistent rainfalls resulting from so-called Vb (or Five B) weather patterns – repeatedly cause floods. However, so far the development of floodwater days has not indicated a significant trend, either for the summer or for the winter half-year (cf. Indicator WW-I-4, p. 76). The formation of floodwater is always related to specific combinations of weather patterns which have so far not occurred either systematically or regularly. An analysis of peak discharge rates in watercourses (cf. Indicator WW-I-5, p. 78) shows clearly that in former years, especially during summer half-years, there have been some very extreme flood events, when the long-term mean values for flood discharge were exceeded 8-fold at some of the gauging stations. The flood disasters in the Ahr and Erft valleys are not even included in the gauging stations selected for discharge readings in the DAS Monitoring Indicators.

Rising temperatures combined with water shortages in summer have grave impacts on water ecosystems. Water temperatures in lakes and reservoirs have been rising significantly since 1961 (cf. Indicator WW-I-8, p. 84). This affected the onset of spring algal bloom (cf. Indicator WW-I-9, p. 86) and lake stratification in summer, thus in turn strongly influencing the chemical and biological processes occurring in lakes. Likewise, watercourse temperatures increased significantly in the course of the last three decades (cf. Indicator WW-I-10, p. 88). High water temperatures combined with reduced oxygen contents are problematic for aquatic organisms – fish, in particular.

Future climate risks – outcomes of KWRA

As mentioned in the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7) towards the middle of this century, high risks of low water levels, of floodwater and the failure of flood protection systems have been forecast. The same applies to flash floods and the associated failure of drainage facilities and flood protection systems. Nevertheless, the certainty of this estimate is categorised as low. As far as sewer networks as well as outfall ditches and sewage treatment plants are concerned, a medium risk (according to a grid of low – medium – high) was estimated to arise by the middle and towards the end of this century. A high risk is forecast to arise as early as the middle of this century in respect of increases in the temperature of water bodies, a decrease in ice cover and the deterioration of water quality. The certainty of this estimate ´has been categorised as medium. The reason for this may be partly the fact that especially the recent extremely hot and dry years 2018–2020 have demonstrated graphically the associated direct impacts on water bodies. As far as the development of the chemical water quality is concerned, there is very little certainty at the moment. It is to be expected that a medium risk may arise towards the end of this century. By the same token, the risk of negative effects on the groundwater level and quality arising by the middle of this century was categorised as high, and by the end of this century this forecast is even given the attribute of high certainty. These developments entail consequential risks in respect of water utilisation. For example, it is expected that by the end of this century there will be a high risk in terms of a shortage of irrigation water, and that there will be a medium risk in respect of restrictions to the availability of drinking water and process water. These estimates were made subject to low certainty.

Where do we have gaps in data and knowledge?

Thanks to the close involvement of the Länder in working out the water-related DAS Monitoring Indicators via the Federal/Länder Working Group Water (LAWA) / Subgroup Climate Indicators, it was possible to build a wide-ranging database for the DAS Monitoring. Moreover, subgroup discussions have helped to prompt further initiatives to improve the availability of data and to deliver monitoring data on other relevant themes. For example, the LAWA expert group on lakes has selected lakes all over Germany for the installation of specific measuring equipment in order to obtain measured data such as temperature data, differentiated by different levels of depth. This will make it possible in future to obtain meaningful data on the development of circulation and stratification regimes prevailing in lakes. Furthermore, the LAWA Panel on Surface Waters and Coastal Waters awarded a contract for a better standardisation of mapping instructions regarding the mapping of water body structures thus enabling the homogeneous application of such instructions by all the Länder. The purpose is to generate comparable data in future on the development of the structure of water bodies and their shores. Against this background it was decided not to re-introduce the response indicators contained in the 2019 Monitoring Report regarding the shore vegetation of small and medium-sized water bodies. It was not possible to expand the case study in respect of Brandenburg, Rhineland-Palatinate and Saxony.

Within the framework of the UBA-commissioned research project on the use of satellite data conducted in parallel with the further development of DAS Monitoring, possibilities were examined for improving the monitoring indicators for water-related themes by means of generating data, whose in-situ collection would be quite laborious or even impossible to implement comprehensively. Primarily, the work covered the establishment of time series on temperature and ice cover and regarding the onset of spring algal bloom in lakes. The time series on spring algal bloom was incorporated in the DAS Monitoring indicator set. However, as far as ice cover and temperature are concerned, the time series are currently still relatively short.

There are major data deficits in respect of quality parameters for watercourses. The investigations carried out within the framework of the WRRL (WFD/Water Framework Directive) can be used only to a very limited extent for the purpose of monitoring the impacts of climate change. Overview monitoring is used for assessing the overall condition of surface water bodies. This is only carried out at major intervals. The operational monitoring complements the measurements taken in the course of overview monitoring; it is used in order to obtain sufficiently reliable data on prevailing fluctuation ranges. However, this type of monitoring is carried out at just a few gauging stations. Investigative monitoring is intended to produce further insights into the causes of negative impacts and to find opportunities for their elimination. These measurements are typically made more frequently. However, the gauging stations are located so that, in a targeted way, they can capture any negative effects caused by anthropogenic activity. This means that they are not compliant with the selection criteria employed for the monitoring of climate change impacts which require the exclusion of anthropogenic influences as far as possible. For the gauging stations underlying the DAS Monitoring Indicator on watercourse temperatures (cf. Indicator WW-I-10, p. 88), it has been ensured, as far as possible, that they are not subject to any anthropogenic influences. However, it is not possible to achieve the complete exclusion of such influences. For the monitoring of climate change impacts it would be necessary to use a targeted approach for the identification of specific gauging stations for this monitoring purpose, and to ensure that these stations are suitable for very frequent investigations to be carried out.

As far as any impacts of climate change on the ecology of water bodies are concerned, indicators used currently in DAS Monitoring permit only the derivation of risk assessments. To date, there has been no direct collection or assessment of data on biological or material changes taking place in water bodies. This is partly due to the limited availability of data, in particular for the description and interpretation of changes in the ecology of water bodies. Notably, as far as material changes are concerned, there are numerous technical questions which remain to be answered. It is difficult to differentiate the specific impacts of climate change from other – especially from anthropogenic – influences.

While DAS Monitoring contains several meaningful indicators at the impact level, it is true to say that there is still a shortage of meaningful indicators at the response level. In this respect too, the development of indicators comes up against the limitations of data availability. For example, the nationwide indicator for the water use index (WW-R-1, p. 90) only shows a 'proxy' entry, in order to generate a theme in the monitoring report for the issues pertaining to a sustainable use of water in accord with the availability and use of water. Further considerations including the subject of a high-frequency collection and interpretation of data on peak utilisations of water are required. So far the theme of waste water management has not yet been embedded in the monitoring report either. Likewise, it is becoming increasingly important to examine the landscape water balance as well as the question how to improve the retention of water and the issue of rewetting at the landscape scale; these subjects have so far only been touched on as marginal themes in the monitoring report.

What's being done – some examples

With regard to the stabilisation of the landscape water balance, flood protection issues, the maintenance and restoration of a good ecological condition of water bodies as well as the availability of sufficient groundwater, there is broad agreement on objectives regarding the adaptation to climate change with the WRRL objectives and the EU Floods Directive (HWRM-RL). Owing to climate change, the implementation of the measures embodied in this directive has attained greater urgency.

As far as flood protection is concerned, there have already been direct political responses to the prevailing increased flood risks. This includes the National Flood Protection Programme (NHWSP) and the special framework plan 'Preventative Flood Protection' (Präventiver Hochwasserschutz), which includes the restoration of natural retention areas in its focus. The funds made available for flood protection have been distinctly increased in recent years (cf. Indicators WW-R-2, p. 92, and WW-R-3, p. 93). In the context of dealing with low-water levels and drought periods, the Länder are in the process of developing precautionary strategies for a sustainable management of water resources and for the prevention and management of water utilisation conflicts. In view of the extreme drought from 2018 to 2020, the work on these issues has gained a particular urgency. A strategic framework was provided for this work by the Federal government when the national water strategy [56] was adopted by the Federal cabinet on 15th March 2023. This strategy is to achieve sustainable use of water resources for people and the environment by 2050, ensuring the conservation and restoration of a near-natural water balance, and enhancing climate-adapted water infrastructures. This strategy has made it possible, for the first time, to pool water-related measures regarding all relevant sectors (agriculture and nature conservation, administration and transport, urban development and industry) with the involvement of Federal government, Länder, municipalities, the water management and all water-using economic sectors and groups. The action programme envisions 78 measures to be implemented immediately and to be completed by 2030. The implementation of the national water strategy is closely interconnected with funding from the action programme 'Natural Climate Protection' (ANK), which also provides funding for climate-related measures in water management, for the purpose of developing water bodies and for measures regarding water-sensitive urban development. Further measures at Federal level include the publication of research findings and information materials such as low-water level reports compiled by the Federal Institute of Hydrology (BfG) which is currently also developing a nationwide user-group specific low-water level information system entitled 'NIWIS'.

State

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Climate changes relevant to the action field

Drought and heavy rain

Although the mean precipitation amounts have changed little in the course of recent decades, there have been repeated phases regionally of extreme water shortages contrasted with fierce heavy-rain events. Since 2003 there have been particularly frequent incidents of dry phases in summer. As far as the heavy-rain events are concerned, high spatial and temporal variability combined with relatively short data series make reliable trend statements difficult. Dry periods as well as heavy-rain events impact the availability of water (cf. page 24).

Impacts of climate change

Impact

Photo: © Kybele/ stock.adobe.com

WW-I-2 Groundwater level and spring flow

High evaporation in summer on one hand, and increasing heavy-rain events on the other – with rainwater predominantly running off the surface – entail decreases in the replenishment of groundwater as well as the medium- to long-term diminution of groundwater levels in Germany, especially while the abstraction of water is increasing as a result of rising demand. All over Germany, record shortfalls were identified in the drought years of 2018-2020 revealing the lowest groundwater levels and spring flows recorded at gauging stations for many years. Of particular concern is the situation in northern Germany.

Impact

Photo: © Robert Poorten / stock.adobe.com

WW-I-7 Water levels in lakes

The water levels of lakes have been distinctly and significantly receding too. This is true for both, the lakes in the North German Plain, which are essentially fed by groundwater and therefore directly affected by receding groundwater levels, and also for lakes in the Alps-and-foothills, along with the Alpine foreland which are largely dependent on inputs from surface water bodies. During the period of 2018–2020 there were some incidents of massive water loss.

Adaptations – activities and results

Response

Photo: ©BMUV

The National Water Strategy has led to the pooling of water-related measures in all relevant sectors, with the involvement of all relevant stakeholders. As water becomes less readily available, the situation can bring about conflicts regarding the utilisation of water. A guideline is being developed at joint Federal and Länder level to facilitate transparent decision-making regarding the prioritisation of water abstraction. In addition, many Länder are currently developing strategies on how to deal with low-water levels and drought and how to safeguard the water supply. The ANK is used for funding climate-related measures in water management, for developing water bodies and for measures required in respect of water-sensitive urban development.

Water storage decreasing

Climate change makes itself felt in terms of rising air temperatures and a changing precipitation regime. The seasonal distribution of precipitation and its intensity are undergoing changes. Such changes influence the entire water balance, in other words, they affect evaporation, soil water, the formation of seepage water, the replenishment of groundwater, surface discharge on one hand as well as surface waters being fed by groundwater, on the other.

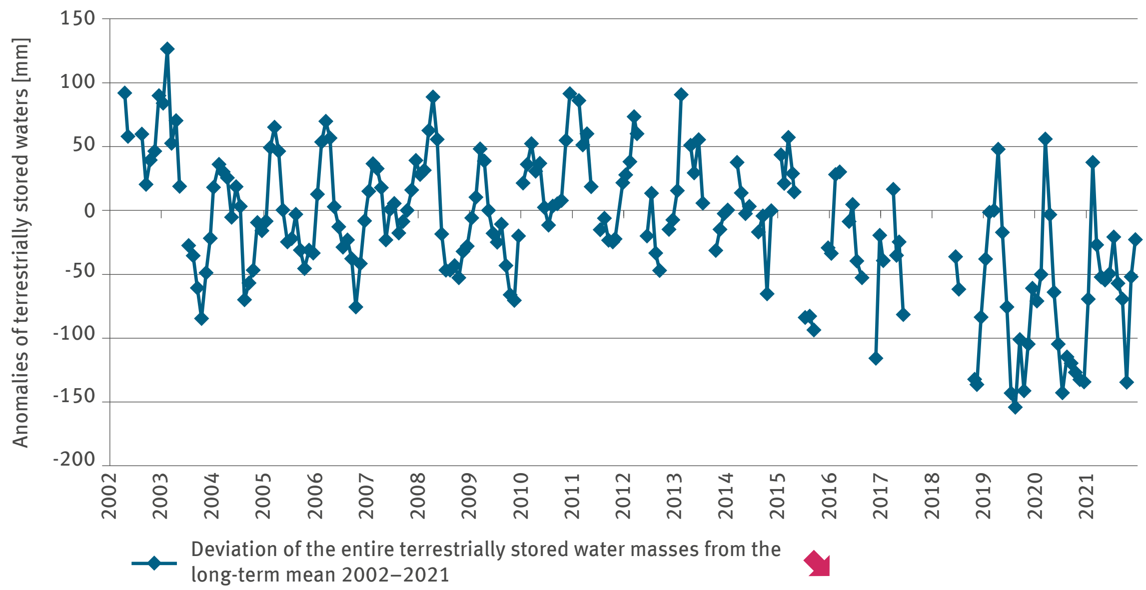
The water budget sums up all components of the water balance. In other words, the difference between precipitation, evaporation and regional discharge is equivalent to the terrestrial water storage. The latter encompasses water in various compartments: Groundwater, soil water, water in lakes, rivers and dams (such as reservoirs) and any water bound up in ice and snow. In the course of the past 20 years, terrestrially stored water has decreased significantly. In strongly simplified terms, this means that in Germany as a whole there is less water available now than just 20 years ago.

Regarding the data underpinning the indicator, they were submitted by the satellite mission GRACE (Gravity Recovery and Climate Experiment, 2002–2017) and its follow-up mission GRACE-FO (GRACE Follow-On, 2018–2023). These satellites are used to observe temporary fluctuations in the Earth's gravitational field. Mass distribution is not the same everywhere on the Earth, as there are liquid rock masses moving around in the Earth's interior, while in the oceans and on the continents, there are water masses and air masses on the move at all times. This uneven distribution of masses means that the Earth's gravitational force is not distributed evenly across the globe; in other words, in places where more mass is present, the gravitational field is a little stronger than elsewhere. In contrast with processes involving radar or optical procedures, satellite gravimetry is able to capture not just storage compartments near the surface, but also deep in the underground.

The GRACE Mission was conceived specifically to improve global insights into the impacts of climate change and to gain a more comprehensive knowledge of the processes

WW-I-1: Terrestrially stored water

In the course of the past 20 years, the terrestrially stored water has decreased significantly in Germany. In particular, the drought period from 2018 to 2020 shows distinctly negative deviations from the mean of the entire time series. The time series is based on satellite gravimetric data captured by the GRACE Missions, resulting from measuring the Earth's gravitational field. This process is able to capture water storage locations both above and below ground.



Data source: ISDC, GravIS – GeoForschungsZentrum (processing of GRACE data) involved. Among other findings, the mission revealed that between 2002 and 2016, the Greenland ice masses diminished annually by roughly 270 billion tonnes[57].

Upon the elimination of atmospheric water content above the land mass of Central Europe, GRACE makes it possible to capture changes in the amounts of terrestrially stored water. As a result, it is now possible to compare also the water volumes calculated by means of hydrological models with the measurements obtained indirectly.

The spatial resolution of the satellite data amounts to 300 kilometres. Subsequent processing enabled the calculation of higher-resolution grid data (approximately 110 km length by 70 km width) thus providing a sufficiently detailed resolution for the entire Federal Republic, with the exception of coastal areas. The time series for Germany provides a very clear illustration of pronounced flood events, for instance the events which occurred in 2011 and 2013 (cf. Indicator WW-I-4, p. 76) and the effects of the drought period from 2018 to 2020[58]. Nevertheless, there are gaps in the data for 2018 as the first GRACE Mission ended in 2017 while GRACE FO was not launched until May 2018. The data coverage during the transitional period between the two missions was insufficient. Other major data gaps occurring in 2015 are due to battery problems on board of GRACE which made it necessary to switch off the instruments temporarily. The increased noise noticeable during the deployment of GRACE FO – in other words the greater amplitude of data – is due primarily to increased solar activity which leads to increased friction on the satellites

In the indicator presented, the deviations from the long-term mean of the entire 20-year time series of 2002–2021 were determined on the basis of the absolute values obtained monthly. Months in which the precipitation exceeds the water loss from evaporation and discharge, are incorporated in the time series showing a positive anomaly. Months in which evaporation predominates show a negative anomaly.

In terms of absolute numbers, Germany is one of the regions worldwide which have the highest loss of water. Since the turn of the millennium the country has been losing 2.5 gigatonnes or cubic kilometres of water annually. Looking at the two decades overall, this amount is equivalent to the water contents of Lake Constance. Obviously, this is an enormous volume of water.[59]

The time series shows distinct matches with the measurement series (as presented in this chapter) – regarding the groundwater level (cf. Indicator WW-I-2, p. 72),

The satellites deployed in the GRACE Mission captured the terrestrially stored water masses. In Germany these water masses decreased in the course of the past 20 years.
(Photo: © dimazel / stock.adobe.com)

floodwater (cf. Indicator WW-I-4, p. 76) uand low-water levels (cf. Indicator WW-I-6, p. 80) as well as water levels in lakes (cf. Indicator WW-I-7, p. 82).

Decreasing groundwater levels

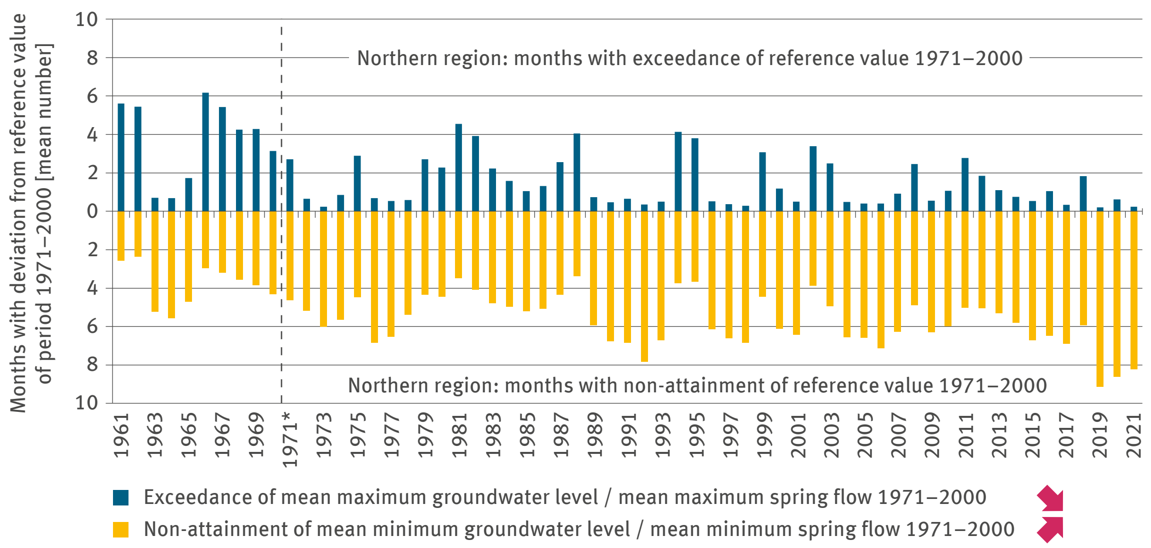
The extent to which groundwater can replenish itself in a location, and the amount of groundwater levels that can develop, are both factors that depend on a variety of influencing variables. Some of these variables include the distance between the aquifer from the top of the ground surface, the characteristics of the upper layers above the aquifer, the size and shape of rock cavities and the subterranean in- and outflow of groundwater as well as the volume of abstractions. Above all, it must be remembered that the groundwater formation in a given location is dependent on precipitation and surface discharge as well as evaporation. If the climatic conditions change, this will affect the formation of groundwater.

Rising temperatures act as triggers for a potentially higher evaporation overall, which means that less water will seep away for infiltrating the groundwater. Years with lower total precipitation do not immediately affect groundwater levels. This is because – in comparison with surface water – groundwater tends to respond relatively slowly to a changed precipitation regime. However, the situation can escalate when the availability of water is restricted long-term by the precipitation diminishing combined with higher evaporation. Both, changes in temperatures and in precipitation, affect the surface discharge, with knock-on effects on the groundwater. If precipitation occurs predominantly in winter, falling on soils saturated with water or possibly on soils that are frozen hard, its ability to seep away is restricted. By contrast in summer soils dry out more strongly and can hardly or not at all absorb precipitation, especially as it falls more frequently as heavy rain. The continuing encroachment of sealed surfaces (cf. Indicator RO-R-5, p. 310) and insufficient variety of structures in intensively farmed areas exacerbate the problem of the reduced replenishment of groundwater resources.

In order to obtain an overview of the development of groundwater levels in Germany, 148 groundwater gauging stations and spring flow points were selected in order to generate two indicators for the majority of the larger Länder (except for Saarland) and hydrogeological environments, for which mostly consistent data are available from 1971 onwards; in respect of 117 gauging stations the observation series even date back as far as 1961. All

WW-I-2a: Groundwater level and spring flow – Northern Region

The extreme dry years of 2018 to 2020 in the Länder located in northern Germany resulted in groundwater levels at numerous gauging stations ultimately dropping to record low levels. Compared to the mean calculated for all gauging stations considered, the years of 2019 to 2021 indicated a monthly mean of groundwater levels or spring flows – in more than 8.5 months per year – which was lower than the long-term mean of the lowest groundwater levels or spring flows



Northern region: Brandenburg, Mecklenburg-Vorpommern, Lower Saxony, North Rhine Westphalia, Saxony-Anhalt, Schleswig-Holstein
* Measuring point collective expanded from 1971 onwards

Data source: groundwater monitoring networks of federal states these gauging stations are in the uppermost aquifers and they are, as far as possible, unaffected by anthropogenic influences. In other words, there is no groundwater abstraction or irrigation taking place in the catchment area, the density of sealed surfaces is low, and during the period of observation there have been few changes in land management in the area. This makes it possible to a considerable extent, to make connections between any changes observed at these gauging stations and changes in the temperature and precipitation regimes.

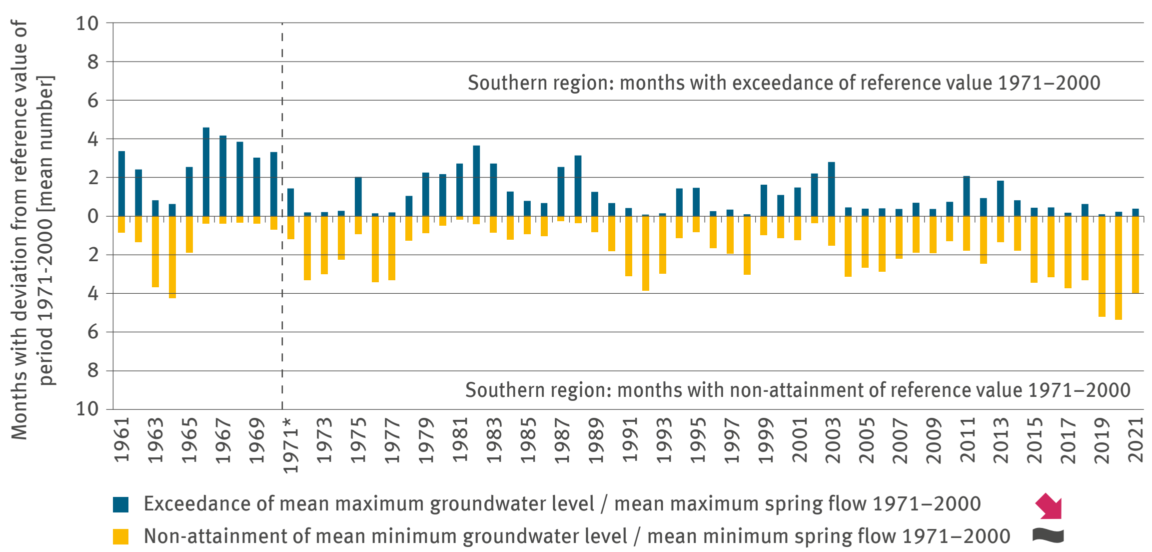
Given the different natural areas and climatic conditions within Germany, the indicator differentiates between the northern and southern parts of the country. The illustration shows the mean number of months – distributed across all gauging stations – in which the monthly mean of groundwater levels or spring flows was lower than the mean of the lowest groundwater levels or spring flows calculated for the relevant gauging stations during the years of 1971 to 2000. The same approach was adopted for comparing the monthly mean of groundwater levels or spring flows with the long-term highest groundwater levels or spring flows.

Trends indicating a falling number of months in which the long-term highest groundwater levels or spring flows are exceeded as well as trends indicating a rising number of months in which the long-term lowest groundwater levels or spring flows are not attained, are more prominent in the north than in the south, and they are statistically significant. In the south, only the decreasing cases of exceedance are significant. However, both regions witnessed record low-water levels from 2019 onwards resulting from the extremely dry years of 2018 to 2019. There are several gauging stations where – from 2019 onwards – the monthly mean of groundwater levels or spring flows was – almost throughout the relevant year – below the long-term lowest groundwater levels or spring flows.

In Germany almost three quarters of drinking water is abstracted from groundwater. The formation of adequate replenishment of groundwater is therefore an essential prerequisite for both – a sustainable supply of drinking water, and for supplying ecosystems with sufficient water.

WW-I-2b: Groundwater level and spring flow – Southern Region

In general, the situation in the southern Länder is similar to that in the north. These findings exemplify the way in which the impacts of drought years are reflected in extraordinarily low groundwater levels or spring flows. While – until the turn of the millennium – the time series was repeatedly characterised by wet clusters occurring more or less cyclically, such clusters have almost completely failed to occur since 2004 or at least they have been distinctly less pronounced.



Southern region: Baden-Württemberg, Bavaria, Hesse, Rhineland-Palatinate, Saxony, Thuringia
* Measuring point collective expanded from 1971 onwards

Data source: groundwater monitoring networks of federal states

Mean discharge values decreasing in the summer half-year

In the distinctly greater part of Germany, the natural discharge regime of watercourses is determined by rainfall. During the warm season, the degree of evaporation also plays a role. This leads to high mean values of discharge rates in winter and early spring, compared to low discharge values in late summer and autumn. Especially in the southern parts of Germany, winter snow cover as well as rain play a crucial part in the discharge regime. In alpine catchment areas with major rivers such as the Iller, Isar, Lech and Inn, winter precipitation often accumulates as snow; therefore discharge is lowest at that time of year. As a result of snow melt in spring and early summer, often accompanied by rainfall, maximum discharge occurs in the middle of the year. This is termed a nival discharge regime.

Apart from precipitation, the catchment area's topography and the substrate play an important role; these factors are crucial for the speed at which precipitation actually affects the discharge regime.

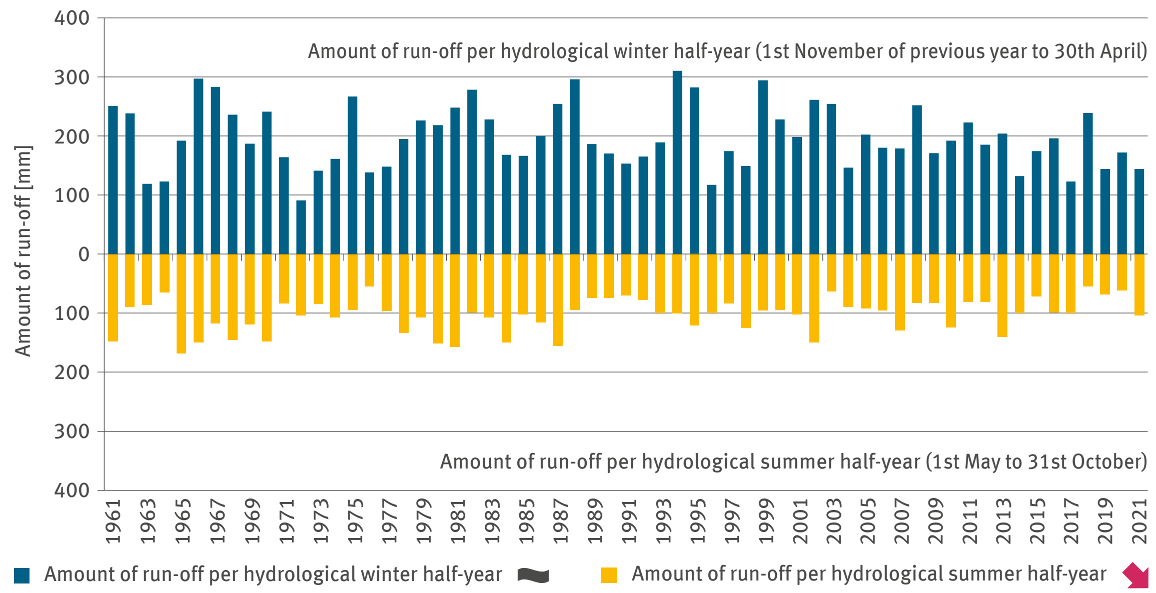
Where climate change affects the precipitation and temperature conditions, it will also affect the discharge regime. Consequences may include impacts on the volume of the total discharge of water and on the seasonal distribution of discharge.

For an analysis of discharge regimes and their development, levels from a total of 76 gauging stations across Germany's river catchment areas were selected. They represent mean catchment area sizes at a scale of 250 to 2.500 square kilometres. These are levels from gauging stations that are, as far as possible, unaffected by anthropogenic influences; in other words, this refers to runoff depths which were observed as not being strongly influenced by, for instance, water transfer systems or water retention systems.

The mean discharge of water (MQ) or the annual runoff depth (Ah), derived in relation to the size of the catchment area concerned, are indicative of the availability of water. This indicator shows the availability of water in principle, including water which is available for

WW-I-3: Mean discharge

The mean runoff depths across 76 levels measured in German river basins show distinct fluctuations from year to year. During the hydrological winter half-year, the runoff depth has been decreasing, albeit not significantly, since 1961. However, a significant decline in the mean runoff depth for the summer half-year has been observed, which suggests a change in the availability of water in summer.



Data source: run-off measurement of federal states

cultivation and for a variety of surface water uses such as cooling water or shipping. Changes in the mean discharge values can also entail changes in groundwater levels near banks (cf. Indicator WW-I-2, p. 72) thus affecting supplies of drinking water and process water. Besides, the water level and associated flow rates are just as important for nearly all ecological functions of water bodies.

Although the time series from the 1960s onwards shows a slight decline in the mean discharge value for the hydrological half-year period from early November to end of April, this cannot be regarded as a statistically significant trend. However, during the hydrological summer half-year, in other words, from early May to end of October, a significant falling trend can be discerned. This is due to reduced precipitation in summer and temperature-related higher evaporation during those months. These developments suggest that changes in the fundamental availability of water in both half-years (winter and summer) are already beginning to take place.

The mean value calculated across Germany, is – owing to the effects of precipitation and evaporation on the winter discharge values – clearly higher in general than the discharge values for the summer half-year. The low-water year of 1972 is the only year in the time series considered when the summer discharge values were a little higher than the winter values. Since then there has not been a single year when this happened again. Nevertheless, the relationship between the mean discharge in the summer half-year and the winter half-year does not suggest any changes that can be described as statistically significant.

In the Danube river basin where the discharge regime is characterised by a predominantly nival discharge regime, there have been – from 1960 until the late 1980s – just as many years in which the values for summer discharge were higher, as there were years in which the winter discharge values were higher. Since 1990 the years in which winter discharge values exceeded summer discharge values have increased in frequency. This suggests that the influence of the snow cover on the discharge regime is diminishing.

The mean discharge of watercourses in Germany decreases in the summer half-year. This means that the availability of water diminishes at that time of year. (Photo: © Uwe / stock.adobe.com)

Flood events – few significant trends

Compared to the variations and changes in mean discharge values (cf. Indicator WW-I-3, p. 74) there is greater awareness among the public of flood events because they have an immediate impact on human activities as they can cause personal injury and material damage.

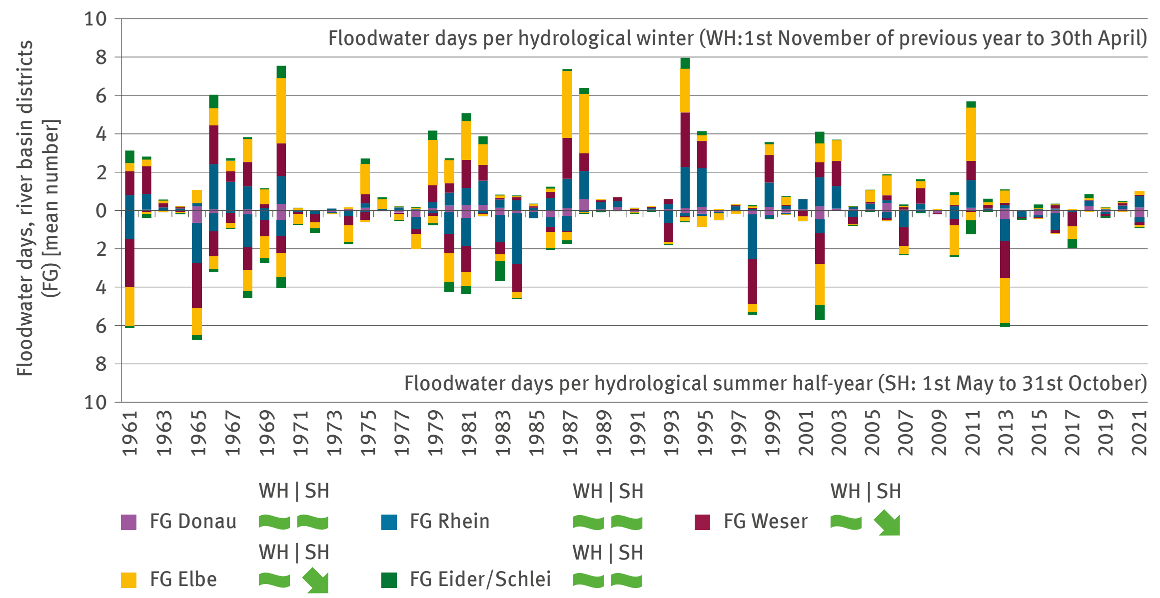
The time series starting in 1961 clearly indicates that the floodwater regime varies considerably from year to year. This is true for both the extent of flood events and for their seasonal distribution. For the purpose of the indicator, floodwater days at gauging stations distributed across 75 of Germany's river basins were evaluated. Floodwater days are days on which the mean daily discharge value is higher than the mean floodwater discharge value (MHQ) calculated for the reference period 1961-1990. The MHQ is calculated separately for the hydrological winter half-year (1st November of the previous year to 30th April) and the summer half-year (1st May to 31st October) on the basis of the highest discharge values (HQ) of individual half-years respectively.

When averaging the number of floodwater days measured at all gauging stations considered in a river basin, it becomes clear at which locations and in which years the flooding scenarios were concentrated. Flood events can be triggered by regionally limited weather conditions. For the summer season, this typically refers to rainfall that continues for several days and to heavy-rain events that can frequently be very localised. In the winter season flooding is caused by precipitation continuing for several days or even weeks and frequently also by thaw combined with rainfall, because under these circumstances discharge of great volumes of water may set in within a few hours.

Among the summer flood events that occurred since the turn of the millennium, the years 2002 and 2013 stand out. In August 2002 flooding in Germany was particularly prevalent in the Elbe and Danube areas. These events were caused by extreme rainfall continuing for days, which resulted in weeks of emergency operations in order to overcome the ensuing flood disaster. Likewise, flood events at the end of May and in early June 2013 were triggered by several days of rainfall. Apart from Germany

WW-I-4: Floodwater

The time series for the flooding scenario are characterised by individual flood events both in the winter half-year and the summer half-year. Significant trends have been discerned in a few cases only. Subject to weather patterns, there are spatial focal points where floods occur. However, as a rule several river basins are affected. Owing to the limited selection of gauging stations available for the indicator, not all flood events are covered.



Data source: run-off measurement of federal states

and Austria, other countries in central and eastern Europe were particularly badly affected. The month of May 2013 is considered to be one of the months in which precipitation was highest since systematic meteorological records began. In 2017 the low pressure front Alfred led to several days of rain resulting in flooding in the region of the Harz mountains and associated foothills. Consequently, the Weser river basin was affected most strongly.

The most recent major winter flood event occurred in January 2011, with focal points again in the Elbe and Main areas, while other river basins were also affected. The flood event was preceded by a month (December) with comparatively high precipitation levels while, at a lower geographical level, substantial amounts of snow accumulated. This meant that considerable water-equivalent amounts were stored in the blanket of snow when suddenly a low-pressure area coming in from the Atlantic triggered a strong thaw in the second week of January, which led to rapid melting of the snow cover, even in the mountains. This period of thaw was followed immediately by several rain fronts resulting in prodigious amounts of precipitation.

The devastating flood disaster of July 2021 which caused the death of more than 180 people, and which affected, in particular, the Länder Rhineland-Palatinate and North Rhine-Westphalia, but also Bavaria and Saxony, is not reflected with extraordinarily high numbers in the indicator. This is because the indicator is intended to illustrate floodwater in regional river basins, thus utilising data concerning levels of medium-sized catchment areas (as far as possible unaffected by anthropogenic influences). As far as small-scale flood events or storm surges are concerned, the geographical density of the gauging stations considered is insufficient. For example the districts in Rhineland-Palatinate and North Rhine-Westphalia that were most severely affected are not sufficiently covered by the indicator. Data for the river Ahr, for instance, where the floodwater caused serious damage in its river basin, are not reflected in the indicator.

As indicated by the time series so far, the development of floodwater days indicates very few significant trends either for the summer or for the winter half-year in those river basins. The development of floodwater is always related to specific combinations of weather patterns; however, these have so far not occurred repeatedly – either systematically or regularly. The distribution of floodwater days impacting the hydrological winter and summer seasons has so far not indicated a trend either. The events occur in both half-year periods, albeit a little more frequently in winter. As far as the rivers Weser and Elbe are concerned,

Severe flood events occur time and again, even though in statistical terms the number of flood events has not increased so far. (Photo: © Seewald / stock.adobe.com)

the number of flood events in summer is regressive. Those areas seem to be characterised by decreasing precipitation in summer, already affecting the flooding scenario.

Climate change cannot be accounted for by a single flood event. Atmospheric conditions and large-scale weather patterns which favour the accumulation of floodwater suggest a wide-ranging variability. In principle, warming enables the atmosphere to store more water vapour, that is to say, warming increases its ability to absorb moisture, thus increasing the potential for heavy rainfall. In future, westerly winds might increase in winter; likewise the frequency and intensity of so-called Five B (Vb) weather front trajectories might increase in summer. In these kinds of weather conditions, low-pressure areas shift to Central Europe from the Mediterranean where they are charged with water vapour. Often these low-pressure areas bypass the Alps and then deposit their rain in the eastern uplands and the eastern foothills of the Alps. The weather conditions which cause the Five B (Vb) trajectories can remain stationary for a long time causing continuous rain and even heatwaves.

Apart from climate change, there are however numerous other developments which affect the scenario of flood events. The increasing sealing of surfaces (cf. Indicator RO-R-5, p. 310) and soil compaction in catchment areas, as well as barriers to natural flood plains and embankments (cf. Indicator BD-R-2, page 210, and RO-R-6. page 312) result in higher and faster discharges into rivers.

Some flood events are extreme

The indicator in respect of floodwater days (cf. WW-I-4, page 76) does not permit any statements on the severity of the flood events concerned. Floodwater days are those days on which the long-term mean floodwater discharge (MHQ) was exceeded at the gauge in question, regardless of the actual amount of exceedance.

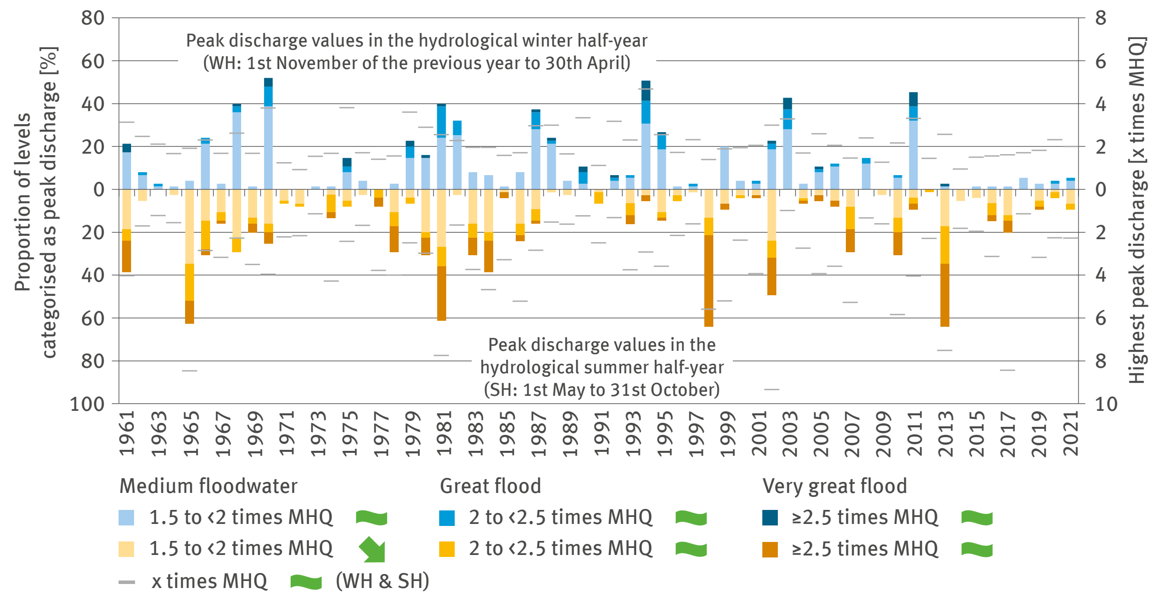
Extreme flood events – depending on where they occur and the degree of water utilisation in the areas threatened by flooding – can lead to serious material damage and personal injury (cf. Indicator BAU-I-5, p. 226). The designation of flood plains and the dimensioning of flood protection measures are often based on a 100-year flood event (HQ100), in other words, a flood event that, statistically speaking, occurs at least once in 100 years. As far as extreme flood events are concerned which exceed the HQ100 concept, this type of flood protection is not sufficient in most cases.

Putting it simply, it can be assumed that an exceedance factor of 1.5 times or less than twice the MHQ is equivalent to a repeat interval of five (HQ5) to 20 years (HQ20). An exceedance of MHQ by a factor of 2 to less than 2.5 is equivalent to a discharge event which, according to past observations, occurs roughly between once every 20 years (HQ20) and once every 50 years (HQ50). If there is floodwater discharge equivalent to at least a factor of 2.5 times the MHQ, this would be equivalent to a discharge event that occurs less frequently than once in 50 years. It has to be borne in mind, however, that the occurrence of extreme floodwater can change the statistics. For instance, it is possible that a single HQ100 event turns into HQ50.

The data analysis of peak discharge values demonstrates that the extreme flood events occur primarily during the summer months. In other words, this is the time of year when events occur which exceed HQ50. Even the most extreme cases of exceedance with factors of 8 or 9 times the MHQ occurred in the summer half-year. Statistically speaking, there are so far no significant trends discernible, with the exception of a decrease in the proportions of floodwater levels categorised as medium in the summer half-year. However, years such as 1998 and 2013 stand

WW-I-5: Peak discharge values in watercourses

Depending on the location and use of the areas threatened by flooding, extreme floodwater discharge events can lead to serious material damage and personal injury. The most extreme flood events so far occurred in the summer months when heavy or persistent rain entailed that the landscape was unable to retain the volumes of water anymore. It can happen that in the case of individual gauging stations, the long-term MHQ is exceeded by a factor of more than 8 or 9.



Data source: run-off measurement of federal states

out, when in many cases floodwater levels at many gauging stations had to be categorised as very high. In 1998, the month of October – usually known as a less rainy month – was characterised by extreme amounts of rainfall. It was the wettest October since the beginning of the systematic recording of weather data. There was flooding in various locations in Germany – the flooding in the catchment areas of the rivers Weser, Aller and Leine was particularly extreme. In 2013 the floodwater forced its way alongside the Danube, Saale, Elbe and other rivers, bulldozing a path throughout large parts of Germany: Bavaria, Thuringia, Saxony, Saxony-Anhalt, Brandenburg, Mecklenburg-Western Pomerania. Lower Saxony and Schleswig-Holstein bore the brunt.

It is also important to remember in respect of this indicator, that the 2021 flood disaster in the Ahr and Erft river basins is not reflected in the data, as the relevant gauges are not part of the selection of gauging stations for the Monitoring indicator. The July 2021 flooding was triggered by excessively heavy rain events. Especially in parts of North Rhine-Westphalia and Rhineland-Palatinate precipitation rates up to 100 litres per square metre were measured within 72 hours, locally even more than 150 litres per square metre in 24 hours. The extreme amounts of precipitation made especially the smaller water bodies swell fast and made them break their banks. When such extreme flood events occur, it can in fact happen that gauges are completely destroyed so that data are not available for the purpose of recording.

In addition, the indicator shows the highest amounts of MHQ exceedance attained in the relevant years at the relevant gauging stations. This means that typically the value is 'supplied' by a different gauging station every year. In 2002 the reading emanated from the gauging station at Lichtenwalde in the municipality of Niederwiesa in Saxony. The flooding which occurred during the flood event of August 2002 was particularly grave in the Mulde basin. The highest daily mean discharge measured amounted to a factor of 9.3 times the long-term MHQ of this gauging station.

In July 2017 the peak value compared to all other levels was reached in Bad Salzdetfurth in Lower Saxony. Precipitation of up to 220 litres per square metre (l/m²) in the course of three days resulted in the rivers Alme, Riehe, Lamme and Innerste rising to levels never attained before. The impacts of this flood were devastating.

In 2013 the gauging station at Zeitz on the Weiße Elster in Saxony-Anhalt supplied the peak value. After persistent rain on 3rd June, the local MHQ was exceeded by a factor of 7.5 at that gauging station.

A flood is never the same from one incident to the next: Flood events can increase to extreme and devastating proportions (Photo: © murat / stock.adobe.com)

Record low-water levels in drought years

Low-water events, in the same way as flood events, are part of a natural discharge regime. In alpine catchment areas low-water events may occur in winter owing to the storage of precipitation as snow. However, in river basins in upland areas and in the case of rivers in lowlands and plains, low-water levels occur especially in summer and early autumn when phases of low or a complete lack of precipitation coincide with high evaporation. In particular, prolonged meteorological droughts, in other words, periods of low or no precipitation, tend to exacerbate seasonal low-water levels, above all during the summer months.

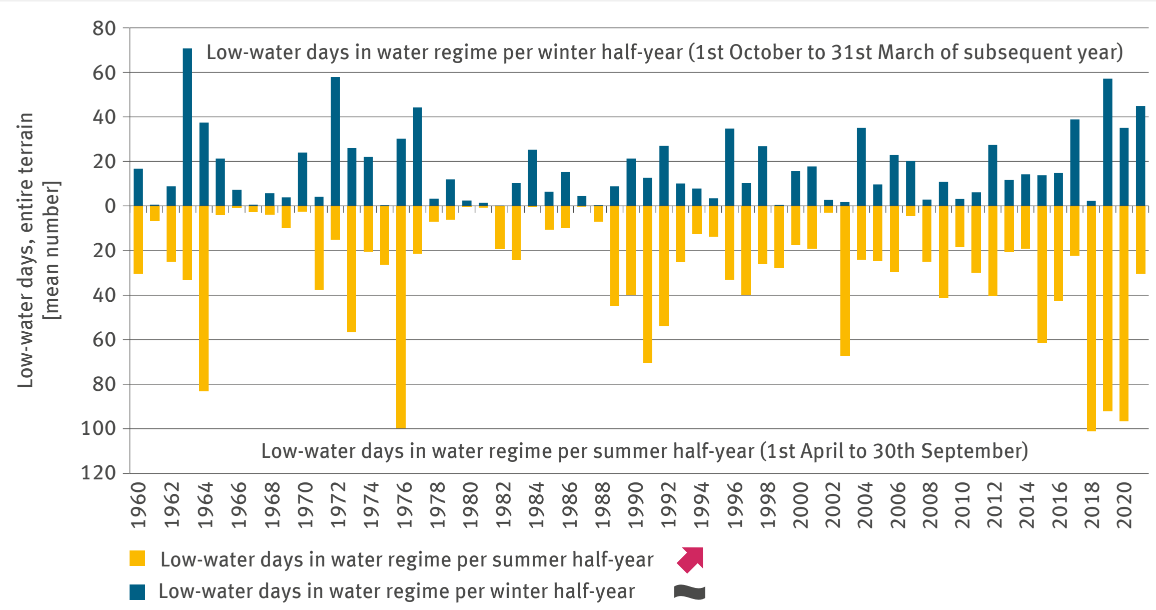
Changes associated with climate change may influence the time, duration and intensity of low-water events in many ways. The projected decrease in precipitation in the summer half-year and a higher evaporation requirement of the atmosphere may lead to a decrease in discharges in the summer half-year.

The impacts of low-water events influence both the ecology of water bodies and their utilisation. The low water volumes prevailing at times of low water levels result in water warming up faster (cf. Indicator WW-I-10, p. 88). Both directly and indirectly, this leads to an intensification of algal growth, especially in river lakes. The subsequent decomposition of dead algae produces oxygen depletion and reduced concentrations of oxygen. Moreover, when discharge decreases, any inputs into the waters are diluted to a lesser extent thus leading to higher concentrations of nutrients and harmful substances. Both processes have far-reaching impacts on aquatic creatures as well as water quality.

For various types of water utilisation, a sufficient discharge quantity and / or adequate availability of water are fundamental prerequisites. In the absence of adequate water levels – a variable specific to each river – the potential for shipping is restricted (cf. Indicator VE-I-2, p. 249). For various types of water utilisation, a sufficient discharge quantity and / or adequate availability of water are fundamental prerequisites. In the absence of adequate water levels – a variable specific to each river – the potential for shipping is restricted (cf. Indicator

WW-I-6: Low water

In recent decades, the low-water regime in Germany's river basins has been characterised to a considerable degree by individual years with distinctly low water levels. However, the hot and dry summers of the period from 2018 to 2020 subsequently led to three extreme years.



Data source: run-off measurement of federal states

VE-I-2, p. 249). Furthermore, lack of discharge and / or excessive water temperatures can jeopardise the abstraction of water for cooling purposes; in other respects, the low water volume can affect the availability of water for agricultural irrigation (cf. Indicator LW-R-6, p. 166). Moreover, such conditions may necessitate the imposition of restrictions on the discharge of waste water.

For the time series illustrated, the discharge values measured at 76 gauging stations of German rivers were examined in order to establish on how many days in the water balance of the summer half-year (1st April to 30th September) and in the winter half-year (1st October until 31st March of the subsequent year) low-water levels were recorded. A low-water day is defined as a day on which the mean annual daily discharge is lower than the mean low-water discharge (MNQ) calculated for the relevant gauging station in the period of 1961–1990. The MNQ is calculated on the basis of the lowest discharge rates of the individual water balance years (NQ). By averaging the number of low-water days across the levels recorded, it becomes clear that again and again there have been individual years with an extreme accumulation of low-water days. Looking back at the past four decades, such accumulations occurred in particular in the years 1991, 2003 and 2015 and lately in 2018 to 2020. This affected in particular the river basins of Rhine, Elbe and Weser, and, to a lesser extent, also the Danube. Regarding the river basin districts of Eider / Schlei, Schlei / Trave and Warnow / Peene, the water balance years 1996 and 2009 as well as the period of 2018 to 2020 recorded a high number of low-water days. Typically, low-water events can also be due to stable high-pressure systems. Accordingly, the impacts tend to be rather large-scale.

Up to that time, a sequence of several extremely dry years – such as latterly in the period of 2018 to 2020 – had been extremely unusual. The drought period began in April / May of 2018. Both months had very little precipitation, especially in the north of Germany. In the summer months and well into September, several stable high-pressure systems resulted in heat and drought throughout Germany. For example, the German part of the Rhine catchment, had just roughly half the usual precipitation[60]. Owing to the resulting extreme low-water levels, this exposed rock formations and gravel banks which had not been seen since the extreme low-water levels of 1921. Very low-water levels were also recorded for the rivers Elbe, Danube and Weser. All German waterways experienced shipping restrictions some of which lasted for some considerable time. Likewise, the summer months of 2019 were too dry throughout, and the summer of 2020 again caused droughts in many regions of Germany, such as the Rhine area. Despite the fact that the winters of 2018 / 2019 and 2019 / 2020 were overall on the wet side, this did not suffice to offset the shortage of water, partly because in individual regions such as Thuringia, there was not enough precipitation in the winter months either.

The extremely hot and dry summers from 2018 to 2020 resulted in many streams running dry and led to extremely low water levels in rivers. (Photo: © christiane65 / stock.adobe.com)

The extreme drought of recent years has characterised the findings of the statistical trend analysis. The trend of low-water levels in terms of the water balance of the summer half-year is significantly rising. Furthermore, a statistical 'breakpoint analysis' makes it clear that the situation in both half-years regarding the water balance has become distinctly more acute since the mid-2010s. Beforehand, the number of low-water days in the winter half-year used to be slightly regressive in general. However, in recent years this number has increased, especially around the rivers Weser and Elbe. In the summer half-year, the number of low-water days increased slightly, but not significantly. In the course of recent years the increase became more pronounced – and this substantial increase in low-water days in summer is reflected in all river districts considered.

Water levels in lakes receding

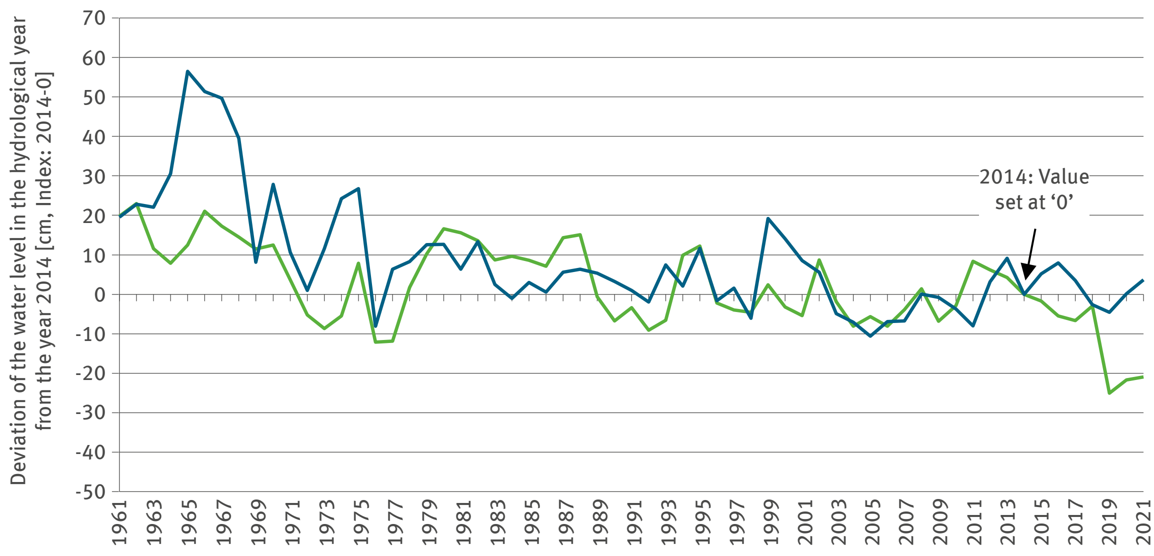
Negative water budgets are reflected not just in receding water levels of rivers; they also affect the water levels of lakes. Rising air and water temperatures (cf. Indicator WW-I-8, p. 84) and the associated evaporation on land and from the water surface result in decreasing water volumes in lakes. If this scenario coincides with low precipitation levels, it will result in reduced inflows into the lakes concerned, either directly via surface discharge or indirectly via inflows from the groundwater[61]. Decreasing precipitation exerts a particularly strong influence on shallow lakes. When the water level of such lakes recedes, this also causes lake shores to dry out for many metres into a lake, thus resulting in footbridges projecting far beyond the surface of the water. This situation may lead to considerable impacts, for instance, on bathers or boating enthusiasts.

If water levels decrease considerably, this will entail a variety of ecological problems. Owing to the decline of the nesting belt on the shore, composed of various kinds of reed and floating-leaf plants, breeding areas for birds or spawning grounds for fish may be reduced in size or lost entirely. Likewise, species of the invertebrate fauna living in the shore area may be affected. When lake water volumes shrink, this can lead to an increased concentration of nutrients and pollutants and the water body heating up faster, with all the associated impacts on the stability of stratification and biogeochemical cycling, as well as the water quality and the water ecosystems (cf. Indicator WW-I-9, p. 86). The higher water temperature in turn increases evaporation, thus leading to a self-reinforcing process of water loss.

Long-term data indicating the water level of 21 lakes in the North German Plain – an area with an abundance of lakes – were evaluated for the indicator. A differentiation was made between large and deep lakes with catchment areas of different sizes in the Länder of Brandenburg, Berlin, Mecklenburg-Western Pomerania, Saxony-Anhalt and Schleswig-Holstein. For the equally lake-rich terrain of the Alps-and-foothills, data from ten Bavarian lakes were analysed. These lakes too were characterised by differences in their expanse and their catchment areas. As far as the uplands region is concerned, there have not

WW-I-7: Water levels in lakes

Little precipitation and high evaporation make lake water levels drop. In both the North German Plain and the area of the Alps-and-foothills, lakes nowadays have less water than they still had in the 1960s. Diminishing groundwater levels have entailed – as a consequence of the extremely dry years of 2018 to 2020 – some massive losses of water, especially in the lakes of northern Germany.



Data source: BB LfU, BE SenMVKU, BY LfU, MV MLU, NI NLWKN, SH LLUR, ST LHW (water level measurements) been any suitable data made available so far. The majority of these lakes are artificial lakes, also called dams or reservoirs where water is retained by a barrage. The data regarding the small number of natural lakes (such as the so-called maars) are not available for sufficiently frequent observations and the time series are too short. However, for the Thuringian reservoirs, there are indications of regressive inflows from discharge, at least in the summer half-year[62].

Given that the lakes are marked by very different morphological and ecological characteristics, it is not possible to calculate mean values in absolute figures covering these strongly differing lakes. Consequently, the indicator is based on indexed values. This means that for each lake a mean value is calculated using the deviations from the index year 2014, for which the water level value is set at '0'. This makes it possible to calculate the mean value for all the lakes concerned on the basis of these deviations. The year of 2014 was chosen as the index year in order to achieve an illustration which is analogous with the Indicator WW-I-8 (Water temperature of lakes, p. 84).

Failure of precipitation combined with high evaporation owing to heat make lake water levels drop.
(Photo: © Robert Poorten / stock.adobe.com)

The lakes in the North German Plain are largely fed by groundwater. This means that water levels in the lakes recede to the same extent as groundwater diminishes. This is shown very clearly by the data as there are distinct matches between the two data sets. In the years of 1976–1977, 1992–1993, 2004–2006 and 2019–2021, when the time series clearly showed negative deviations of the lake water levels from the index year 2014, there was also a particularly high number of months with non-attainment of the long-term mean of the lowest groundwater levels in the northern regions (cf. Indicator WW-I-2, p. 72) The greatest decrease in water levels occurred during the very dry and hot years of 2019 and 2020. For instance, in April 2018, the Groß Glienicker lake in Berlin went into decline with a level of 192 cm during the drought period. By October 2018, the level had dropped by more than half a metre to just above 140 cm. The lowest level was reached in October 2020 with 110 cm. The situation was similar in the Müritz lake in Mecklenburg-Western Pomerania – from 227 cm in April 2018 the water level dropped to all of 159 cm in October 2018 – and also in the Dümmer lake in Lower Saxony where the water level dropped during the same period from 221 to 166 cm. In the Parsteiner See – the third-largest natural lake in Brandenburg – the water level had receded so much by the end of 2020 that the measuring gauge became almost completely dry. The water level had practically dropped down to almost zero. When this gauge was first fitted, nobody would have expected that the water level would ever drop as low as this. While in 2021 the water levels in most lakes went up again, there are, however, some lakes – such as the Drewitzer See in Mecklenburg-Western Pomerania – which retained a very distinctly low water level even as late as the end of 2021.

Contrary to the lakes in northern Germany – in the lakes in the Alps-and-foothills, the inflow from surface discharge plays a far greater role. To some extent, these lakes are in alpine catchment areas, which means that snow and snow melt have a greater influence on water levels. Besides, precipitation is in general higher in the Alps-and-foothills. But even there, receding water levels have been observed in the lakes since 1961. However, the impacts of recent drought years were distinctly less incisive with regard to diminishing water levels and were offset by persistent precipitation. In January 2019 the Alps and their marginal areas experienced snow masses to an extent not seen for a very long time. In May 2019 there was a period of very heavy, persistent rain in the southern part of Swabia and in much of Upper Bavaria. And in 2020 the south of Bavaria also experienced several periods of abundant precipitation.

Rising water temperatures in lakes

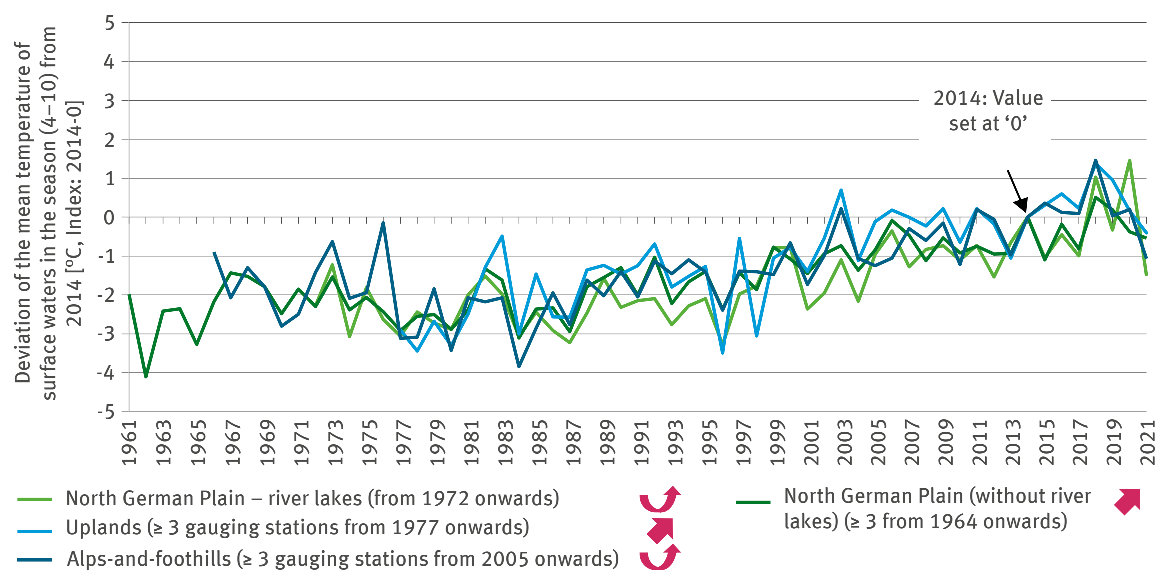
The water temperature of standing waters is influenced very directly by the air temperature. It hence follows that changes in water temperature are part of the direct impacts of climate change. Water temperature is one of the key influencing variables affecting the physical, chemical and biological processes occurring in lakes and reservoirs. It influences major factors such as the duration of ice cover and the mixing and stratification conditions. The reaction speed of numerous chemical and bio-chemical processes accelerates at higher temperatures: For example, salts dissolve more easily in warmer water, whereas gases such as oxygen take longer. Some organisms can cope with low oxygen content or high mineral concentration whereas others are dependent on excellent water conditions. Apart from an increase in the water temperature itself, the material changes triggered by the rise in temperature also have a considerable influence on plants and animals in water bodies, also on the composition of species communities as well as on the structures and functions of food webs in the ecosystems of water bodies.

Many creatures occurring in water bodies are adapted to specific temperature conditions. Therefore, even minor changes can entail shifts in the species composition in standing water bodies. This may result in the displacement of originally occurring organisms by other species, including allochthonous species which benefit from the increased temperatures. Furthermore, these circumstances can also lead to changes in the cycle of the seasonal development of living organisms in the ecosystem. For example the onset of algal development in spring (cf. Indicator WW-I-9, p. 86) is influenced strongly by water temperature. In eutrophic waters, thermophilic, toxin-forming cyanobacteria can occur in increased concentrations in summer, causing health problems to bathers (cf. Indicator GE-I-6, p. 50).

There are more than 12,000 natural lakes in Germany[63]. Depending on their geographical location, and on the natural spatial conditions, these lakes are fundamentally different in terms of trophic relationships, water flows and water body depth. In order to obtain a nationwide overview of the development of water temperatures at

WW-I-8: Water temperature in lakes

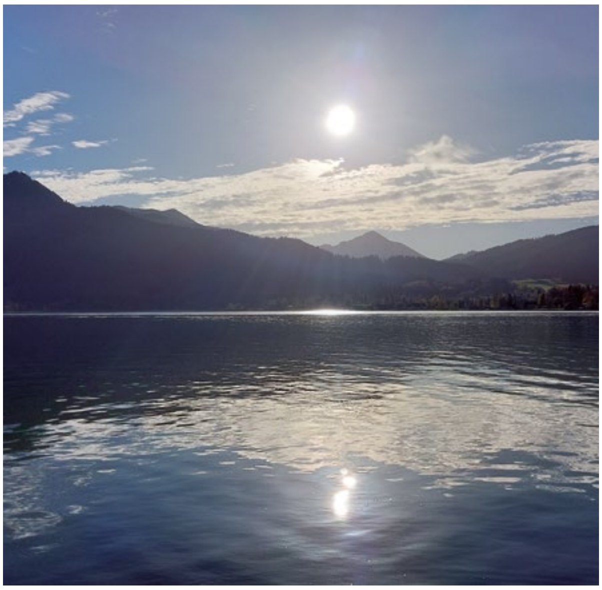
Judging by the seasonal mean examined for April to October, the water temperatures – observed in the 38 lakes and reservoirs distributed throughout Germany – have risen significantly. This applies to both, the lakes in the Alps-and-foothills as well as the reservoirs in the uplands region. The increase in water temperature has far-reaching impacts on chemical, physical and biological processes occurring in water bodies.



Data source: BE SenMVKU, BW LUBW, BY LfU, BB IGB, MV MLU, NI NLWKN, SN LTV, ST LHW, TH TLUBN, TH TFW (lake monitoring, reservoir monitoring) the same time as acknowledging, as far as possible, the special features of different lake types, a differentiation is made between the 38 lakes and reservoirs considered in the indicator, in respect of the three major ecoregions of the Alps-and-foothills, the central uplands and the North German Plain.

The lakes of the North German Plain are characterised by warmer and calcium-rich inflows. The spectrum ranges from lakes shaped by the ice age with depths up to 70 metres as for instance in respect of the Stechlinsee and to polymictic lakes such as the Große Müggelsee which – owing to their relatively minor depth of water – do not have any lasting thermal stratification phases, and to very shallow river lakes such as the Untere Havel or the Große Wannsee. The last-mentioned are basically lake-type, mostly elongated extensions of rivers. Owing to their specifics they are illustrated separately in the indicator. Given that in the area of the central uplands, there are only few sizable natural lakes, reservoirs were included in this group – to make it possible to illustrate this region. However, only those reservoirs were considered in which no water is abstracted from the uppermost water strata which is where the temperature data are collected. The lakes in the Alps (such as the Königsee) and the foothills of the Alps (such as the Ammersee, Chiemsee, Schliersee, Starnberger See, Tegernsee and Lake Constance) are all stratified lakes, predominantly with extensive catchment areas and usually also with a great depth of water. They are fed distinctly and predominantly from streams and minor rivers which have their sources in the Alps and are comparatively cold.

The temperature levels of these types of lakes vary. While the river lakes – in the decade prior to the extreme years of 2018 to 2020 – reached temperature means for the season from April until October of roughly 17.7 °C, the lakes of the North German Plain (except for the river lakes) reached mean values of roughly 16.5 °C. The reservoirs in the uplands and the lakes in the foothills of the Alps averaged approximately 16 °C whereas the Königsee – the coldest of all lakes considered – reached barely 13 °C. Given the different temperature levels of the lakes (including those within the regions), it would not make much sense to calculate straightforward mean values based on the absolute temperature data across the lakes. Consequently, the indicator – in the same way as the indicator for the water level (cf. Indicator WW-I-7, p. 82) – is based on indexed values: For each lake a mean value is calculated using the deviations from the index year 2014, for which the temperature value is set at ‘0’. The values of these deviations are used to calculate the mean value across all the lakes. 2014 is the earliest year for which data are available from all the lakes considered.



In all natural areas of Germany the water temperatures of lakes have been rising. (Photo: © Konstanze Schönthaler)

The data used for illustration in the indicator emanate from measurements taken in the uppermost epilimnion, in other words, from a water depth down to 50 cm. This layer is usually well mixed and reacts comparatively directly to any changes in the air temperature. By contrast, the development of water temperatures in the deeper hypolimnion – depending on the stratification pattern of individual lakes – can be very different for each lake, and the relationships with climate change are distinctly more complex.

The water temperatures of all the lakes considered in those three regions, have been rising significantly during the relevant periods of observation. Years with above-average high air temperatures such as the years of 2003, 2018 and 2019 stand out quite conspicuously in all regions. It is important to bear in mind that water temperatures are raised, above all, by extended heatwaves. For example, a few hours per day with great heat of more than 30 °C make less of an impact on the temperature of the water body than for instance permanently mild night temperatures of more than 20 °C: Furthermore, the intensity in which the upper water strata are mixed, play a role: Overall, high temperatures combined with high wind produce higher warming effects than heat on a calm day.

Spring algal bloom setting in ever earlier

Ecological processes in a lake are influenced substantially by water temperature. An examination of the onset of spring algal bloom reveals relevant changes in water ecosystems, as the spring algal bloom is on one hand dependent on circulation conditions and stratification of water layers in a lake, while on the other, spring algae are very important building blocks in a food web.

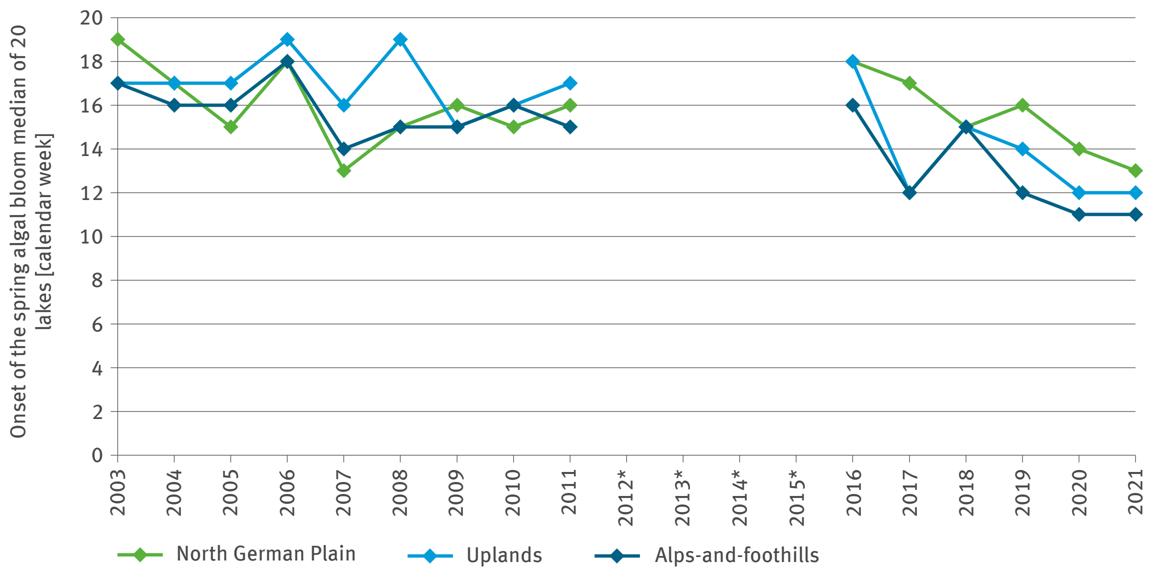
There is a direct connection between climate change, ice cover in winter, the onset or end of thermal stratification and the water temperature of a lake, as well as the temporal onset of spring algal bloom. When winter ends with surface water warming thus ending the stagnation typical of winter, prompting the onset of spring circulation, nutrient-rich water is transported from the depth of a lake to its surface while water rich in oxygen is transported deep down. Provided this coincides with the presence of sufficient light, this scenario will trigger a growth phase in phytoplankton. This spring algal bloom will fade once the nutrients have been used up, the stability of stratification increases and foraging pressure is brought about by zooplankton thus creating a clear-water phase. Increased filtration rates thanks to the presence of mussels can also reduce the amount of phytoplankton.

Higher winter and spring temperatures can lead to an earlier onset of algal bloom, increase the algal growth rate and change the species composition. The earlier onset of algal bloom indicates that summer stagnation will begin earlier too. The stratification typical of the summer season, puts an end to the exchange of nutrients and oxygen among the layers. Consequently, this causes a depletion of oxygen in the deeper water layers – the hypolimnion – especially, when the stable stratification lasts unusually long owing to warmer autumn temperatures. The potential dissolution of nutrients in the sediment caused by anaerobic conditions can lead to eutrophication.

The indicator shows the temporal shift of the onset of spring algal bloom based on data for 20 lakes in Germany. Five lakes each are located in the Alps-and-foothills and the uplands region, while 10 of the lakes are located in the North German Plain. The differentiation by region

WW-I-9: Spring algal bloom in lakes

The time of the onset of spring algal bloom depends strongly on the temperatures prevailing in late winter and spring. Particularly mild winters and above-average high spring temperatures as for instance in 2019 and 2020 led to a distinctly earlier onset of spring algal bloom. Spring algae are an important building block in the food web of lake ecosystems.



* No data, as no suitable satellite sensors deployed

Data source: Brockmann Consult GmbH, CAU Kiel (analysis of satellite data) is necessary, in order to take into account the different macro-climatic baseline conditions as well as the morphological differences between the lakes in these regions.

Given that there are few data available from on-site surveys regarding the point of onset, the indicator was developed on the basis of satellite data. These data made a distinctly broader spatial coverage of lakes possible. The reflexion of chlorophyll-a in the algae can be captured by means of satellites. The high temporal resolution provided by the data available is the crucial factor for a (timely) recognition of spring algal bloom: The interval between repeat flights is between one and two days. The determination of the (first) localised maximum is based on valid satellite photos and is limited by cloud cover, fog or ice cover. The exact temporal recognition of spring algal bloom on the basis of satellite data is therefore dependent on cloudless periods. This can mean that an event of spring algal bloom simply cannot be captured owing to weather-related influences. Given that the first maximum only lasts for a few days, the bloom might also occur just at a time between two observation flights. This shows that the capture of images by satellite has its own limitations. For all 20 lakes, the data series are available at a spatial resolution of 300 metres for the years 2002–2012 and 2016–2020 respectively. In the years between, there were no satellites active that were equipped with appropriate satellite sensors.

While the mean of the first four years of the time series shows that the spring algal bloom occurred – according to region – between the end of the 16th and the middle of the 17th calendar week, that is to say, between the middle and end of April, the first maximum bloom occurred – based on the mean of the last four years of the time series – already between the beginning of the 12th and the middle of the 14th week, in other words between end of March and the beginning of April. Given the disrupted time series, it made no sense to carry out a statistical trend analysis. However, the illustration of the time series demonstrates that a remarkable forward shift occurred in the space of a relatively short period of time in all regions leading to a much earlier onset of algal bloom. In addition, this diagnosis is reinforced by the earlier onset of the phenological spring phases (cf. Indicator BD-I-1, p. 202).

The overall extraordinarily warm year of 2018 followed a mild winter although there was a very cold spell in February. All over Germany it was permanently frosty with two-digit degrees below zero occurring in most areas. There was another significant spell of cold air prevailing in March of that year. This is a major reason for the onset of spring algal bloom in 2018 occurring later

Spring algal bloom can be captured well by means of satellite remote sensing. (Copernicus Sentinel 2 Data [2023, modified]: Kummerower See, image dated 07.05.2018)

compared to subsequent years. In early April the weather in the whole of Germany made a transition from winter to summer weather in a matter of just a few days. In the second week of April, the first maximum spring algal bloom occurred across three regions with major synchronicity.

The winter of 2018 / 2019 was very mild, with plenty of sunshine, subsequently followed by a mild March and a warm April. The scenario was very similar in 2020: After what had been the second-warmest winter since records began in 1881, Germany was under the influence of mostly warm air masses in spring, and it was unseasonally warm as a result. Consequently, spring algal bloom started early in those two years. However, the equally early bloom in 2021 is harder to put into context with the weather patterns prevailing at the time. Although the winter of 2020 / 2021 was unusually mild, it was followed by comparatively cool spring.

Rivers are getting warmer

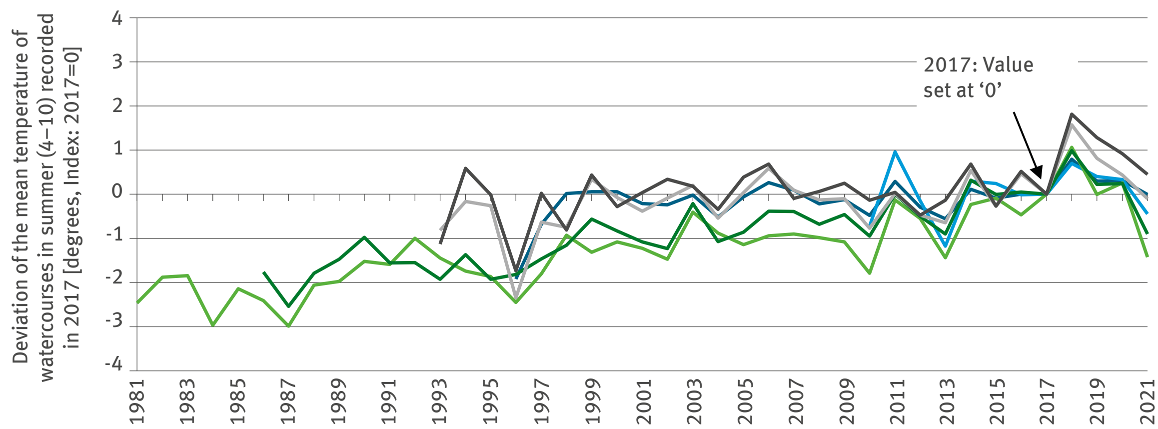
As in the case of lakes, watercourses too are indicating increases in water temperatures owing to higher air temperatures. There are indeed some direct anthropogenic influences such as infeeds of cooling or waste water, also the removal of trees growing on riverbanks and cases of increasing urbanisation. However, targeted investigations involving the river Rhine have revealed that water temperature increases despite reduced infeeds of warm water[64]. Rising water temperatures are also found to be connected with the water volume present in water bodies. At low water levels (cf. WW-I-6, p. 80) the risk of excessive warming resulting from a diminished water volume is increased even further.

The temperature of the water body controls and synchronises many processes involving plant life and other organisms in the water body, which makes temperature particularly important for the ecological functions concerned. Water temperature is of direct importance to the living conditions of aquatic organisms the majority of which are poikilothermic. Besides, water temperature is part of a complex effects relationship in terms of the chemistry of water bodies. Apart from other negative effects, the reduced solubility of oxygen in water worsens respiration conditions.

Individual parts of the course of streams or rivers are differentiated by individual zones which differ according to the occurrence of characteristic species of fish. These are therefore sometimes termed fish regions. The typically cool trout region is located in the upper regions of a river where the current is usually very strong and the water passes through gravel and where larger stones are overturned by the current and enriched with oxygen. This is followed by the greyling region with similar conditions albeit more intensive vegetation, followed in turn by the region characterised by cyprinids. In the barbel region the watercourse has become wider, with the current becoming weaker. The (lower) bream region is the most species-rich fish region, in addition characterised by luscious vegetation. The chub-flounder region is already classed as the area of brackish water, and this is the last of the fish regions. Owing to its location in the river delta close to the sea, this region is already subject to the tides.

WW-I-10: Water temperature of watercourses

In recent decades the temperatures in watercourses have risen significantly in all fish regions. The greyling region is the only one for which, so far, there is no clear trend discernible. Anyway, this time series is too short to make any statements regarding long-term trends. The extremely high temperatures in 2018 and the associated lack of oxygen led to fish dying in many German water bodies, including the Upper Rhine basin.



- Trout region (Sa-ER, Sa-MR) (≥ 3 gauging stations from 1996 onwards)
- Greyling region (Sa-HR) (≥ 3 gauging stations from 2010 onwards)
- Region characterised by cyprinids (Cyp-R) (≥ 3 gauging stations from 1981 onwards)
- Barbel region (EP) (≥ 3 gauging stations from 1986 onwards)
- Bream region/carp bream region (MP) (≥ 3 gauging stations from 1993 onwards)
- Chub/flounder region (HP) (≥ 2 gauging stations from 1994 onwards)

Data source: BB LfU, BfG, BE SenMVKU, BW LUBW, BY LfU, HE HLNUG, HH BUKEA, MV LUNG, NRW LANUV, NI NLWKN, SH LLUR, SN LfULG, ST LHW (water quality monitoring, water level measurement networks)

As in the case of different types of lakes, there is no point in calculating the mean for all watercourses and fish regions. Consequently, the indicator illustrates the evaluation of individual fish regions separately.

The indicator is based on temperature measuring data of 43 gauging stations for measuring water-quality and levels distributed across Germany's fish regions. Important criteria in the selection of gauging stations included sufficiently long, gap-free time series based on daily sampling. Furthermore, the gauging stations were chosen well away from any direct influence of dams and anthropogenic infeeds of warmth, such as the discharge of cooling water, process water and waste water.

As in the case of indicators for the water level of lakes (cf. Indicator WW-I-7, p. 82) and the water temperature of lakes (cf. Indicator WW-I-8, p. 84) this indicator, too, is illustrated by means of indexed values. It makes no sense to calculate an absolute mean temperature value, as the individual gauging stations indicate different temperature levels, even within individual fish regions according to the specific local water morphology, natural environments and climatic conditions. In the process of indexing, a mean value is calculated for each measuring point, using the deviations from the index year 2017, for which the temperature value is set at '0'. The values of these deviations are used to calculate the mean value across all gauging stations and fish regions respectively. 2017 is the earliest year for which data are available from all the gauging stations considered.

The water temperatures have been rising significantly in all fish regions. The greyling region is the only region for which there is no clear trend discernible. However, this may be due to the relatively short time series so far.

The comparatively low values recorded in 2010 and 1996 can be attributed to the relatively cool weather pattern prevailing in those years. For example, the annual mean temperature in 2010 of 7.8 °C was distinctly below 2011 with 9.6 °C. 1996 with an annual mean temperature of 7.2 °C was the coldest year in the decade of 1991–2000. The high values in 2018 and 2019 were due in part to high summer temperatures and low water levels.

So far the indicator, in its present design, does not permit any statements on the exceedance of critical temperatures (for instance in terms of tolerability to fish). The surface water regulations – differentiated by fish regions – provide benchmarks for maximum watercourse temperatures, with the objective to achieve a good and very good ecological condition. In order to maintain a

The water temperatures in rivers have been rising in all fish regions entailing all associated impacts on the ecology of water bodies. (Photo: © Sebastian / stock.adobe.com)

very good ecological condition 18 °C is considered the maximum summer temperature for the trout and greyling regions, while in the regions characterised by cyprinids and barbels it is 20 °C, and in the bream and chub-flounder regions it is 25 °C.[65] In 2018 these critical temperatures were exceeded in many locations. For instance, in August 2018, the Rhine became overheated to 28 °C in places. In many of Germany's watercourses, such as the Upper Rhine, fish died from lack of oxygen. In the case of massive losses of fish in the river Oder from the end of July until August 2022, the suddenly intensified concentration of salt, irradiation by the sun as well as high temperatures contributed to a growth burst in the populations of the poisonous brackish-water alga Prymnesium parvum. This example demonstrates the fatal chain reactions that can occur in ecosystems.

The situation is particularly critical in cases where the increase in water temperatures of water bodies is exacerbated by distinctly anthropogenic activities and when the watercourses lack structure and shading. In natural or near-natural water bodies fish can seek sanctuary in deeper and more shaded layers of water. Besides, in water bodies with natural watercourse dynamics, more oxygen is able to penetrate thanks to currents and turbulences. At high concentrations of nutrients and pollutants, thermophilic and potentially toxic algae are able to reproduce thus affecting aquatic organisms.

Water use decreased further

The droughts prevailing in the years 2018 to 2020 and in 2022 demonstrate that in Germany too, there are challenges from seasonally and regionally decreased water volumes, which have to be addressed much more vigorously. As far as the long-term mean of the period 1961–1990 is concerned, roughly 188 billion cubic metres of groundwater and surface water were considered potentially available water resources; by comparison, the mean of the period 1991–2020 with roughly 176 billion cubic metres is lower.

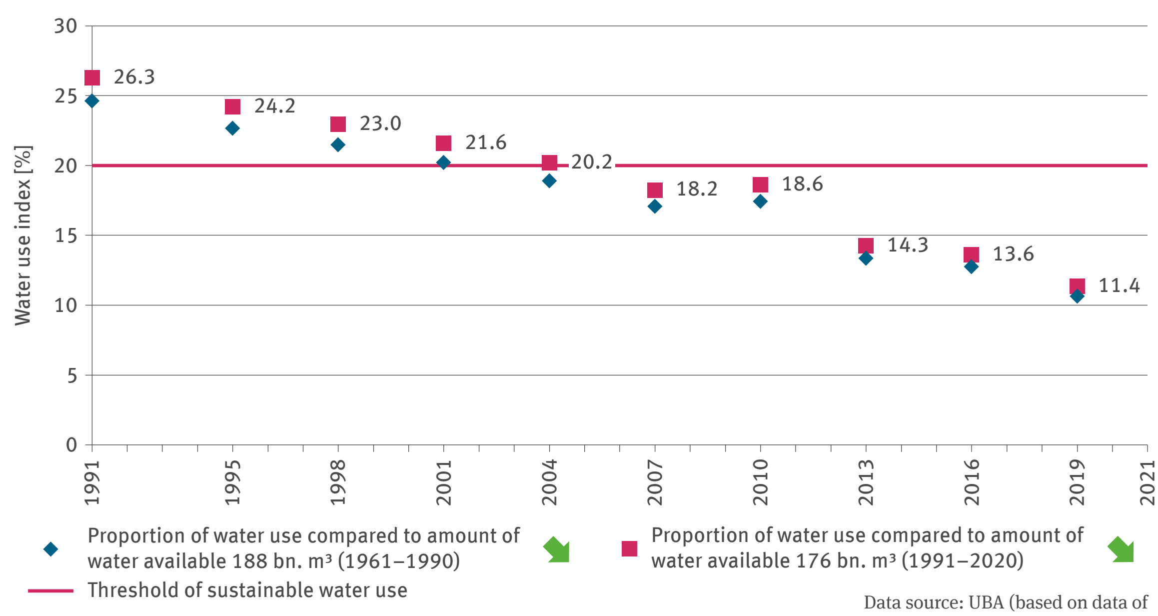
Extended and more frequently occurring drought periods and low-water periods can – owing to a decrease in the volume of water available – cause regional utilisation conflicts regarding surface water and groundwater abstraction (for instance for the purpose of irrigation in agriculture and horticulture, cf. Indicator LW-R-6, p. 166). This is true, in particular, for central parts of eastern Germany, the north-eastern German lowlands and the south-eastern German basin where unfavourable climatic water budgets occur; in other words, where comparatively little rain falls while evaporation of water is high owing to high summer temperatures.

The water use index provides basic clues as to whether the usage of water resources in Germany is sustainable or whether water shortages are developing. Cases of water abstraction can be termed sustainable as long as they do not exceed the threshold of 20 % of available water supply. Notably, the 20 % threshold is an internationally valid benchmark. Once water usage exceeds this threshold, this is regarded as a sign of water stress. Values of 40 % and above are termed high water stress. The causes for exceeding this threshold can be sought in an increased water abstraction or scarcity of naturally available water supplies. In calculating the indicator, the annual public and non-public water abstraction in terms of water use has been contrasted with the long-term availability of water supplies.

Owing to a reduction in both the commercial and private water usage in Germany, this 20 % threshold has been undercut regularly since 2004. Overall the values recorded in the water use index have been declining significantly since 1991. Hence it follows that according to internationally valid benchmarks, the extent of water usage can

WW-R-1: Water use index

Water use has experienced a significant decrease over the past 30 years. 2007 was the first year in which water usage undercut the water use index of 20 %, perceived to be a critical threshold value. This means that not more than 20 % of the potential water supply is utilised. There are, however, distinct regional differences. Climate change confronts water providers with challenges, for instance, in terms of meeting the demand at times of seasonal consumption peaks.



Data source: UBA (based on data of StBA on water abstraction and BfG on water availability) be considered sustainable. Energy producers as well as industrial and mining operations have contributed to this distinct reduction; as these companies clearly command the greatest share (70 %) of water usage (cf. Indicator IG-R-1, p. 266). Coolant abstraction by power plants for energy generation accounted for the lion share of commercial water usage. Consequently, efficiency improvements in terms of recycling or cyclical usage, had particularly favourable effects on the water budget, at least until 2007. In view of the closure of the last remaining nuclear power plants after the April 2023 temporarily extended deadline, it is expected that cooling water abstraction by power plants will decrease further.

Likewise, water use by private households and small businesses was reduced substantially since 1991 from 144 litres per person per day to 123 litres per person per day in 2016. However, thereafter water use increased slightly again to 128 litres in 2019. More recent figures are not available. However, there are signs indicating that in 2020 and 2021, the impacts of the Covid-19 pandemic also affected water use, given that private households required more water on account of home offices, home schooling, cancelled travel arrangements and increased hygiene requirements. In addition, another trend evolved that has led to increased private use of water, unfortunately at a time when water supplies are already less abundant. Private and other swimming pools are becoming ever more popular. Such pools typically have major capacity for water, and the pools will probably be refilled with fresh water several times per season. An estimate on the basis of a survey involving roughly a thousand respondents – a representatively selected number of Hamburg residents[66] – has shown that up to 6 % of the entire annual consumption of drinking water is taken up by households in the city state of Hamburg during the summer months. The numbers involved add up to relevant scales. Peaks in drinking water consumption can also be attributed to the irrigation of gardens.

The water use index used as an indicator so far does, however, have its limitations when it comes to illustrating the adaptation requirements and related activities in the water management. An overview of the situation nationwide does not take into account any distinct regional differences within Germany. In future, the water budget – owing to climate change and a further decrease in summer precipitation as well as increased evaporation e.g. in eastern Germany – might become even more unfavourable by reducing the availability of water in that area (cf. Indicator WW-I-2, p. 72). Moreover, in individual years, the renewable water resource is subject to strong fluctuations, thus distinctly undercutting the long-term mean underpinning the indicator[67]. At the same time, extended heat periods may – at least temporarily – lead to an increased demand for water.

Overall, water use is decreasing. Nevertheless, extended drought periods can lead to local and temporary water shortages. (Photo: © bai / stock.adobe.com)

The overall decreasing water usage on one hand and the climate-induced higher consumption peaks on the other as well as variations in the regional distribution of water resources and water demand, confront water providers with new challenges. In particular the managers of water providers in rural areas and in upland regions who have largely decentralised as well as precipitation-dependent supply structures (such as municipality-owned wells), may be confronted with predicaments during prolonged drought periods. Nevertheless, with regard to central or pipeline-based supply systems, it has been possible so far to keep a balance between the local or regional supply of, and temporary differences in, demand for water. Even in the case of several consecutive years of persistent drought, the drinking water supply for the population must be safeguarded. With this in mind, the conscious and conscientious saving of water continues to be important. An individual who saves water, is saving energy at the same time, because energy is used not just for supplying warm water but also for its supply in general and, of course, its treatment.

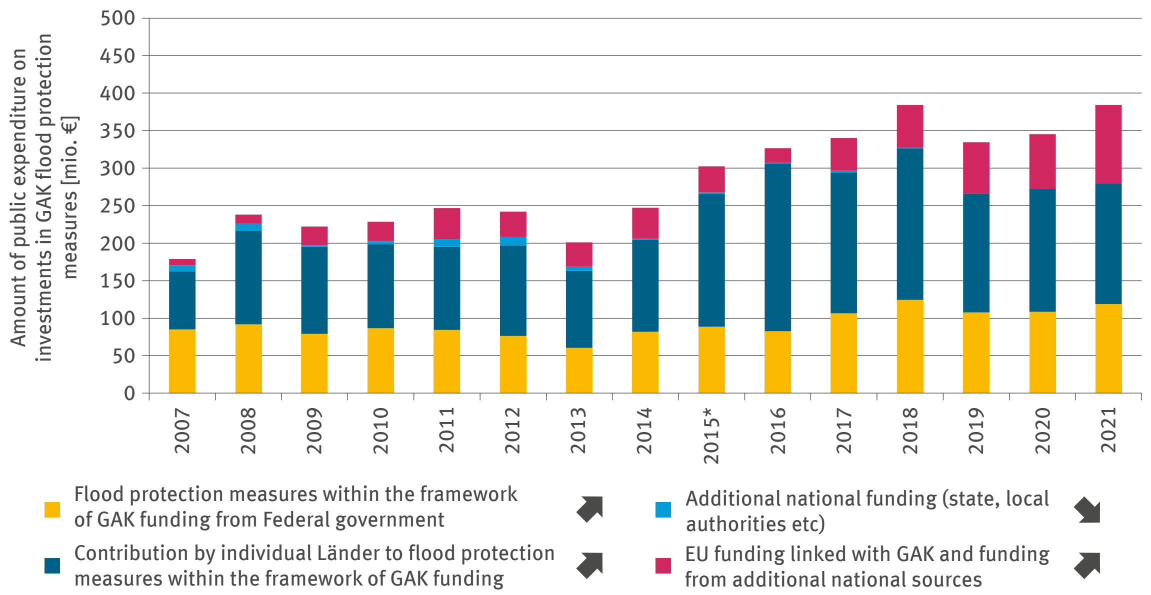
Flood protection – expenditure is mounting

Flood events are a natural phenomenon. Human interventions such as separating alluvial meadows from rivers, straightening rivers, clearfelling of alluvial forests and property development in flood plains entail that the topography of the landscape is less able to retain floodwater thus accelerating discharge into water bodies. It is to be expected that progressive climate change will increase the flooding risks of watercourses. This increases the importance of flood risk management as embedded in the European Flood Directive (HWRM-RL) enacted in 2007, thus giving it legal status as well as urgency and significance. Every six years, these flood risk management plans, issued for all German river basins, have to be updated by those Länder which are responsible for floodwater precautions; this work has to be done taking into account the anticipated impacts of climate change. Such plans contain measures for technical flood protection, restoration of retention areas and the rehabilitation of near-natural structures of water bodies. Additional measures such as demarcation and designation of floodwater areas or preliminary planning work for the implementation of operational measures for flood protection have been embedded in the German Water Resources Act (WHG).

Given the enormous costs to the national economy resulting from flood events, the Federal government has been supporting the Länder in terms of flood protection already since 1973 within the framework of the joint task entitled 'Improving the agricultural structure and coastal protection' (GAK). The Federal government reimburses 60% of expenditure on the construction of new and the reinforcement of extant flood protection defences, on relocating dykes and on measures taken to achieve the development of near-natural water bodies. In the follow-up to the devastating floods in June 2013 in the river basins of Elbe and Danube, it was furthermore decided to design the NHWSP. Primarily this programme is to speed up the implementation of supraregionally effective measures for a preventative flood protection such as measures involving the relocation of dykes and the reclamation of natural retention areas as well as measures for the controlled retention of floodwater (flood control reservoirs and polders). Since 2015 Federal government has been

WW-R-2: GAK funds for flood protection

As part of the GAK, the Länder receive financial support from Federal government for the construction and reinforcment of flood protection defences, the relocation of dykes and the development of near-natural water bodies. Furthermore, the EU provides grants in connection with GAK and additional national funding. Since 2015 the SRP 'Measures for preventative flood protection' has been in existence. Since then, the expenditure incurred by the Länder has increased significantly.



*from 2015 onwards, inclusive of GAK special measures entitled 'Preventative floodprotection'

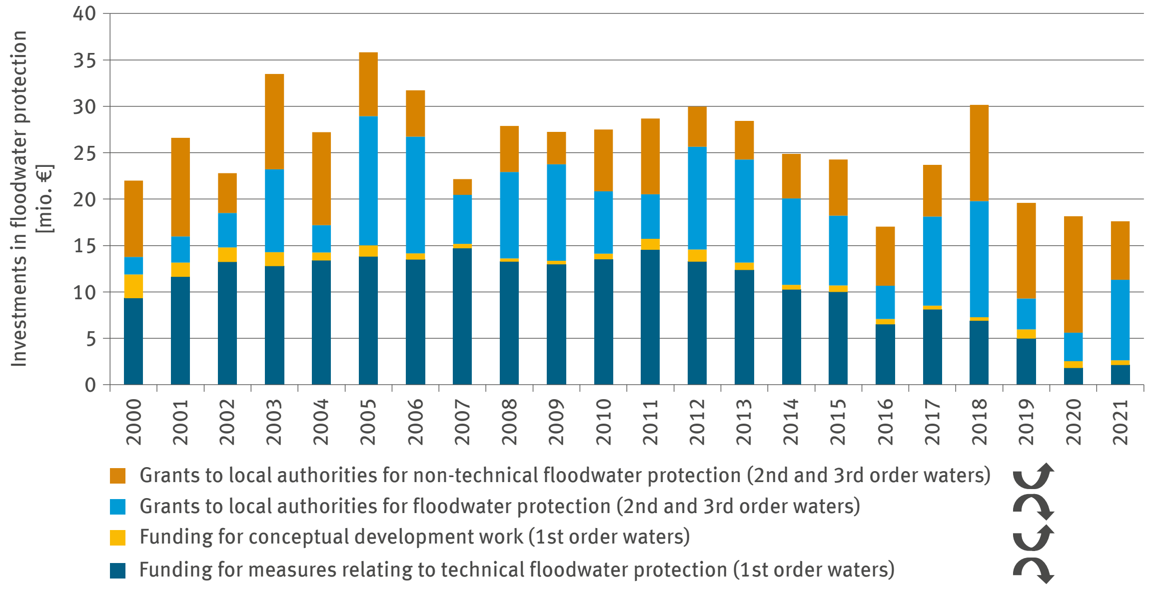
Data source: BMEL (GAK reporting)

supporting the Länder additionally via the GAK special framework plan entitled 'Preventative flood protection' in the implementation of such preventative measures. For the first time this has included the Federal government promoting the purchase of retention areas.

In order to implement flood protection measures in respect of 1st order waters, the Länder use further funds from their own budgets, in addition to the resources available under GAK. Furthermore, the Länder grant funding to local authorities within the framework of their responsibility for 2nd and 3rd order waters; in other words, for implementing measures in respect of rivers of the 2nd and 3rd order. These investments were illustrated by using Hesse as an example. The funds invested by local authorities by themselves without the support of their relevant state are not illustrated. In Hesse investments in technical flood protection such as dams, walls, rain and flood retention basins, barrages, pumping stations and flood channels have declined in recent years, because the protracted dyke rehabilitation work in the areas of Rhine and Main have by now been essentially completed. On the other hand, non-technical measures have been gaining more importance. Natural or near-natural water body structures are able to retain water, stabilise the landscape water balance and can, in particular, mitigate flood events of medium proportions. Renaturation is therefore promoted wherever possible. Meandering rivers and streams reduce discharge rates and attenuate floodwater discharge peaks. Where the bed of a watercourse is permeable, consisting of types of sand and gravel, this enables the natural exchange between surface water and groundwater and is thus able to buffer, at least in part, floodwater peaks or water shortages. Cut-off meanders, alluvial meadows and flood plains in the vicinity of watercourses, are able to absorb part of the floodwater discharge. While many renaturation measures are often informed mainly by nature conservation objectives, they also help to reduce flood risks. One of the core challenges regarding non-technical flood protection continues to be the availability of additional retention areas which are safe to be flooded in a flood event. In addition to flood protection measures in water bodies and catchment areas, important adaptation measures include precautionary building decisions (cf. Indicator RO-R-5, p. 310) as well as flood forecasting and warnings (cf. Indicator HUE-2, p. 334).

WW-R-3: Investments in flood protection – case study

In Hesse, around 234 million euros have been invested in flood protection by the federal and state governments over the last ten years. This does not include the local authorities' own investments. As the obligation to maintain water bodies is only a federal state responsibility in the case of the old Rhine waters, non-technical flood protection measures regarding 1st order water bodies in Hesse are only carried out to a limited extent (impossible to represent in the chart).



Data source: HMUKLV (budget account)

Photo: © helmutvogler / stock.adobe.com

Coastal and marine protection

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

The coastal regions are of particular socio-cultural, ecological and economic importance to Germany. Habitats in the intertidal zone between land and sea are unique and characterised by both high dynamics and great sensitivity. This zone is home to many rare animal and plant species. At the same time, the sea and adjacent coastal areas are of major economic importance. For example, the deep-sea fishing and fish-processing industries in coastal areas continue to be major employers (cf. 'Fisheries' action field). In addition, there is the maritime industry such as ship- and boatbuilding with its suppliers and service providers as well as marine and offshore technology including wind turbines. Coastal lowland areas are used for agricultural production. Not least, the high leisure and recreation value of coastal areas affords substantial opportunities to neighbouring communities for added value from tourism activities. The intensive utilisation exerts considerable pressure on the seas and the coastal regions. In many places the condition of the sea and adjacent coastal areas suffers from economic activities. The impacts of climate change entail additional burdens and challenges.

Seas are themselves massively affected by climate change. Global warming gives rise to extensive changes in ecosystems. At the same time, seas are CO_2 sinks, thus playing an important role in the protection from climate change.

DAS Monitoring –what is happening due to climate change

Their storage, buffering and exchange functions give the Earth's oceans a key role in its climate system. Especially in their deepest layers, the oceans store a major part of the additional amount of warmth caused by the anthropogenic greenhouse effect. However, the influence of rising air temperatures owing to climate change can also be measured at the water surface. For example, the mean warming of the North Sea water surface has been amounting to 0.26 °C per decade. The annual values are subject to natural fluctuations (cf. Indicator KM-I-1, p. 100). The seas warming up has massive effects on the marine ecosystem. This is directly reflected, for instance, in a changed composition of the fish fauna (cf. Indicator FI-I-1, p. 122) and in shrinking fish stocks in respect of individual fish species such as herring (cf. Indicator FI-I-2, p. 124).

Another direct impact of heat storage in the ocean is the increase in seawater volume. This factor is a crucial cause of sea level rise. Both in the North Sea and the Baltic Sea, sea levels have been increasing in the course of recent decades (cf. Indicator KM-I-2, p. 102). As far as coastal regions are concerned – in particular estuaries, coastal watercourses and lowlands that are partly below sea level – sea level rise without recourse to countermeasures is tantamount to increasing the risks involved. One of these risks is the danger of flooding due to storm surges as these can increase the height of the sea level to the same extent as mean sea level rise. Moreover, storm surges can – without a strong tidal flow – increase the volume of seawater being pushed up the watercourse where it flows into the sea, thus temporarily reversing the flow of the watercourse (cf. Indicator KM-I-5, p. 108). However, the intensity and frequency of storm surges – both in the North Sea and the Baltic Sea – has not shown a distinct, unambiguous development in the course of roughly the past 150 years (cf. Indicator KM-I-3, p. 104).

Very direct impacts are visible in terms of rising sea levels along the coastlines. When waves and storm surges increase in height as they break on the shore, they gain additional attack surface along the coastline. As a result, active cliffs recede faster, and coastal sections that were stable so far can begin to recede. This is indicated by a case study carried out in Mecklenburg-Western Pomerania, based on data from a representative segment of cliffscape on the peninsula of Fischland in the Baltic Sea (cf. Indicator KM-I-4, p. 106). Owing to erosion, the cliffscape in this area has been shifted further inland by 20 to 40 centimetres every year. . Especially in years with frequent and major storm surges combined with considerable hydrodynamic loads (high swells and strong currents), the amount of erosion along the coastline can be distinctly greater.

In coastal lowlands, climate-change related greater precipitation can lead to more frequent flooding. Winter precipitation consists predominantly of rain while in summer there is a greater risk of heavy-rain events. As a means of preventing damage, and in particular for the sake of maintaining the continuity of agricultural production in the lowlands, there is an increasing requirement for artificial drainage by means of pumping stations in coastal areas. More frequent flood scenarios require higher performance from pumping stations, thus resulting in rising electricity consumption (cf. Indicator KM-I-6, p. 110).

Future climate risks – outcomes of KWRA

Based on the findings of the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7), the highest risks in respect of sea temperatures and ice cover are expected to occur – with major certainty – with regard to the action field 'Coastal and marine protection'. High climate risks also exist in respect of seawater quality and groundwater salination, height of sea level, changes to natural features along coastlines and overload conditions in drainage systems in areas at risk of flooding. The certainty of estimating such climate change impacts is between medium and high.

In addition, a high risk of damage to, or destruction of, coastal settlements and infrastructures is expected to set in by the end of this century. The probability of hydrodynamic climate change impacts such as increased water levels in connection with storm surges or changes in the current and tidal dynamics is estimated as medium. The same applies to the consequential increase in loads on, or the failure of, coastal protection structures. Nevertheless, the risk assessment for such climate change impacts is subject to low certainty.

Where do we have gaps in data and knowledge?

The coastal and marine areas associated with the North Sea and Baltic Sea differ in terms of their morphological and hydrodynamic properties. Steep and shallow sections alternate along the coastline, and they react differently to the impacts of climate change. Furthermore, the North Sea is influenced by strong tides, whereas the tidal activity in the Baltic Sea is much less pronounced. For the purpose of monitoring, this requires that the indicators be developed and interpreted in a differentiated way for North Sea and Baltic Sea respectively. At the same time, the nationwide design of DAS Monitoring imposes restrictions on making statements regarding state-specific or even region-specific statements. This made it necessary for the 2023 Monitoring Report to work with case studies, in order to address important themes such as coastal erosion or the increasing challenges involved in the drainage of coastal lowlands (cf. Indicators KM-I-4, p. 106, and KM-I-6, p. 110).
Case studies, of course, do not allow drawing any generic inferences regarding German coastal regions overall. For example, the case study on changes in the cliffscape on Fischland/Baltic Sea does not permit any statements on the coastal erosion experienced along other types of coastlines. Likewise, it would be out of the question to make any direct comparisons between the drainage conditions prevailing in the area covered by the case study carried out by the Eider-Treene-Schöpfwerksverband (Pumping Station Association) – illustrated in the indicator KM-I-6 – and other pumping station associations. As far as these themes are concerned, it is important not just to explore additional data sources, but also to develop advanced conceptual ideas of how to arrive at generalising statements that take into account any prevailing heterogeneous conditions.

Likewise, there are substantial methodical, partly also data-technical, challenges regarding the description of phenomena such as the displacement of the brackish-water zone within estuarine areas or even far inland, the salination of coastal groundwater resources or even the impacts of storm surges on flood protection in inland areas. The subgroup entitled Klimaindikatoren (climate Indicators), launched by LAWA for the purpose of developing joint indicators relating to water issues, has discussed these and other themes. Nevertheless, there are further scientific debates required in order to facilitate the development of meaningful indicators. A particular problem is that especially the coastal areas, including the estuaries of watercourses, are in several parts of their course strongly influenced by anthropogenic activities, thus producing a multi-layered complex of influences. Given this background, it is to some extent simply not possible to tease out the direct effects of climate change.

Given that in Germany, investments in coastal protection are financed predominantly from GAK funding, these investments can be illustrated in the nationwide GAK Reporting system (cf. Indicator KM-R-2, p. 114). However, damage caused to coastal protection systems is not covered by a central database. The situation is similar with regard to any damage to settlements and infrastructures in the hinterland. It is not possible either to assess insurance data specifically for these regions. It is conceivable, however, that the ongoing work by BMUV and UBA in setting up a nationwide climate-damage register will produce further insights.

Potential negative effects on the coasts, resulting from utilisation for tourism purposes, are covered under themes in the DAS action fields entitled 'Tourism industry' (cf. Indicators TOU-I-1, p. 278, and TOU-I-3, p. 282) as well as 'Human health' (cf. Indicator GE-I-7, p. 52). However, so far it has not been possible to carry out a comprehensive and systematic consideration process. This is true also, and particularly, with regard to adaptation measures and activities. In this respect, too, there are – in addition to data gaps – conceptual challenges that remain to be dealt with.

Generally speaking, the links between marine protection and the adaptation to climate change have been illustrated only marginally in DAS Monitoring, while marine ecosystems have to date hardly been focused on. As before, there are still knowledge and data gaps regarding these themes whilst there is genuine concern that climate change is fast becoming the predominant driver of the extinction of marine species. There is need for an in-depth discussion on potential indicators for themes such as acidification and the loss of oxygen (also the increase in death zones without oxygen) and associated impacts on species composition.

What's being done – some examples

Effective adaptation to climate change is indispensable with regard to coastal protection. As a result of climate change, the existing technical and protective facilities have to withstand increased hydrological loads. At the same time the intensity of utilisation and the damage potential in coastal regions continue to increase. The dimensioning of coastal protection structures is therefore subject to regular inspection and adaptation of input parameters. An example of comprehensive consideration of the increasing danger from heightened storm surge water levels is the adaptation of land protection dykes in Schleswig-Holstein (cf. Indicator KM-R-2, p. 114). With a view to the expected rise in sea levels, unsafe dykes have been reinforced since 2001 with a safety margin of 0.5 metres. It is possible to offset a sea level rise of up to 1.0 metre by broadening the dyke crest and constructing a more gradual outer slope; this mode of construction has been implemented in dyke reinforcements since 2009. In 2018 the concept entitled 'Klimadeich' (climate dyke) was introduced, and incorporated in the general coastal protection plan (GKP) in 2022. This plan envisions increasing the height of land protection dykes by means of several construction phases, with the purpose of offsetting a sea level rise by up to 2.0 metres. Recently, the proportion of land protection dykes without a safety deficit increased to 81.7 %.

The implementation of coastal protection measures is costly. The protective measures cover stabilising, extending or increasing the height of structures, but also the building of new protective structures, and increasingly, beach nourishment. Their purpose is to prevent the increasing coastal erosion and to offset the erosion of beaches. In Germany technical measures for coastal protection are financed predominantly by the GAK (cf. Indicator KM-R-2, p. 114). For the purpose of adjusting to climate change, the Federal government has granted an additional 25 million Euros to the coastal Länder – via an GAK special framework plan covering the period of 2009 to 2025 – for coastal protection measures. The funding for the modified special framework plan covering the period of 2023 to 2026 has been increased substantially with effect from 2023. Furthermore, the funding from Federal government sources for measures to be taken in the run-up to 2040 has been secured already.

The national strategy for an Integrated Coastal Zone Management (IKZM) – relevant to the development of Germany's coastal zones – was adopted by Federal government in 2006. Its objective is to develop and maintain the country's coastal areas as ecologically intact and economically flourishing habitats. This constitutes an informal approach to coordination, participation and the exchange of experience. Although climate change is considered in the IKZM process, the process does not incorporate a specific adaptation strategy.

As far as marine protection is concerned, there have been no DAS Monitoring Indicators developed so far. It remains difficult to state any concrete adaptation measures. Ultimately, the issue must be to achieve a distinct reduction in pressure from anthropogenic utilisation, to provide more protective periods or to designate protective zones.

As far as research is concerned, core research objectives for marine, coastal and polar research were defined within the Federal government's framework of the research strategy 'Research for Sustainability' (FONA); this definition is embedded in the inter-departmental specialised programme entitled MARE:N. MARE:N consists of the three pillars of coastal, marine and polar research and is conceived as an action framework for future funding measures. The MARE:N concept papers entitled 'Küste im Wandel' (coasts undergoing change) and 'Blauer Ozean' (blue ocean) (2018) as well as 'Polarregionen im Wandel' (polar regions undergoing change) (2021) paved the way for future research funding by the Federal Ministry of Education and Research (BMBF) in respect of coastal, marine and polar research. There are extensive research activities in progress under the two first-named programmes with focus on climate and coastal dynamics, ecosystem-related coastal protection and changes in biodiversity and material flows.

State

Photo: © peterschreiber.media / stock.adobe.com

Climate changes relevant to the action field

Air and seawater warming

Some of the ways in which climate change makes itself felt are – rising air temperatures and a changing precipitation regime. With an increase by 1.7 °C between 1881 and 2022, the temperature rise in Germany was 0.6 °C greater than the global mean (cf. Fig. 1, p. 19) including the marine regions which are not subject to fast warming. As air temperature rises, sea temperature rises too. Approximately 90 % of the additional heat quantity induced by climate change is absorbed by the oceans. As a result, the oceans cumulatively become a ‘reservoir’ of gigantic quantities of heat.

Impact

Photo: © Dietmar / stock.adobe.com

Impacts of climate change

KM-I-2 Sea levels

The warming of oceans leads to an increase in the volume of seawater. Apart from the melting of glaciers and polar ice shields, this expansion of the seas is considered a crucial cause of global sea level rise. The sea levels on North Sea and Baltic Sea coasts are rising too. In this context, the rates of increase (adjusted for land uplift and land subsidence respectively) for the 20th century are between 1.4 and 2.1 mm annually thus equating to the same scale as the increase in global sea levels. According to the current progress report (AR6) issued by the Intergovernmental Panel on Climate Change (IPCC), the scenario entitled ‘Der fossile Weg’ (The fossil pathway, SSP5-8.5) predicts a probable increase of sea levels by 0.63 to 1.01 metres by the end of this century. The ice-shield processes – so far inadequately understood – in the Antarctic might contribute an additional metre to the increase in sea levels.

KM-I-3 Height of storm surges

For coastal regions, in particular estuaries and coastal lowlands, rising sea levels signify an increasing risk of exposure to storm surges and inundations. At the moment, trends are not indicating the imminence of more frequent or more intensive storm surges. However, it is inevitable that the higher baseline values in terms of sea level rise will result in higher absolute water levels at times of storm surges. In addition, the hazard potential is augmented by the increasing utilisation pressure on coastal areas.

Impact

Photo: © bevisphoto/ stock.adobe.com

Adaptations – activities and results

KM-R-2 Land protection dykes without safety deficit

In order to protect infrastructures, buildings and human life in endangered coastal regions, the coastal Länder implement coastal protection measures. In Schleswig-Holstein land protection dykes protect the adjacent coastal lowlands from inundation for a total length of 433 kilometres. To make dykes strong enough to withstand future loads, unsafe dykes (that fall short of valid protection standards), are reinforced in line with the concept entitled ‘Klimadeich’ in order to be able to withstand a sea level rise by up to 2.0 metres. Recently, the proportion of land protection dykes without a safety deficit increased to 81.7 %.

Response

Photo: © Lehnerfoto / Generalplan Küstenschutz SH 2022

The North Sea is getting warmer

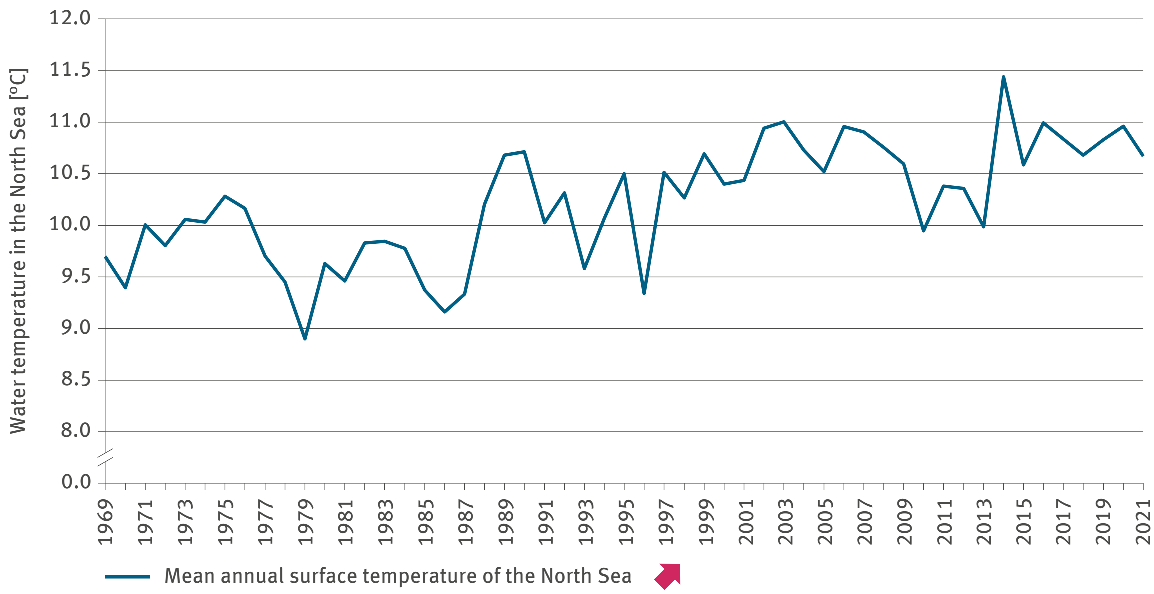
Global warming is reflected not just in rising air temperatures – the seas and oceans are warming increasingly too. Especially in years with persistent heat waves, water temperatures rise distinctly. As a result, some extraordinarily high water temperatures were recorded on Germany's coasts in the exceptionally hot summer of 2003. In August of that year, the mean surface temperature measured across the entire North Sea fell short of the August 1997 temperature of roughly 17.6 °C by just 0.2 °C.[68] In some locations and for individual days, temperatures may have been even higher. In the hot summer of 2018, the maximum temperatures measured at coastal gauging stations in the North Sea and the Baltic Sea rose as a high as 26 °C, thus reaching a Mediterranean level[69]. Latterly, the 2022 water temperatures in the North Sea broke the heat records. In some places, the surface mean temperature in summer amounted to more than 1 °C above the long-term summer mean of 1997 to 2021[70].

Their storage, buffering and exchange functions give the Earth's oceans a central role in its climate system. More than 90 % of the additional heat energy generated by the anthropogenic greenhouse effect is stored in the oceans. Contrary to the air temperatures above the mainland, which are more exposed to the influence of localised weather patterns as well as natural climate variation, the oceans' temperature development indicates less pronounced fluctuations, especially in deeper strata. Between 1960 and 2020 the heat energy contained in the upper 2,000 metres of the earth's oceans increased by 380±81 sextillion Joule (380±81 x 1021 J[71]). The mean warming rate for the entire surface of the Earth amounts to 0.39±0.08 Watt per square metre (W/m2). On detailed inspection it became clear that over the past roughly 30 years, the warming of the ocean proceeded more strongly than when records began. The mean of the heat energy absorbed annually in the period of 1986 to 2020 was approximately 8 times higher than between 1958 and 1985[72]. In recent years, the world's oceans have absorbed more heat energy every year than in the preceding year.

The warming of the seas and oceans does not just take place at the surface, because the heat energy absorbed is transferred into the innermost parts of the sea, reaching

KM-I-1: Water temperature in the sea

The annual mean surface temperature of the North Sea has been rising significantly since 1969. For example, the mean warming amounts to 0.26 °C per decade. The annual values are subject to natural fluctuations.



Data source: BSH (North Sea monitoring stations) even deeper layers, down to the sea floor[73]. It therefore follows that measuring global warming primarily in terms of the increase of the globally calculated mean of the surface temperature is tantamount to a gross underestimation and misperception of this complex issue. In fact, global warming came into question when the increase in the surface temperature in the period of 1998 to 2013 more or less stagnated (global warming hiatus)[74].

Evidence for the warming of North Sea and Baltic Sea is found in the large-scale analyses of surface temperatures which have been carried out in the North Sea for over 50 years by the Federal Maritime and Hydrographic Agency (BSH). For the indicator, the annual mean temperatures were calculated on the basis of aggregated measurements. Statistically speaking, a significant linear trend is discernible for the entire period in question. It is notable that the linear mean of the temperature increase amounting to roughly 0.26 °C per decade is overlaid with fluctuations in various timescales. This is caused by various natural variability patterns such as the Atlantic Multidecadal Oscillation. The time series of the annual mean air temperature in Germany shows a similar development (cf. Fig. 1, p. 19). Similar variability phenomena can also be observed in other parts of the world. Given the development of the mean surface temperatures along the North American Pacific coast well into the central Pacific ocean, it can be assumed that a warming regime has existed in that part of the Pacific since 2014.[75]

The highest annual mean temperatures of the North Sea so far – typically resulting from extreme warming in the summer months – amounted to 11.0 °C (2003, 2006, 2016, 2020) and above (11.4 °C, 2014), and latterly 11.2 °C (in 2022).

The consequences of warming in the North Sea and the Baltic Sea as well as other seas in the world with regard to marine ecosystems have been documented in various scientific studies[76]. Species either adapt their range of distribution or become extinct – either locally or regionally (cf. Indicator FI-I-1, p. 122). Indirect side effects of climate change such as lack of oxygen and the acidification of the seas also contribute to changes in the diversity, composition and distribution of species thus changing the entire food web prevailing in marine habitats. The economic impacts on deep-sea fisheries are difficult to distinguish (cf. Indicator FI-I-2, p. 124). As far as German coastlines are concerned, high seawater temperatures have made headlines in recent years when raised concentrations of vibrios created health hazards for bathers (cf. Indicator GE-1-7, p. 52) or when bathing tourism was affected by blue-green algal bloom. An additional driver of these developments is the persistent eutrophication via nutrient inputs from rivers. The maximum nitrogen concentrations at the limnic-marine transition point stipulated for Germany, are nowadays complied with in respect of the mean for all rivers flowing into the North Sea, but they are still being exceeded with regard to the Baltic Sea. Some of the tributaries to the North Sea and the Baltic Sea still indicate high concentrations.

It is not just the surface temperature which is rising in the North Sea. Immense amounts of heat energy are stored in the deeper water layers too.
(Photo: © Dudarev Mikhail / stock.adobe.com)

A direct consequence of heat storage in the oceans is the expansion (increase in volume) of seawater which is one of the crucial causes of sea level rise (cf. Indicator KM-I-2, p. 102). In 2021 the global sea level was 97 mm above the 1993 level (when satellite measuring began) thus reaching a record level. Just under 40 % of this increase is due to the thermal expansion of seawater, most of the rest of the increase in mass is due to melt water inflows.[77]

Continuously rising water levels in North Sea and Baltic Sea

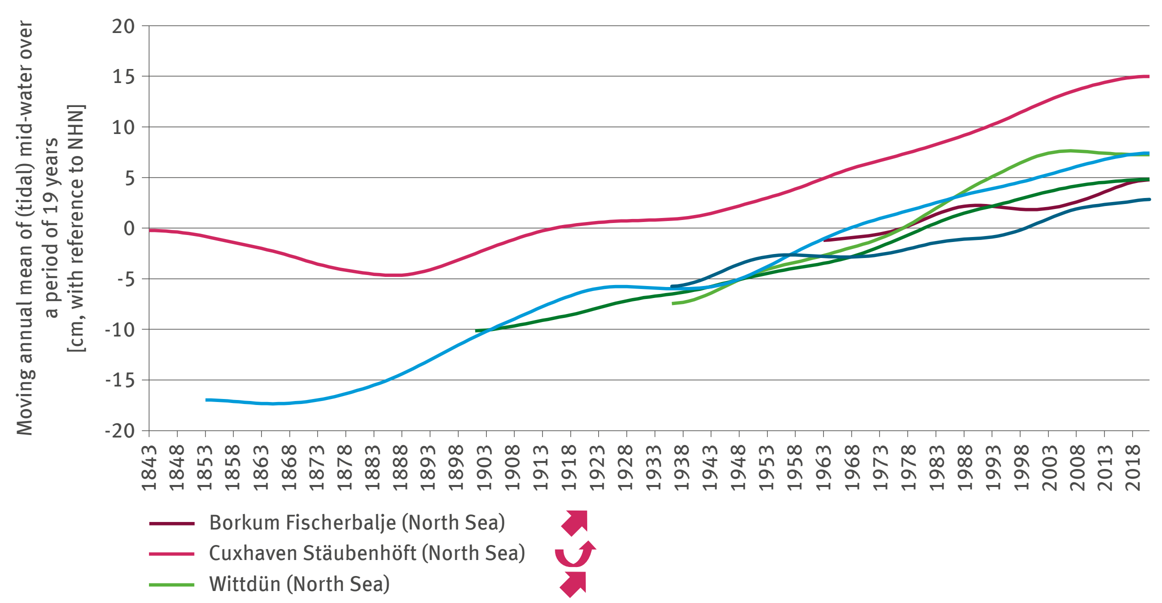
Owing to climate change, the glaciers and ice shields at the poles are melting. They feed great amounts of freshwater into the seas. At the same time rising water temperatures make the seawater expand. Consequently, this leads to a global rise of sea levels. For this century, the 6th IPCC Progress Report published in 2021 projects a probable bandwidth for the global rise of sea levels – regardless of any potential scenarios of human action – by 0.3 to 1.0 metre. Nevertheless, these values reflect only those processes that are well understood and thus can be modelled. For example, the processes of ice melting in the Antarctic have so far not allowed adequate modelling. However, it is conceivable that by 2100 they might lead to an additional increase in sea levels by more than a metre. As far as German coasts are concerned, it is expected that values would hardly deviate from the global means mentioned above[78].

Various factors of influence such as the redistribution of masses in the ocean, wind conditions and air-pressure conditions might either increase or decrease the global development. Furthermore, vertical land movements have a decisive influence on the absolute sea level increase at a specific location: During the last glacial period massive ice shields covered the coastal areas of the North Sea and the Baltic Sea. Their enormous weight made the land masses sink. Ten thousand years ago, the ice melt triggered an isostatic equalising movement which has been continuing to this day. These factors are responsible for the fact that the increase in sea levels differs both regionally and locally.

The water levels at German coasts have been measured regularly for up to 180 years at individual gauging stations. The long time series provide insights into the historic development of the sea level of the North Sea and the Baltic Sea. The indicator illustrates the mean annual water level measured at individual selected gauging stations in centimetres with reference to the standard elevation zero (NHN). The NHN signifies the zero point of the current elevation frame of reference in Germany – termed the ’Deutsche Haupthöhennetz’. The three gauging stations at Cuxhaven Steubenhöft, Borkum Fischerbalje and Wittdün on the island of Amrum are located on the

KM-I-2: Sea levels

The calculated mean of water levels measured for 19 years at selected gauging stations in the North Sea and Baltic Sea illustrate the sea level rise. Measurements from gauging stations in the North Sea and the Baltic Sea show that water levels have been rising significantly. For coastal regions, in particular estuaries and coastal lowlands, rising sea levels signify an increasing risk of exposure to storm surges which can lead to flooding.



Data source: BfG (Gauge database (Pegeldatenbank) of the Federal Waterways and Shipping Administration)

North Sea coast, whereas the gauging stations at Kiel, Travemünde and Sassnitz record and portray the sea level development on the Baltic Sea coast.

The North Sea is characterised by the tidal system. This is the reason why the indicator shows the mean tidal sea level (MTmw) for the gauging station concerned. By contrast, the Baltic Sea – owing to its geographical location and tenuous links with the oceans – is subject to a comparatively weak tidal influence; that is why in this case the annual theoretical mean water levels (MW) are relevant. For these coefficients of water level, a low-pass filter was used to calculate a moving average across 19 years.

All gauges examined show that the mean (mid-tide) water levels have, statistically speaking, risen significantly in the course of the past 60 to 180 years. Analogous to the development of the increase in the global sea level[79], the trend analysis carried out for the gauging station at Cuxhaven Steubenhöft on the North Sea coast, shows a secular trend (statistically significant square trend) that started roughly towards the end of the 19th century, accompanied by variability which in each case covers several decades. From the beginning of records to roughly the end of the 1880s, the sea level measured at this gauge dropped at first, before a continuous increase was observed. The water levels measured at the Wittdün gauge were slightly regressive latterly. This can possibly be attributed to morphological changes in the gauging station's environment.

Coastal regions, in particular estuaries and lowlands – some of which are even below sea level – can be exposed to increasing risks from rising sea levels and associated storm surges that can result in flooding (cf- Indicator KM-I-3, p. 104). Another consequence of rising sea levels is progressive coastal erosion which affects sandy coastal zones, thus also affecting sections of cliffscapes (cf. Indicator KM-I-4, p. 106).

In the German Bight and adjacent estuaries the increase in sea level also affects the tidal dynamics (tidal water levels and current velocities). For example, modified tidal dynamics change the sediment transport in mudflats and estuaries. Higher current velocities at high tide (compared to ebb-tide velocities) carry more sediment into those areas. The extent to which mudflats grow in line with the increase in sea level, depends – among other factors – on the availability of sediments. There are still some uncertainties. The same is true for the small islands known as the Halligen. They too increase in size owing to sediment input from inundation. However, if the sea levels rises faster in future, the Halligen islands and the salt marshes will be seriously at risk unless targeted protective measures are taken[80]. In estuaries – which are also used as shipping lanes, for instance as access routes to the port of Hamburg via the Elbe – greater input of sediments might lead to the need for increasing maintenance efforts, if the decrease in the depth of water owing to increased sediment inputs outweighs the increase in water depth resulting from the rising sea level. Besides, it is important to remember that marine-engineering measures can also strongly influence these processes.

The sea level keeps rising. This entails impacts not just on beaches but also on mudflats, estuaries and coastal lowlands. (Photo: © Dietmar / stock.adobe.com)

The uncertainties of projections regarding increases in the sea level combined with the impacts of regional and localised changes, make a targeted collection of data on the development of water levels on the coasts indispensible. These factors are equally important as benchmarks for measures required in coastal protection and in respect of other coastal structures that have to be continuously adapted to new challenges (cf. Indicator KM-R-2, p. 114).

Storm surges increase flooding risks

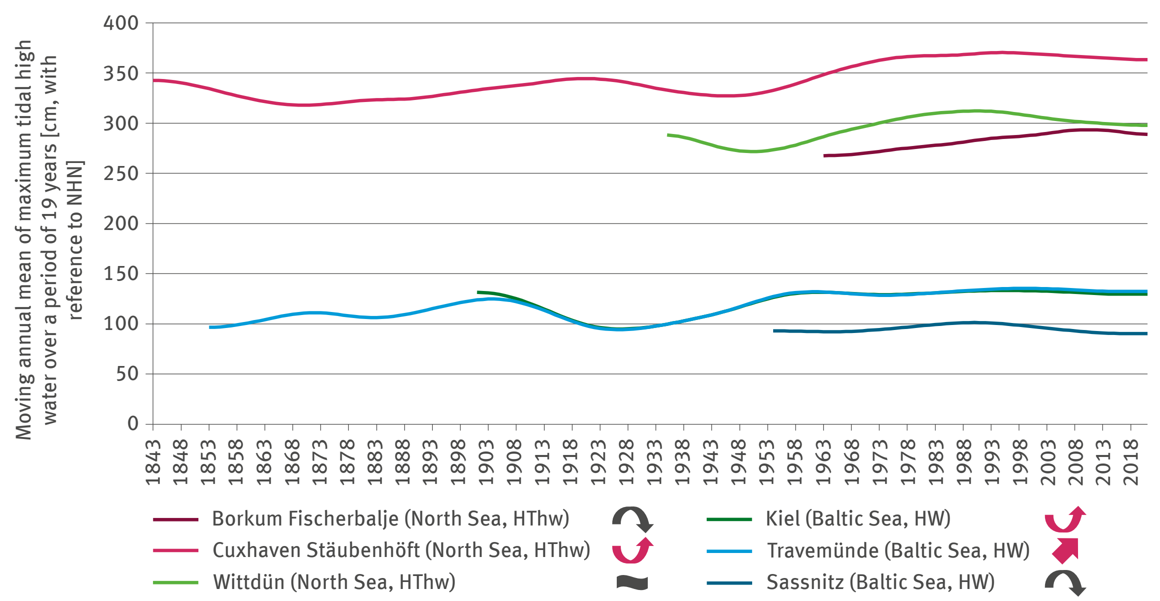
In coastal regions, storm surges are among the greatest natural hazards. Storm surges occur when strong onshore wind pushes large volumes of water towards the coast. Storms and hurricanes, in particular, lead to a massive build-up of wind which, depending on the tides, can lead to the development of storm surges in the North Sea. Depending on the wind intensity, the orographic nature of coastal waters and any measures taken for technical flood protection, there is a risk of serious floods in coastal lowlands. On the German coast, storm surges are not uncommon, especially in the winter half-year. On the North Sea coast of Schleswig-Holstein, weather patterns with winds from the west, and in Lower Saxony, with winds from the north are very efficient in causing storm surges, thus making them particularly hazardous.

The water level rise in the North Sea and the Baltic Sea due to climate change provides storm surges with a better starting point so that water masses can mount higher as they reach the shore. In the estuaries, the storm-surge water levels rose to even greater height owing to local anthropogenic measures. This can be seen in particular with regard to the rivers Ems, Weser and Elbe. Engineering measures such as the dyking and straightening of rivers eliminate natural flood plains.

Nowadays people refer to storm surges on the North Sea coasts when the water level rises to at least 1.50 metres above the current mean high water (MHW). Exceeding this threshold value is linked with the (fluctuating) mean sea level (cf. Indicator KM-I-2, p. 102). Although that does not mean that this will necessarily lead to more frequent storm surges, it nevertheless indicates that storm surges – assuming otherwise equal meteorological framework conditions prevail – will increase in height and are thus apt to cause greater damage. Individual and particularly serious storm surges generally entail damage to coastal buildings and infrastructures. In the past, such damaging storm surges occurred repeatedly on the North Sea coast. For almost 2000 years storm surges have been documented on German coasts. One of the most devastating storm surges of the past 100 years was an event on 16th February 1962, which caused damage on the coastline of the entire German Bight, but especially in Hamburg, involving

KM-I-3: Height of storm surges

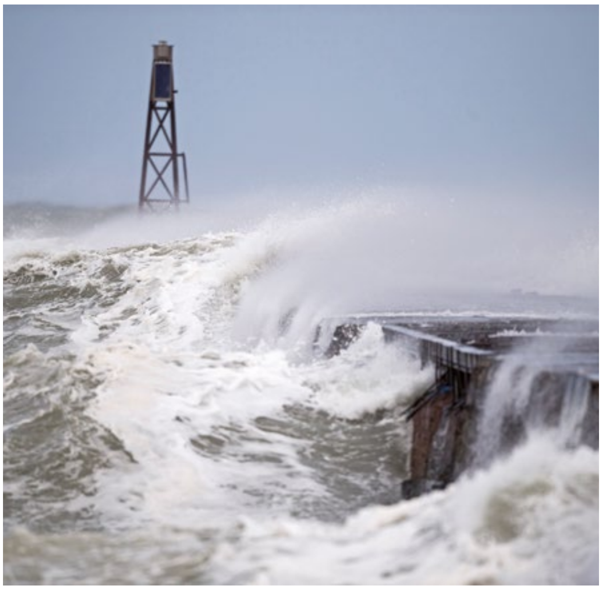
The maximum tidal high water levels measured at six selected gauging stations in the North Sea and the Baltic Sea indicate a cyclical progress. The time series fluctuate in phases of rising and falling storm-surge water levels. The illustration based on moving 19-year mean values does not indicate any extreme individual events. The trend development differs between the gauges observed.



Data source: BfG (Gauge database (Pegeldatenbank) of the Federal Waterways and Shipping Administration) numerous fatalities. Although the storm surge of 1976 reached a greater height, there was better protection in place thanks to coastal protection having been implemented previously. The big storm surge in northern Friesland in November 1981 caused extensive damage to dunes on the North Sea islands. In December 1999 hurricane Anatol reached storm peaks up to 200 kilometres per hour and briefly caused very high increases in sea level throughout the North Sea area. In December 2013 the entire North Sea area was affected by hurricane Xaver and storm surges which were quite severe in places. The dykes on the mainland managed to withstand the onslaught of water masses, whereas on the islands in eastern and western Friesland, dunes were severely breached in many places. Latterly, in the beginning of 2022, several – partly severe and one very severe – storm surge / s (>3.5 metres above MHW) occurred on the North Sea coast. However, those storm surges have not yet been incorporated in the data base for the Indicator KM-I-3 illustrated in this report.

On the Baltic Sea, the duration, direction and intensity of the wind determine whether storm surges occur. Water levels of one meter and more above the mean sea level are regarded as storm surges here. Given that the tides hardly play a role in this sea, storm surges in the Baltic Sea can last for one or two days. To a lesser extent, the volume of water in the Baltic Sea, natural oscillations in water masses (also known as 'seiches') and changes in air pressure contribute to this phenomenon. The most severe storm surge in the south-western part of the Baltic Sea occurred on 13th / 14th November 1872 causing major destruction. 271 people lost their lives in this disaster.

On the German Baltic Sea coast minor storm surges occur every year. Serious storm surges are less frequent, but they did occur at the beginning of 2017 and 2019 respectively. The highest water levels were recorded in Wismar: towards the evening of 4th January 2017 with 1.83 metres, and on the afternoon of 2nd January 2019 with 1.91 metres above the mean water level. After these events had taken place, damage was recorded especially on the coasts and beaches. At the end of 2022, the low-pressure system Nadya first caused a low-water level followed instantly by a storm surge. Owing to the low-pressure system shifting, it first resulted in a strong south-west wind which made water levels recede; subsequently, the wind shifted north thus capturing also the central part of the Baltic Sea. From there the water was pushed towards the western part of the Baltic Sea while localised hurricane-type gusts from the north pushed the water towards the coast. In Flensburg, for instance, the water level dropped within roughly 16 hours from 1.59 metres to 1.49 metres above the mean water level, thus in fact rising by a total of more than 3 metres.



Storm surges are extreme events. As sea levels rise, storm surges may increase in height too. (Photo: © bevisphoto / stock.adobe.com)

Changes in the intensity of storm surges caused by rising sea levels can be illustrated by the annual maximum tidal high water (HThw) measured at the North Sea gauging stations and for the annual maximum high water (HW) measured at the Baltic Sea gauging stations. For the indicator, these coefficients of water levels were calculated by the BfG by means of using a low-pass filter to determine the 19-year moving mean.

For the purpose of illustration in the indicator, meaningful individual gauging stations were selected, making sure that readings would not be influenced too much by structural changes that took place in recent years or by local circumstances. Furthermore, the objective was to ensure a regional distribution of gauges between the North Sea and the Baltic Sea, and also between the relevant coastlines. As far as the levels occurring in the North Sea are concerned, the gauging stations at Cuxhaven Steubenhöft, Borkum Fischerbalje and Wittdün on Amrum were selected. The gauging stations at Kiel, Travemünde and Sassnitz are located on the Baltic Sea coast.

The height of the storm surges measured at the selected gauging stations in the North Sea and the Baltic does not indicate a significantly rising trend. Phases of rising and receding maximum levels alternate with a periodicity of roughly 50 to 70 years. The illustration based on moving 19-year mean values does not indicate any extreme individual events. It is only when such events occur very frequently that values increase.

Coastlines shift further inland

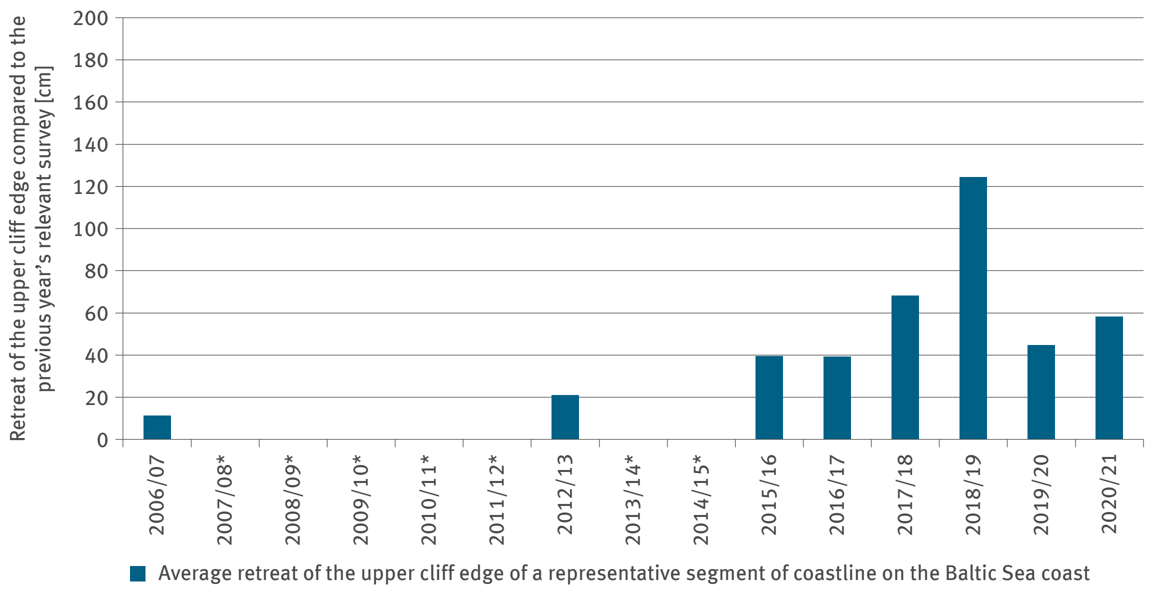
Coastlines delineate a natural border between sea and mainland thus continuously exposing coasts to the force of the water. The interplay of erosion, transport and cumulative processes subjects them to continual change: The sediment removed from many parts of beaches or cliffs, once deposited elsewhere, can become new terrain. The nature of individual coastal segments and the way they are shaped, depend on their geomorphological properties, especially on the solidity of the rock concerned. Likewise of crucial importance are hydrodynamic factors such as sea currents, the tides, the water level and the state of the sea, but also heavy-rain events.

These factors of influence are the reason why coastal morphological changes are closely bound up with the impacts of climate change. As sea levels rise, the loads affecting coastlines increase. Storm surges will increase in height (cf. Indicator KM-I-3, p. 104) and the waves are able to reach new areas available for attack. Extreme weather events such as heavy rain or frequently alternating frost and thaw periods can favour the erosion of cliffscapes. Given the multi-faceted functionality of coastal landscapes, their erosion or displacement are of major impact. The coast is a habitat for numerous, in some cases rare, animal and plant species. In addition to its ecological value, the coast is an important factor in the country's economy owing to its high leisure and recreation value. Many adjacent communities are tourism-oriented. Combined with the high intensity of utilisation, the climatic changes exert increasing pressure on coastal areas and, in the absence of counter-measures, increase the ecological and economic risks confronting these areas.

The German coastline along the Baltic Sea is one of the areas where beaches shrink and cliff edges keep receding further inland. It is a characteristic feature of the coastline that steep and shallow shores alternate, where especially certain types of sand and loose materials are eroded. It is uncertain how much material has actually been eroded. So far there are no continuous or contiguous data available on the material decline of German coastlines. Owing to the complexity of erosion processes, data collection is requires major technical effort and is subject to inaccuracies.

KM-I-4: Coastal morphology – case study

Climate change influences hydrodynamic factors that can affect coastal erosion. Data from aerial laser surveys of a representative segment of the cliffscape on the peninsula of Fischland on the Baltic Sea coast have every year been showing evidence of a further 'retreat' of the upper cliff edge. In particular, years with severe storm surges lead to substantial amounts of material breaking off.



*no data

Data source: StALU Mittleres Mecklenburg (laser flights)

In order to gain insights on the erosion-related decline of the German Baltic Sea coast and defying these adversities, the Staatliche Amt für Landwirtschaft und Umwelt Mittleres Mecklenburg (StALU), has been conducting laser flight surveys on the coast of Mecklenburg-Western Pomerania on an annual basis. Every autumn, the representative segment of cliffscape between the municipalities of Wustrow and Ahrenshoop is subjected to measuring surveys over a distance of roughly three kilometres. Data on the location of the upper cliff edge are used to determine the average annual retreat of the coastline. The survey data were used to underpin the case-study indicator presented in this report. Like most of the coastlines marked by cliffscapes in Mecklenburg-Western Pomerania, this coastal segment too is subject to natural dynamics, characterised by the fact that eroded material from these cliffscapes is deposited in parallel with the coastline thus benefiting shallow sections of the coast occupied by settlements.

The erosion proceeding at this cliffscape is subject to a cyclical pattern. First, the offshore part of the cliff face – an accumulation of sediments already fallen off the cliff face – is eroded during a storm surge. As further material is removed from the bottom of the cliff, a cavity is created. The resulting overhang and the instability of the cliff – often combined with heavy-rain events – lead to rockfalls and material sliding down thus reshaping the foot of the cliff. Within the framework of these continuous processes, the cliffscapes in the coastal segment observed shift further inland by an average of 20 to 40 cm annually. In cases where extreme conditions, such as storm surges, prevail causing erosion processes to accelerate and intensify, the relocation of the upper cliff edge proceeds more rapidly increasing the distance by which the cliff edge ‘retreats’ inland.

The data examined in the case study underline the influence of storm surges on coastal decline: During the periods of 2017 / 2018 and 2018 / 2019 storm surges (some of them severe), caused partly severe erosion on the Fischland-Hochufer shore. In the autumn of 2018, east winds combined with major water volumes in the Baltic Sea, caused sea levels to rise on the coast. At the beginning of 2019, strong winds gave rise to two storm surge events in quick succession. In 2018 / 2019, the upper cliff edge on Fischland – compared to the survey findings of the previous year – retreated on average by more than 1.2 metres inland. In the interval between aerial surveys carried out in 2020 and 2021, the upper cliff edge had shifted inland by just under 60 cm. Given the brevity of the time series and the years when no aerial surveys took place, it was not possible to carry out a statistical trend analysis of the time series concerned.

As sea levels rise, the loads affecting coastlines increase. This causes material displacements just like in the case of the Ahrenshoop cliffscape. (Photo: © fotografci / stock.adobe.com)

The data provide insights into the erosion of a selected cliffscape segment on the coast of the Baltic Sea. As far as the coastal decline of other types of North Sea coasts is concerned, it would be either impossible or at least subject to major restrictions to draw any inferences from the findings above. Also with regard to the conditions prevailing on Fischland, these data can only be regarded as approximations. Given the distance of aircraft from the ground and for technical reasons, aerial laser surveys should not be regarded as accurate. Moreover, the length of the segment of coastline surveyed varies every year by some metres. Consequently, it is likely that more or less strongly eroding areas of coast at either end of the coastal segment surveyed are potentially not captured every year. Moreover, the intervals between years are not necessarily equal in duration.: Although the aerial surveys are always carried out in the same season, the dates of the actual flights tend to vary.

Despite these restrictions, the case study is able – thanks to any anthropogenic influences on Fischland being of a minor extent – to provide an impression of the naturally and climatically influenced erosion processes. Elsewhere counter-measures such as beach nourishments and groynes are used effectively to ward off erosion and shifts in the coastline. In the sandy, receded coasts of Mecklenburg-Western Pomerania, dunes combined with groynes are the most important elements employed in the coastal protection strategy (cf. Indicator KM-R-1, p. 112).

Discharge from coastal watercourses influenced by storm surges

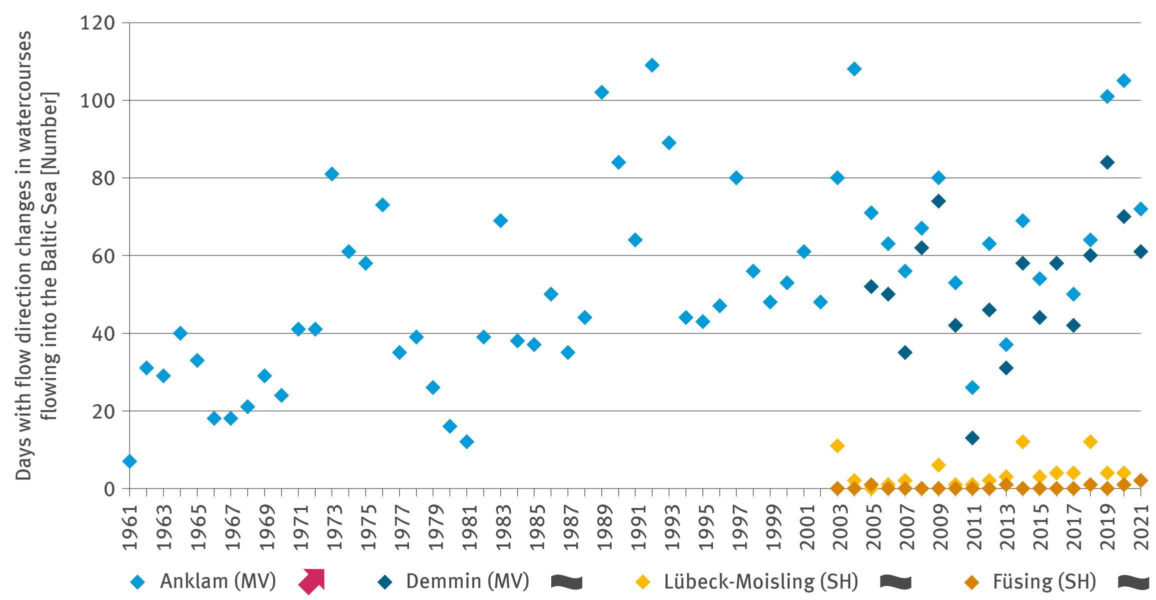
Where sea and rivers meet, the interplay of natural forces creates unique natural spaces. In estuarine areas and coastal watercourses, surf and tides interact with the river currents from further inland. Owing to variable freshwater and saltwater proportions, the dynamic landscapes are characterised by specific ecological properties. Zones of brackish water provide habitats for specialised animal and plant species, that can be used as 'nurseries' by fish species considered of economic importance. In many places, estuarine and brackish water areas inform the character of the North German coast.

For example in the North Sea, the tides influence the hydrodynamic scenarios in sections with coastal watercourses: During ebbtide, the river water can flow unhindered into the estuarine area, whereas at high tide this flow is slowed down or the river water is backed up. Especially when strong wind and a rough swell force seawater into estuarine areas and inland waters, it can happen that in a section near the coast, the flow direction of a watercourse is temporarily reversed. In cases of any such backwater events, the gauging stations alongside the river sections concerned record negative discharge values. If the tidal force is rather weak as in the Baltic Sea, storms are always the decisive factor responsible for causing backup in a watercourse. In particular when water levels are high, strong wind can push the seawater far into the inland waters. Climate change favours the occurrence of backwater events: Rising sea levels generally cause higher water levels on the coast. Rising sea levels also cause the baseline level of storm surges to rise thus causing these surges to increase water levels (cf. Indicator KM-I-3, p. 104).

Apart from the maritime influence of storm surges and rough seas, the backing up of watercourses is linked with specific characteristics of water bodies. Watercourses prone to turning into backwaters are characterised by a (very) weak water discharge and low valley floor gradient (< 0.5 permille, more rarely up to ≤ 2 permille). These conditions apply to the young moraine landscapes of

KM-I-5: Change of flow direction

At the Baltic Sea, storm surges in particular can lead to a change in the direction of flow in sections of watercourses close to the coast. Due to climate change, the risk of such backwater situations is increasing. At the gauging station Anklam, Mecklenburg-Western Pomerania, the number of days with flow direction changes has increased significantly since 1961. The readings from the other gauging stations do not show any trends, possibly because the time series are still relatively short.



Data source: LKN.SH, LUNG MV (water level measurements)

Mecklenburg-Western Pomerania and eastern parts of Schleswig-Holstein shaped by the last ice age. In areas of shallow Baltic Sea coasts, watercourses flow into a slightly brackish coastal water, silted up to various extents. The Peene river, for instance, flows into the Stettiner Haff, a brackish water area separated from the Baltic Sea by a spit or the island of Usedom. The mineral-rich bed of a watercourse prone to causing backwater is usually distinctly below the water level of the Baltic Sea. Owing to natural sedimentation processes, mud is often deposited in the bed of the water body.

When a watercourse is backed up, this can bring about changes in the ecological and hydro-dynamic characteristics in, and pertaining to, sections of the watercourse concerned. For example, during storm surges the river mouth of the Peene into the Baltic Sea is shifted inland thus exposing areas to the influence of the sea which were never before exposed to such influences. The mud deposits can cause lack of oxygen impacting the water quality as well as the ecological structure of the water. Moreover, backwater can also exacerbate the risk of flooding areas alongside the inland watercourse. In such cases dykes would be the primary flood protection tool. However, such dykes are usually dimensioned for flood events which arise in areas further inland.

Four gauging stations were selected for the indicator to show the number of days with flow direction changes for selected watercourses – prone to backing up – flowing into the Baltic Sea[81]. It was significant for the gauging station to be selected in a location that was as little as possible influenced by anthropogenic activity. The gauging stations differ in terms of their exposure to the Baltic Sea, the topographic nature of the beds of the watercourses and the gradient of the valley bottom. Two of the gauging stations are located at the Peene river: The gauging station Anklam is located in the Peene's river mouth where it flows into the Stettiner Haff. The gauging station Demmin is located 58 kilometres further inland thus indicating how far inland the watercourse is backed up. The gauging station Lübeck-Moisling at the Trave river is located in an area that is exposed to both coastal and river flooding. Despite its distance of 20 kilometres from the coast, this gauge reacts to raised water levels in the Baltic Sea and to storm surges. The gauging station Füsing at Füsinger Au is located in the backup area of the river Schlei.

Owing to the influence of individual extreme events, the time series proceed subject to fluctuations. In the hydrological year of 1989 the gauging station Anklam witnessed – for the first time – a flow direction change caused by backwater occurring on more than 100 days. Notably in August of that year, negative discharge values were recorded when a severe storm with hurricane-like gusts resulted in flooding the Baltic Sea coast with waves several metres high causing substantial damage. In the hydrological years of 2019 and 2020, with similar frequency, a backwater situation was recorded at the gauging station Anklam. In the beginning of 2019 two storm surges in quick succession contributed to flow direction changes in the river Peene. In that year the highest value of the time series so far occurred, with flow direction changes recorded on 84 days by the gauging station Demmin. The greatest number of days with flow direction change recorded by the gauging station Lübeck-Moisling was measured in September 2014: At the end of the month, the low-pressure system 'Gudrun' impacted the Baltic Sea area. As the wind in the western part of the Baltic Sea gained momentum and shifted north, the water level on the coast reached the monthly maximum value and pushed seawater up the coastal watercourses.

The hydrodynamics prevailing in sections with coastal watercourses are subject to the influence of tides and storm surges. (Photo: © Peter Engelke / stock.adobe.com)

In northern parts of Germany, the summers of 1992, 2003, 2018 and 2019 were characterised by extraordinary heat and low precipitation levels. Consequently, the runoff from watercourses was distinctly reduced. The low discharge volumes of the rivers Peene, Trave and Schlei may have favoured the flow direction changes recorded in those years.

Operation of pumping stations safeguards lowland areas

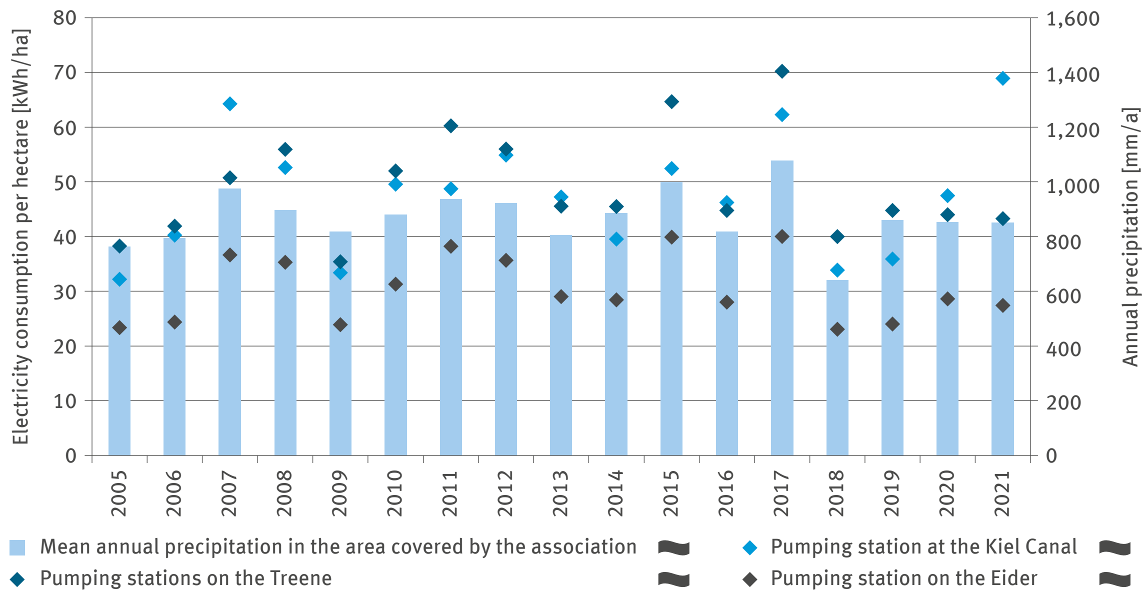
On the North German coast, the scenery of entire regions is characterised by lowland areas. The plains, some of which are quite extensive, are in part due to glacial erosion and formative processes at the end of the last glacial period, when the glaciers that had advanced into northern Germany, began to melt. Later on, the fertile plains were subject to cultural-historical influences. To this day the North German Plain continues to be subject to a wide and extremely varied spectrum of utilisation: Some of the lowland areas provide habitats for rare species of plants and animals which makes them of singular importance to nature conservation. Furthermore, there are settlements and trade and industry businesses scattered over some areas. In particular near the coast, tourism is becoming increasingly relevant. The major part of the North German Plain is currently used for agricultural production.

The low altitude of the landscape – in most cases amounting to just a few metres above the mean sea level – combined with a low gradient have a compelling impact on the water regime and the hydrological conditions in these lowland areas. In order to maintain or even improve the conditions required, especially for the agricultural use of some areas, it is often necessary to implement supplementary artificial drainage in places where a continuous drainage in free incline is not possible. Generally speaking, agricultural areas can tolerate long-term backwater residence times of maximum 14 days before serious damage ís to be expected. For the purpose of artificial drainage, technical structures such as sluices with storage basins or pumping stations are used. In the latter case, the water is raised to a higher level thus allowing it to flow into a watercourse or the sea.

The lowland areas and the operation of equipment for artificial drainage are affected directly by the impacts of climate change. For northern Germany, an increase in winter precipitation and heavy-rain events in summer are to be expected. This development increases the hazards of flooding. At the same time, the rising sea level makes it difficult to direct the flow of water into the North Sea or the Baltic Sea. More frequent and more extensive storm surges can cause an additional increase in drainage requirements. The more frequent operation of pumping

KM-I-6: Pumping station performance – case study

In order to keep, in particular, coastal lowland areas in agricultural production, artificial drainage including the use of pumping stations is an essential tool supplementary to drainage in free incline. Especially storm surges and floods which can occur more frequently owing to climate change, increase the need for drainage thus increasing electricity consumption by pumping stations in the area covered by the Eider Treene Association.



Data source: Eider-Treene-Verband (operational data on pumping station operation), DWD (CDC) stations entails increases in electricity consumption. Moreover, operating costs rise when machinery is operated for longer periods or more frequently thus increasing wear as well as maintenance frequency.

In Schleswig-Holstein almost a quarter of the entire terrain is below 2.5 metres above sea level, thus belonging to the category of lowland areas. Most of this land is located on the North Sea coast in the areas of Elbmarschen (Elbe marshland). Dithmarschen, Eiderstedt and Nordfriesland as well as the riparian areas of Eider, Treene and Sorge. Notably, half of these lowland areas are already being drained with the aid of pumping stations. Their operation is in the remit of some 500 water- and soil-related associations in the country. These are part of main associations which include members such as the Eider Treene Association. Extending to roughly 113,000 ha, this is the largest terrain covered by any dyke-and-sluice association in Schleswig-Holstein. Approximately 50,000 ha of the catchment area are categorised as lowlands. The situation prevailing in the Eider Treene Association is used as an example for this theme illustrated in the case-study indicator.

The pumping station Steinschleuse on the Eider river is contributing to the draining of lowland areas in the terrain covered by the Eider Treene Association. There are no significant trends discernible. (Photo: © Rainer Knäpper / Free Art License, (http://artlibre.org/licence/lal/en/))

The indicator shows the annual electricity consumption of selected pumping stations within the terrain covered by the association, in hectares. In addition, the annual mean precipitation of the entire terrain covered by the association is illustrated. This is because the need for drainage in this area is essentially dependent on the precipitation scenario. The data demonstrate that the pumping stations used the greatest amount of electricity in the years with higher precipitation: In 2007 the pumping stations operating in the area of the Kiel Canal were consuming electricity at a rate of roughly 64 kWh / ha. The summer of 2007 produced a particularly high amount of precipitation, especially in northern Germany. In 2017, the utilisation of the pumping station in the areas of the rivers Eider and Treene respectively rose to its highest value. This was also the year in which the greatest amount of precipitation fell since 2005 for the area covered by the association. There is no significant trend for any of the time series.

However, the energy required by the pumps is not solely dependent on the duration of its operation and the hydrological requirements. The water- and soil-related associations endeavour to operate the most energy-efficient pumps. Technical improvements aimed at increasing energy efficiency can influence the progress illustrated by the indicator. Furthermore, the associations take every chance to reduce the cost of using the electricity network in an atypical way. For example, pumping takes place ‘in advance’ at times when the electricity cost is lower, regardless whether at that particular moment there is a hydrological requirement for operating the pumps. The water level of the watercourse on its way to the river mouth is another factor that influences the operation of the pumping station: If the water level rises too much in this watercourse, for instance, as a result of a heavy-rain event, the watercourse is unable to carry the pumped water away. In order to prevent recirculation of the water, the pump operation is ceased. In almost half of the pumping stations located in the Eider Treene area, pump operations are stopped at the time of flooding.

Owing to these circumstances, the interpretation of data on electricity consumption with regard to climate change is subject to restrictions. Many factors of influence interact in complex ways. Moreover, it has to be borne in mind that the situation regarding the relevant remits among the pumping station associations can vary substantially. Some terrains covered by associations are already now influenced more strongly by sea level rise. Against this background there is work in progress on developing the indicator further. These issues are highly relevant to the pumping station associations and agricultural businesses in the lowland areas. For the future it is to be expected that the existing drainage structures will come up against (economic) limitations. The intensification and expansion of pumping station operations will be inevitable in order to maintain the current utilisation of agricultural areas as well as the existing infrastructures.

Effective coastal protection requires ongoing investments

Coastal regions worldwide are particularly affected by the impacts of climate change. In parallel with the sea level rising, it is to be expected that the height of storm surges will increase the risk of flooding in coastal areas. In Germany, particularly those lowland areas are endangered which are just a few metres above or even below sea level. This flood hazard extends over more than 12,000 square kilometres of coastal lowlands in Germany, inhabited by roughly 2.5 million people.

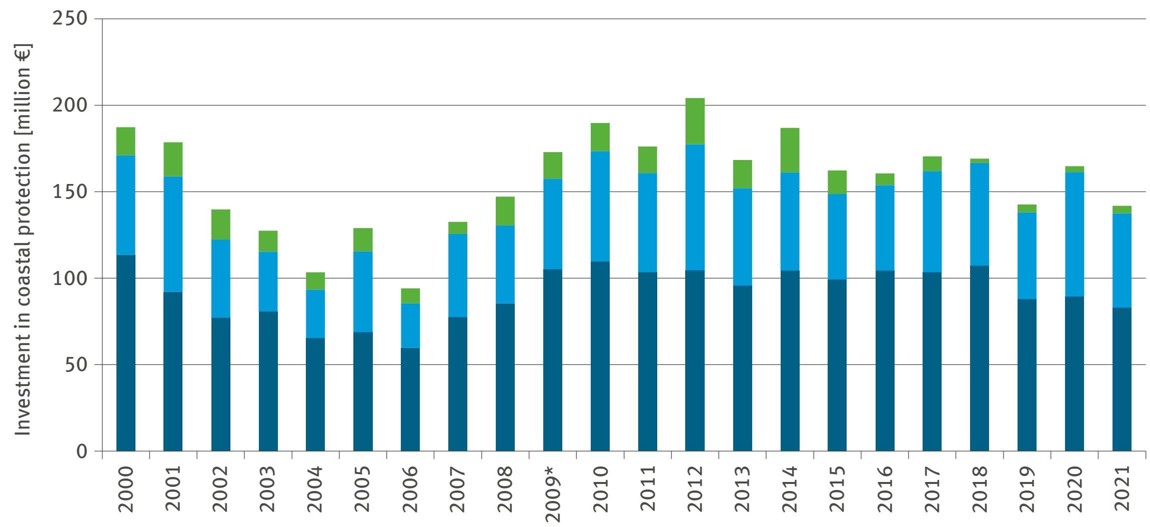
Apart from climatic changes, the increased risk in coastal regions is also related to the particular socio-cultural and economic importance of coastal areas. These areas are often densely populated and used intensively. Industries such as shipping or fisheries depend on their proximity to the sea. Furthermore, the coastal areas are highly attractive for people to live there, but also as travel and holiday destinations in view of their high leisure and recreation value. In numerous adjacent communities on the North Sea and Baltic Sea coasts, the focus is increasingly on the further expansion of their tourism offerings. Such developments also entail an increase in tangible assets in the coastal regions: In the North German Plain, the value of the total of assets runs to three-figure billions.

The protection of infrastructures, buildings and human life in these endangered coastal regions requires effective measures to be taken for coastal protection. This includes for instance the building of dykes, the maintenance of dune systems, shore protection structures, groynes or barrages. On declining sandy coastlines, beach nourishment assists in counteracting coastal decline, thus contributing to the stabilisation of the sediment regime on the coast. Such measures entail high expenditure which requires extensive investments. Moreover, climate change necessitates the cost-intensive and continuous adaptation of extant structures to increasing protection requirements. Dykes are increased in height or reinforced, stabilising structures are reinforced or expanded, and beach nourishment measures are intensified.

In Germany, the dimensioning of coastal protection structures is subject to regular inspection and adaptation of input parameters in order to adapt to climatic

KM-R-1: Investments in coastal protection

The funding made available by Federal government for the purpose of coastal protection decreased between 2000 and 2006. From 2012 onwards the investment increased again to more than 200 million Euros, partly due to additional funding sourced in 2009 within the framework of an GAK Special Framework Plan. Investments have been decreasing again since 2012. However, it must be borne in mind that – owing to the long planning periods – the flow of funding is not continuous.



*from 2009 onwards including the special framework plan 'Coastal protection measures owing to climate change impacts'

Data source: BMEL (GAK reporting)

changes in appropriate ways. This also ensures – in line with the directive on flood risk management – that the projected sea level rise and the increasing danger resulting from associated higher storm surges are taken into account in the implementation and adaptation of coastal protection measures. The design principles have a considerable influence on medium-term planning. The building of new and the heightening of extant structures – as well as possibly in future a more frequent and more extensive implementation of measures – are reflected in the costs involved. For instance, it has been stipulated since 2018 in the Generalplan Küstenschutz in Schleswig-Holstein that insecure landscape protection dykes be reinforced to become so-called 'climate dykes', built in a way to allow adaptations at some later stage. This would allow the adaptation to a sea level rise by up to 2.0 metres in two or three construction phases (cf. Indicator KM-R-2, p. 114).

In Germany technical measures for coastal protection are financed predominantly from GAK. The Federal Government and the Länder contribute the bulk of the funding, sharing the investment costs at a ratio of 70 to 30. The objective is to speed up, or in individual cases, to supplement the ongoing reinforcement of coastal protection structures; the Federal Government therefore provides the coastal Länder with an additional 25 million Euros per annum via an GAK special framework plan over the years 2009 to 2025 for coastal protection measures necessitated by climate change.

These coastal protection measures which qualify for GAK funding include, for instance, the construction of new – and the reinforcing and heightening of extant – coastal protection structures as well as dykes, barrages, groynes, breakwaters and other coastal flood defences. Likewise, operations in foreshores in front of dykes without embankment foreland up to 400 metres and beach nourishment qualify for funding. Other elements qualifying for funding include the essential acquisition of land as well as nature conservation actions and landscape maintenance necessitated by coastal protection measures.

Between 2000 and 2006 the investments in coastal protection decreased by about half. Subsequently, investments increased again reaching an amount of roughly 200 million Euros in 2012. In subsequent years, annual expenditure from funding provided by Federal government, EU and Länder fluctuated around 150 million Euros. Investments by the Federal government remained relatively consistent between 2009 and 2018 with just above 100 million Euros before decreasing latterly to roughly 70 million Euros from 2019 onwards. Likewise,

The requirements for coastal protection increase in line with the impacts of climate change.
(Photo: © Image'in / stock.adobe.com)

expenditure based on funding from the Länder and EU funds decreased in 2021 compared to the previous year: The total volume of investments in coastal protection amounted to 125 million Euros. Statistically speaking, there are no significant trends discernible which is due to the fluctuating development of investments in coastal protection since 2000. However, it has to be borne in mind that coastal protection measures can extend over long periods, both in terms of planning and implementation, thus not occurring in a continuous flow.

In general, coastal protection enjoys high priority both at Federal and Länder level. Notably, this is demonstrated by the decision regarding changes in respect of the GAK Framework Plan 2023–2026: In order to promote and accelerate the urgent measures of coastal protection required owing to climate change, the Federal government has made available distinctly increased funding starting in 2023 for the GAK Special Framework Plan. The volume is expected to be more than doubled in future. Furthermore, the funding from Federal government for measures to be taken in the run-up to 2040 has been secured already.

Land protection dykes meet increasing protection standards

The impacts of climate change put increased pressures on coasts and coast protection structures. The adaptation to climate change is indispensable in order to keep any negative impacts on human health in socially acceptable proportions; the same applies to impacts on the environment, on cultural heritage, on economic activities and, not least, on coastal protection. In Schleswig-Holstein this challenge is met to a large extent by land protection dykes. These dykes currently extend over a total distance of 433 kilometres, thus protecting more than 90 % of potentially flood-threatened coastal lowland areas of the country.

The case-study indicator presented in this report in respect of land protection dykes without safety deficit was developed in 2019 in Schleswig-Holstein as an indicator for monitoring the implementation of UN sustainability objectives. This indicator 47 entitled 'Generalplan Küstenschutz' of Action Field 5 'Infrastructure and climate protection' is evidence for the fact that the climate change adaptation strategy laid down in the Master Plan for Coastal Risk Management (GPK) has been taken into account in Schleswig-Holstein.

Sea level rise and the future development of the storm scenario in the regions of North Sea and Baltic Sea are crucial factors to be observed in planning and in respect of the continuous adaptation of measures for coastal protection and safeguarding in Schleswig-Holstein. The protection standards to be met and their underlying design principles are part and parcel of the declared strategy laid down in Schleswig-Holstein's GPK. As a core planning and management tool, the GPK pools essential principles, guidelines and measures in respect of coastal protection. Approximately every 10 years, this plan is updated and adapted to current circumstances. This process is concurrent with a safety inspection of the land protection dykes: Purpose of this inspection is – by means of a procedure complying with the current state of technology and as far as possible long-term and current time series of annual maximum high water levels – to verify whether the land protection dykes would be able to withstand a storm surge with a statistically determined annual probability of 0.5 %. If that is not the case, the dyke segment is entered into a list of land protection dykes to be reinforced.

KM-R-2: Land protection dykes without safety deficit – case study

In Schleswig-Holstein land protection dykes protect the adjacent coastal lowlands from inundation over a total length of 433 kilometres. Given that the rising sea level increases the danger of flood events, these dykes are continuously adapted to increasing challenges. Recently, the proportion of land protection dykes without a safety deficit increased to 81.7 %.

*from 2012 onwards, modified protection standards within the framework of hydrological safety inspection

Data source: MELUND Schleswig-Holstein (recording of the land protection dykes as part of the general plan for coastal protection)

The reinforcement measures take climate change fully into account. Their implementation adopts the concept of 'Klimadeich' which has evolved in the course of the past two decades. Already since 2001, the dykes in Schleswig-Holstein (for the first time in the world) have been extended in height as a protective measure to offset an expected sea level rise by another 0.5 metres. Furthermore, they have been fitted since 2009 with a wider dyke crest and a more gradual outer slope. This measure is intended to offset a sea level rise up to a total of 1.0 metre. By making the outer slope more gradual it will be possible to facilitate a subsequent structural adaptation, thus ultimately – in the course of several construction phases – offsetting a total sea level rise by approximately 2.0 metres compared to the present sea level. This demonstrates that the planning measures are indeed taking into account the current projections regarding the most unfavourable sea level rise.

The indicator shows the percentual proportion of land protection dykes without safety deficit compared to the total length of all land protection dykes in Schleswig-Holstein. The indicator thus reflects the current condition of land protection dykes with reference to the hydrological loads imposed by storm surges. At present, 81.7 % of land protection dykes do not show any safety deficits. This is a higher proportion than the value of 76.5 % determined by the previous safety inspection in 2011. Nevertheless, as a result of the severe storm surge known as Xaver in 2014, a 5.6 kilometre stretch of the dyke line was additionally categorised as unsafe. The strong decline in 2012 is due to the hydrological safety inspection in 2011 of land protection dykes based on a higher safety criterion applied than in 2001 (annual probability of 0.5 % instead of 1.0 %). This was the main reason for extending the length of dykes to be reinforced from 72.7 kilometres again to a total of 101.5 kilometres which equates to 23.5 %.

As can be seen from the chart, there was no dyke reinforcement completed in the years of 2006 or 2015. It would be incorrect to take this as evidence that no dyke reinforcement took place in those years. Usually, dyke reinforcements take several years to complete; this is why in some years the work is not completed despite ongoing construction work. By the same token, the fluctuations should not be directly related to the availability of financial resources as having caused these fluctuations. In fact, the specific costs of dyke reinforcements are dependent on several factors.

Based on developments so far, it appears as though all land protection dykes in Schleswig-Holstein were

The dykes were reinforced at the Alte Koog on Nordstrand in Schleswig-Holstein. By 2016 the first 'Klimadeich' was installed here. (Photo: © Lehnerfoto / Generalplan Küstenschutz SH 2022)

reinforced once after 120 years according to the Klimadeich (climate dyke) principle. Whether the actual interval extends over longer or shorter periods depends, above all, on the human and financial resources made available. Another challenge continues to be the increasing complexity of planning and application procedures. In early February 2022, precisely 60 years after the last flood disaster on the German North Sea coast, the government of Schleswig-Holstein adopted a resolution on the fifth update of the GPK including another safety inspection of land protection dykes. As far as the length of the land protection dykes to be reinforced is concerned, there have been no fundamental changes.

The aim of this indicator is to illustrate a technically appropriate and up-to-date strategic consideration of climate change and associated impacts in the regular updating of the GPK. However, it would not be appropriate to set a concrete target for this indicator, as its development is also strongly influenced by several external framework conditions, such as the budget funding made available by state parliament, Federal government and the EU; it is also important to remember the influence of the stochastic nature of extreme storm surges in this context.

Photo: © Rico Ködder / stock.adobe.com

Fisheries

Impacts of climate change – Impact

On the relevance of the action field

From an economic point of view, sea fisheries (coastal and deep-sea fisheries) as well as freshwater fisheries (lake and river fishing, aquaculture, pond farming and angling) are only regionally of major importance in Germany. Germany's own productive output from deep-sea and freshwater fisheries satisfies a proportion of roughly 11 % of domestic demand. Consequently, imports are of much greater importance to meeting the demand of the German market. As far as the productive output and the generation of revenues are concerned, aquaculture is the most profitable sector. However, in coastal regions deep-sea fishing is a major employer. Nevertheless, deep-sea and inland fisheries such as pond farming are considered cultural heritage and, last not least, of importance to tourism.

Both deep-sea and freshwater fisheries are currently faced with major challenges which include strict regulations in terms of nature conservation. Deep-sea fisheries are faced with the additional problems of unfavourable stock conditions and the loss of fishing areas resulting from Brexit. Climate change and associated changes in living conditions for fish and other aquatic wildlife are adding to the pressure on stocks and enterprises.

In the same way as agriculture and forestry, fisheries – in other words the catching of fish in the wild – are particularly and directly dependent on the availability and regenerability of natural resources. If there are changes – owing to climate change – in the size and location of fish stocks, and if there are changes in the species communities and the food supply, this will directly affect the (production) conditions prevailing in the fishing industry. The nature of pond farming and aquacultures dictates the species composition by itself. However, the species also depend on the availability of sufficient fresh water and other natural resources.

Sustainability at the European and national levels is a fundamental principle of fisheries policy. In this context, the principles refer not only to the long-term conservation of fish stocks but also to maintaining the skills involved in fishing. For example, it is one of the declared objectives of Federal government to conserve Germany's relatively small deep-sea and coastal fisheries[82].

DAS Monitoring –what is happening due to climate change

The water in the seas, rivers, lakes and ponds is warming. Fish species – like all poikilothermic creatures – are very reliant on certain temperature ranges. Consequently, water temperature has a direct influence on the health and size of fish stocks. When a species' thermal optimum is exceeded, fish and other aquatic organisms suffer stress. This makes them more vulnerable to diseases. Where migration is possible, animals will retreat to regions where conditions accord better with their thermal requirements. Migratory movements are also likely to occur when the food sources of fish and other seafood (edible marine invertebrates) shift their location, presumably when smaller species – according to their thermal optimum – migrate north with their predators following. Besides, it is possible for predator and prey to become decoupled or, in technical terms, 'mismatched'. This occurs when, owing to increasing temperatures, the phenology of one of the species concerned is changed so much that the prey is no longer available at the point in time when they are needed by their predator.

Owing to the seas warming (cf. Indicator KM-I-1, p. 100) the habitats of species will shift northwards. This applies in particular to the North Sea – an open sea on the edge of the Atlantic. To date, indigenous species in Germany's fishing regions have been migrating to northern waters while species indigenous to southern waters – so-called lusitanian species (cf. Indicator FI-I-1, p. 122) – have been moving into their habitat.

Species indigenous to the Baltic Sea are unlikely to be able to migrate anywhere else. As a rule, they are adapted to the specific conditions prevailing in this comparatively small enclosed sea. However, here too the increasing water temperatures are affecting stocks by decoupling the food chains. Herring stocks in the western parts of the Baltic Sea are threatened because the species now spawns earlier and its larvae are short of food (cf. Indicator FI-I-2, p. 124). If these stocks were to collapse, the impact would significantly change the entire ecosystem currently prevailing in the Baltic Sea.

As far as watercourses such as rivers are concerned, water warming (cf. Indicator WW-I-10, p. 88) causes migratory movements – prevailing conditions permitting – up-river rather than in a northerly direction. In this case, the losers of climate change are, above all, the psychrophilic species which already now colonise the upper reaches of rivers thus being unable to evade rising temperatures. The same applies to lakes and ponds, where the possibility of migration is per se either low or entirely absent. Thermophilic species, on the other hand, are able to benefit, as exemplified by carp living in Lake Constance (cf. Indicator FI-I-3, p. 126).

As far as inland aquaculture is concerned, there is currently a focus on discussions regarding the impacts of climate change, especially with a view to bottlenecks regarding the availability of water required in the management of pond farming. Adverse effects can also be caused by rising water temperatures, heavy downpours and flooding. Especially the farming of salmonids such as brown trout (Salmo trutta) and char (Salvelinus spp) – which depend on oxygenated water that is free of suspended matter – is subject to potential problems as a result.

Future climate risks – outcomes of KWRA

As mentioned in the findings section of the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7) regarding the action field Fisheries, a high climate risk is expected to arise – with a high degree of certainty – by the middle of this century, and this is likely to cause the decoupling of food relationships in the Baltic Sea. In this case, too, the main focus is on herring. The risk for fisheries may also become high if, by the middle of this century, the distribution of fish species in watercourses changes to a relevant degree. A high climate risk is also forecast – albeit with very low certainty – for the end of this century, owing to stress from pests and diseases in inland water bodies and aquaculture facilities.

According to the KWRA, there is a medium risk for the middle and end of this century in terms of losses to fisheries from an increased migration of thermophilic species to the North Sea thus bringing about changes to the ecosystem. Likewise, the KWRA study argues that there is a medium risk of damage to inland aquaculture operations.

Where do we have gaps in data and knowledge?

The impacts of climate change on fish stocks are currently being researched, and there are numerous questions left to be answered. Individual stocks or regions are being researched with particular intensity, such as herring in the western part of the Baltic Sea. However, to date no comprehensive overview has come to light. The indicators illustrated in the monitoring report are therefore to be seen as exemplifying various effects paths associated with global warming: the shifting of habitats, decoupling of food relationships, and the climate favouring thermophylic species. Given the great variety of marine ecosystems and ecosystems of inland water bodies, the existing illustrations in indicators provide only a partial insight into potential climate change impacts.

As far as the inland realm is concerned, there is so far a lack of nationwide surveys, for instance on the temperature requirements and distribution ranges of species indigenous to German rivers. Likewise, the incidence of fish diseases has not been centrally documented to date. Consequently, it has not been possible either to develop a nationwide indicator on these subjects for inclusion in the current monitoring report. The same applies to damage due to incidents of fish ponds drying out or being flooded. The absence of data in a centralised form – which might indicate climate change impacts on fisheries and aquaculture operations – is to some extent also due to the heavily decentralised and small-scale production structures prevailing in this economic sector.

A similar situation prevails with regard to deep-sea fisheries. Especially in coastal fisheries, the prevailing production structures are mostly very small-scale. Besides, sea fishermen/-women active in the North Sea are less closely tied to particular target species or fishing grounds than their colleagues elsewhere. This is an additional impediment to assessing climate change impacts on the fishing operations concerned.

There is a lack of response indicators in the ‘Fisheries’ action field which is, in part, due to the less than centralised capture and maintenance of data. As far as deep-sea fisheries are concerned, the prevailing strongly politically oriented regulations complicate matters. For example the outcomes of international negotiations – which take place on an annual basis – decide where and how much fish the German fleet is permitted to catch. This makes it difficult to plan a targeted adaptation of fishing operations and thus also to develop a response indicator for the illustration of specific adaptation responses.

What’s being done – some examples

In fisheries, the adaptation to climate change can be implemented in two ways: on one hand increased protection of fish stocks; and on the other, adaptation of enterprises to changed production conditions. For the protection of fish stocks, a distinct reduction of anthropogenic pressures is crucial. This means primarily that fishing activities are curtailed. However, it also means that any other burdens such as the input of pollutants or eutrophication as well as revitalisation measures in inland waters are reduced.

In deep-sea fisheries, fishing quotas dictate where and how much fish is permitted to be caught. The quotas result from a political negotiation process at European level. As mentioned above, the fishing opportunities in the North Sea and the North-East Atlantic are the outcome of international negotiations, above all with the United Kingdom and Norway. On an annual basis, the International Council for the Exploration of the Sea (ICES) publishes scientific recommendations – prior to the determination of fishing quotas – on the question how high these quotas should be for specific stocks in order to safeguard conditions for their sustainable reproduction. Scientists working at the Thünen Institute (TI) of Sea Fisheries and Baltic Sea Fisheries are among the members of the scientific advisory team. Their research involves marine ecosystems, thus allowing these scientists to obtain important insights which form the basis of scientific recommendations. The political responsibility for Germany’s deep-sea fisheries is in the remit of the Federal Ministry of Food and Agriculture (BMEL). Consequently, the BMEL represents Germany in negotiations on fishing quotas. The principle of Maximum Sustainable Yield (MSY) and the precautionary principle have constituted the core objective for fish stock management since 2013. Overall, the sustainability of fisheries has improved, especially in the North-East Atlantic. However, the fact remains that not in all cases the scientific recommendations on the allocation of quotas are adopted; as a result, many fish stocks have so far not been able to recover from the impacts of overfishing. This is true, in particular, for the Black Sea and the Baltic Sea. In addition, there are problems with data deficits and climate change impacts, for instance, regarding the availability of fish species available as prey.

In view of the critical situation regarding Baltic Sea fisheries, the BMEL launched a commission charged with providing a mission statement in November 2020 for the future of Germany’s Baltic Sea fisheries. The commission is tasked to develop a model for sustainable and future-proof Baltic Sea fisheries and to propose concrete measures for the implementation of relevant principles and proposals[83]. The back story to this is the persistently critical stock situation regarding cod and herring and the consequential loss of important fishing opportunities. The BMEL considers that the tradition of Baltic Sea fisheries requires reorientation in order to keep it going. To this end, the TI for Sea Fisheries and Coastal Fisheries in the North Sea and the Baltic Sea is conducting research on the structural change required.

The BMEL addresses deep-sea fisheries, inland fisheries and aquaculture with its ‘Agenda – adaptation of agriculture and forestry as well as fisheries and aquaculture to climate change’ (AMK)[84] and the associated programme of measures[85]. Politically speaking, the latter are in the remit of individual Länder. However, the BMEL intends its Agenda to promote explicitly a closer cooperation between Federal and Länder governments. The Agenda is part and parcel of the DAS Adaptation III Action Plan (APA III); for instance it is promoting new breeding objectives such as the adaptation to higher temperatures or the reduction of health risks arising from changes in pressures from parasites and pathogens. Furthermore, there are ongoing discussions on shading as a potential adaptation measure for inland waters and aquaculture facilities. The adaptation to climate change of deep-sea fisheries and the inland fishing sector is to be supported nationwide by means of the transfer of scientific knowledge to practical applications; and a national information and data portal is to be installed and managed at both Federal and Länder level. It is also proposed to establish a permanent task force with representatives from Federal and Länder authorities in order to review the regulative and funding policy aspects of framework conditions for adaptation to climate change, and to develop proposals regarding implementation.

Given that freshwater fisheries are in the Länder’s remit, several Länder operate scientific institutes which, among other aspects, look into the impacts of climate change on fish stocks in watercourses and also deal with the inland fishing sector in general. However, it must be said that the endeavours to develop a nationwide overview of this subject are still in their infancy. The AMK (see above) may provide a starting point for intensifying cooperation in this field.

Ultimately, it is up to fishing operators on the coast and inland to prepare for any changes in production conditions, to deal with them appropriately and to make adequate in-house decisions for adaptation measures. This may affect fishing methods, timings and (to a limited extent) fishing locations, as well as the target species and the management of aquaculture facilities and pond farming. Nevertheless, it is expected that the public purse will be willing and able to provide favourable framework conditions in this respect.

Photo: © Gieri-Foto / stock.adobe.com

Climate changes relevant to the action field

Air temperatures

Climate change has resulted in air temperatures rising. In the period from 1881 to 2022 temperatures in Germany rose by 1.7 °C thus amounting to 0.6 °C above the global mean (cf. page 19). In the course of the past 50 years, the speed of temperature rise has distinctly increased in Germany: Looking at the entire period from 1881 to 2022 temperatures increased every decade by 0.12 °C, and since 1971 the warming rate of 0.38 °C per decade has resulted in making this value three times as high.

Photo: © Dudarev Mikhail / stock.adobe.com

Impacts of climate change

KM-I-1 Water temperature in the sea

As air temperature rises, sea temperature rises too. The seas are getting warmer thus changing the ecosystem conditions for fish communities and all other sea life. The annual mean surface temperature of the North Sea has been rising by 0.26 °C. The annual values are subject to natural fluctuations.

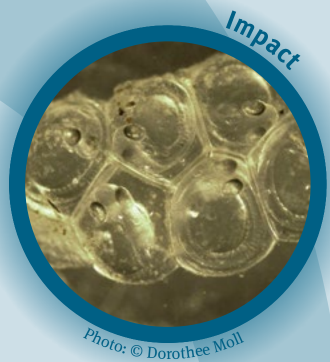


Photo: © Dorothee Moll

FI-I-2 Herring larvae in the Greifswalder Bodden

The increasing water temperatures result in herring spawning earlier in the western part of the Baltic Sea, and their larvae consequently needing external food earlier too. However, this food is not available or not available in sufficient quantities at this early stage thus leading to the starvation of larvae. Consequently, the recruitment success of herring stocks has declined drastically since the late 1990s.

Adaptations – activities and results

Photo: © ferkelraggae/ stock.adobe.com

In order to maintain herring stocks in the western part of the Baltic Sea, it is crucial to reduce fishing pressure on this species and to identify the sources of their natural mortality with the objective, where possible, to minimise the impact of such sources. The more adult fish are able to spawn, the greater their recruitment success, provided that the herrings, in the early stages of their life, are able to benefit from favourable environmental conditions. In past years, the fishing quotas for these stocks have already been reduced significantly. The ICES (see above) had recommended a fishing ban for each year between 2019 and 2023. This recommendation has meanwhile been extended to the duration of 2024.

Thermophilic fish species in North Sea and Baltic Sea

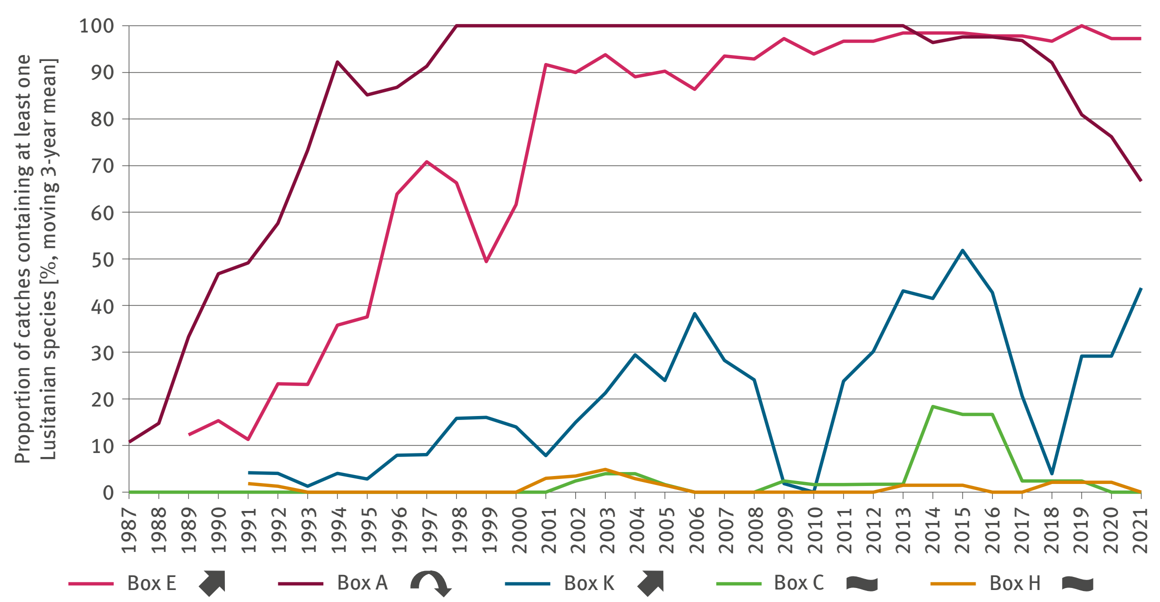
Rising water temperatures (cf. Indicator KM-I-1, p. 100), the changed regimes of sea currents as well as rising CO_2 concentrations in sea water, change the living conditions for all marine organisms. It is worth remembering that water masses in the North Sea do not warm up in the direction of north to south. In fact, the warming process takes place in complex spatial patterns. In the North Sea it has been observed that the stocks of psychrophilic (cold-loving) fish, molluscs and crustaceans have a tendency to move to cooler zones as warming increases. Their organism requires a specific range of temperatures, which is no longer available to them in a warming habitat. Besides, they follow the plants, plankton and other marine organisms they feed on and which – like the fish themselves – prefer water at colder temperatures. At the same time, new species emanating from more southerly seas have encroached on the North Sea.

The brackish water of the Baltic Sea, with its mixture of freshwater and seawater, has given rise to unstable ecological equilibria. The high variability of these environmental conditions provides only few, very tolerant fish species with adequate conditions for living and reproduction. In view of the higher tolerance of the species occurring there, it is to be expected that the consequences of climate change in the Baltic Sea will have less pronounced impacts on species shift than in the North Sea. Nevertheless, changes have been observed already to the productivity of fish stocks in the Baltic Sea (cf. Indicator FI-I-2, p. 124).

Changes in the distribution of fish stocks and in species composition confront marine fisheries with new challenges. In this light, the spatial shift of North Sea fish populations towards cooler zones may entail economic losses to the fishery operators concerned, if new ranges of well-known species become harder to reach thus requiring distinctly greater expenditure. It is hard to predict with any certainty to what extent such economic and ecological effects might be offset against the distribution and abundance of other species. At any rate, under current circumstances, it would not yet be worthwhile for fisheries to target these alternative species.

FI-I-1: Distribution of thermophilic marine species

The effects of climate change on fish stocks are visible already today in the North Sea in terms of the encroachment of southern European thermophilic (lusitanian) species on northern latitudes. In the most southern research areas nearest the German North Sea coast, most catches now turn up at least one southern species. Likewise, the more northerly research areas show an increase too.



Data source: TI für Seefischerei (GSBTS)

An important foundation for future adaptation of fishery management is the accurate observation of the spatial shift in fish stocks and the observation of changes in the species communities. Under the 'German Small-scale Bottom Trawl Survey' (GSBTS), standardised catches are carried out every year in designated areas of the North Sea. The objective is to assess the natural variability of fishing yields for various species of fish and to record medium to long-term changes in the composition of fish communities.

The analysis of catch records relating to more than the past 30 years in five research areas within the German Bight, reveals that more and more frequently thermophilic south-European (lusitanian) species have been identified in catches. Typical representatives of this group of species are, for instance, the tub gurnet (*Chelidonichthys lucerna*), the red mullet (Mullus surmuletus), the yellow sole (*Buglossidium luteum*) and the Mediterranean scaldfish (*Arnoglossus laterna*) as well as the anchovy (*Engraulis encrasicolus*) and the sardine (*Sardina pilchardus*).
In the most southerly fishing zones nearest the German coast (Box A and Box E), every catch – landed over the past decades – turned up at least one of these species, whereas in the late 1980s such catches would have been rare. At the turn of the millennium, Box A already contained some thermophilic species every time.

However, the frequency of such catches decreased in recent years, and distinctly so after 2017. In those areas, the catch frequency relating to the lusitanian species – as represented in the indicator – declined during the period of 2017 to 2021 from almost 100 % to 67 % in 2020. This trend reversal is attributed to the two small flatfish species of yellow sole (*Buglossidium luteum*) and in particular the Mediterranean scaldfish (*Arnoglossus laterna*) occurring more rarely. The underlying reasons are currently being researched.

Beginning in the mid-1990s, a little further north – approximately in the latitude of Denmark's Esbjerg (Box K) – representatives of the lusitanian species appeared, and this subsequently happened with medium frequency, albeit not continuously. Likewise, there have been catches further north, in the eastern North Sea (Box C) sporadically, which suggest a potential distribution occurring also in these areas, that goes hand-in-hand with increasing temperatures.

At the same time as the encroachment of southern European species, a decline in psychrophilic species has been observed. As a case in point, the codfish (*Gadus morhua*) has almost completely disappeared from the southern North Sea which represents the southern edge of the distribution range of codfish. This is not just a consequence of intensive fishing, but – due to the detrimental effect of the seas warming in these latitudes – also of the basic food source of this species of fish and its metabolism.

Especially in the southern and central North Sea, sample catches frequently contain also lusitanian species such as sardines (Mullus surmuletus). (Photo: © André LABETAA / stock.adobe.com)

The increasing warming effect appears to play a major role in the spatial shift of fish stocks. However, apart from climate change, there are other factors, such as commercial fisheries, that are responsible for changes in the spatial distribution of fish stocks. Mild winters have enabled some southern fish species to survive winters and reproduce in the North Sea.

In the Baltic Sea herrings appear to lose their progeny to starvation

Herring fishing has a long tradition in Germany and is of major importance regionally. Particularly in Mecklenburg-Western Pomerania the herring is considered a food staple. On average this species accounts for roughly 70 % of catch contents in this area.[86] Likewise, the Atlantic herring (*Clupea harengus L.*) is internationally a fish species of great economic importance.

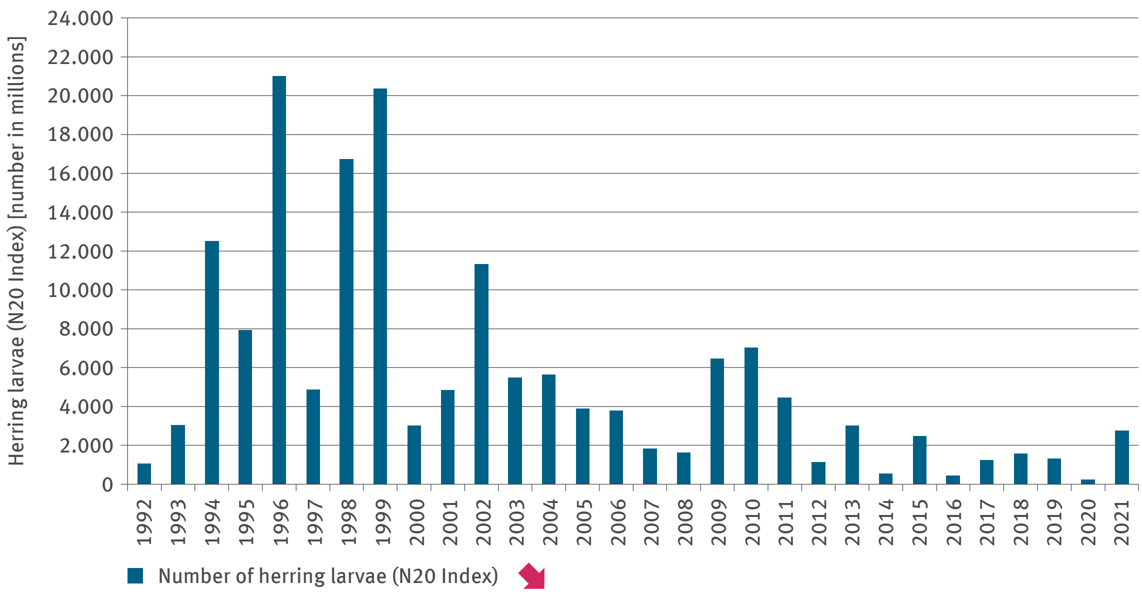
Moreover, the species is of central importance to the Baltic Sea ecosystem: For porpoises, Atlantic grey seals and fish-eating seabirds, the herring is an important food source. Moreover, it has its place in the food chain between plankton – its own food source – and the carnivorous predatory fish. The herring shares this position with only one other fish species – the sprat. If herring stocks in the western part of the Baltic Sea were to collapse, the food chains of this ecosystem would have to depend solely on the stocks of sprat.

Contrary to other stocks, occurring, for instance in the North Sea, herrings in the western part of the Baltic Sea spawn in spring. In order to deposit their eggs, herrings migrate from their wintering grounds in the Oresund, to their spawning grounds. These locations are primarily in the Greifswalder Bodden and the Strelasund – the strait between the island of Rügen and the mainland. This is where the spawn is deposited on certain aquatic plants in shallow water. After hatching the herring larvae first feed on their own yolk sac. Once this has been consumed, they feed on zooplankton, such as the larvae of copepods.

The water temperatures influence herring reproduction in various ways. This stage is also known by the term 'recruitment' in fisheries. On one hand, water temperatures determine the point in time when adult herring leave the Oresund to migrate to their spawning grounds. If a certain water temperature is reached at an earlier time in the year, herring migration will begin earlier. On the other hand, temperatures influence the time of egg deposition

FI-I-2: Herring larvae in the Greifswalder Bodden

Owing to the warmer water in the Baltic Sea, herring spawn earlier in the year in the Greifswalder Bodden. As a result, their larvae depend earlier on external food which at that time is not yet available in sufficient quantities. Since the beginning of the 2000s, herring reproduction has been distinctly less successful than in the 1990s and consequently, herring stocks have been severely affected.



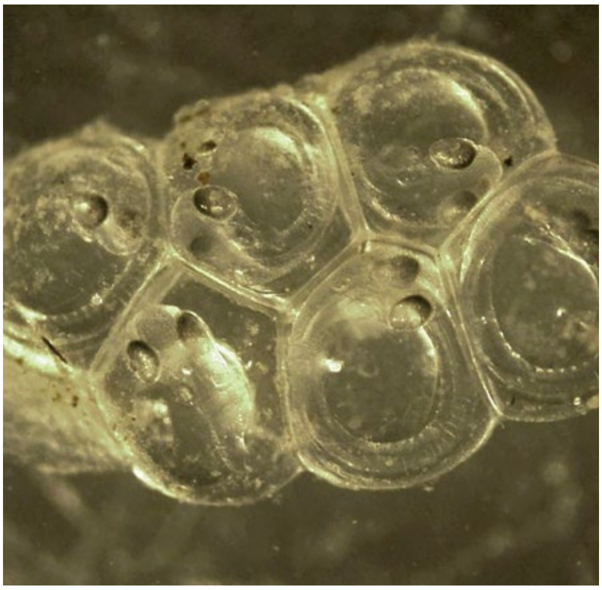
Data source: TI für Ostseefischerei (RHLS) as well as the speed at which the eggs develop. Likewise, herring larvae grow faster in warmer waters owing to their metabolism speeding up. As a result, the larvae depend earlier on external food – zooplankton – and their need of food increases.

Although further research is required in respect of the relationships described, scientists maintain that the herrings' changed phenology leads to the decoupling of their progeny from their food source owing to loss of synchronicity, as the development of zooplankton – according to current findings – is influenced by light rather than warmth. In other words, their food source is not available any earlier in the year than before and therefore not as early as it is required by the herring larvae owing to changed water temperatures. Consequently, having hatched too early plus developing faster, the herring larvae are exposed to starvation[87].

The indicator used for herring recruitment success in the western part of the Baltic Sea is the 'N20 Index'. This index is based on the findings of the Rügen Herring Larvae-Survey (RHLS), which has been conducted by the Thünen-Institute for Baltic Sea Fisheries since 1992, in order to identify the abundance of herring larvae stocks in the Greifswalder Bodden area. In fact, this index represents the modelled total of herring larvae which, by the end of the spawning stage, have reached a body length of 20 mm. Among other things, the index provides an important basis for recommendations submitted by the International Council for the Exploration of the Sea (ICES) regarding fishing quotas for herring in the western part of the Baltic Sea.

Since the early 2000s the number of herring larvae in the Greifswalder Bodden area has declined drastically. Even prior to that, herring progeny had suffered several bad years. This is true for 1992 and 1993 when recruitment was not very successful. The winter of 1991 / 1992 was unusually mild, followed by comparatively warm weather in spring 1992. However, in the 1990s, the impacts of this phenomenon were always short-lived. Nevertheless, larvae numbers have been relatively low – even in the better years – since the beginning of the 2000s.

Apart from the decoupling of herring larvae from their food source owing to asynchronicity – which is seen as the key influential factor responsible for the herring's declining recruitment success – there are other factors influencing herring reproduction in the western part of the Baltic Sea. For example, there has to be an adequate growth of aquatic plants for herring to deposit their spawn. However, the nutrient inputs into the Baltic Sea, caused by human activity, lead to a reproduction boom in algae unsuitable for



In the Greifswalder Bodden area, herring spawn is increasingly exposed to spring storms. When larvae hatch too early, they lack adequate food supplies. (Photo: © Dorothee Moll)

oviposition, thus displacing the plants required for spawning purposes. Suitable aquatic plants grow increasingly in very shallow water. However, spawn is more exposed to spring storms in these locations and thus destroyed more easily. If the intensity of storm surges were to increase as a result of climate change (cf. Indicator KM-I-3, p. 104), this development would be particularly unfavourable. Moreover, owing to nutrient surpluses in the Baltic Sea, there is an increased occurrence of several species of algae which are poisonous to herring eggs. Furthermore, it can be assumed that owing to the shortage of food supply, herring larvae – having to search for food more actively than in the past – are more likely to fall prey to predators.

Last not least, the pressure exerted by fishing activities plays a part. If fewer adult herring were caught, the chances of successful recruitment would be greater. In that light, the fishing quotas for the protection of stocks in the western part of the Baltic Sea were heavily curtailed in recent years, albeit at a later point in time than had been recommended. In the meantime, a ban has been issued regarding the targeted fishing for herring, although there are exceptions in force for the small coastal fisheries provided that passive fishing equipment is used such as set nets and pots. The ICES scientists had recommended fishing bans long ago arguing that these measures would allow stocks to recover within a few years provided fishing pressure remained low thereafter. However, it is unlikely that the size of fish stocks existing in the 1990s will ever be seen again.

Developments in freshwater fisheries still uncertain

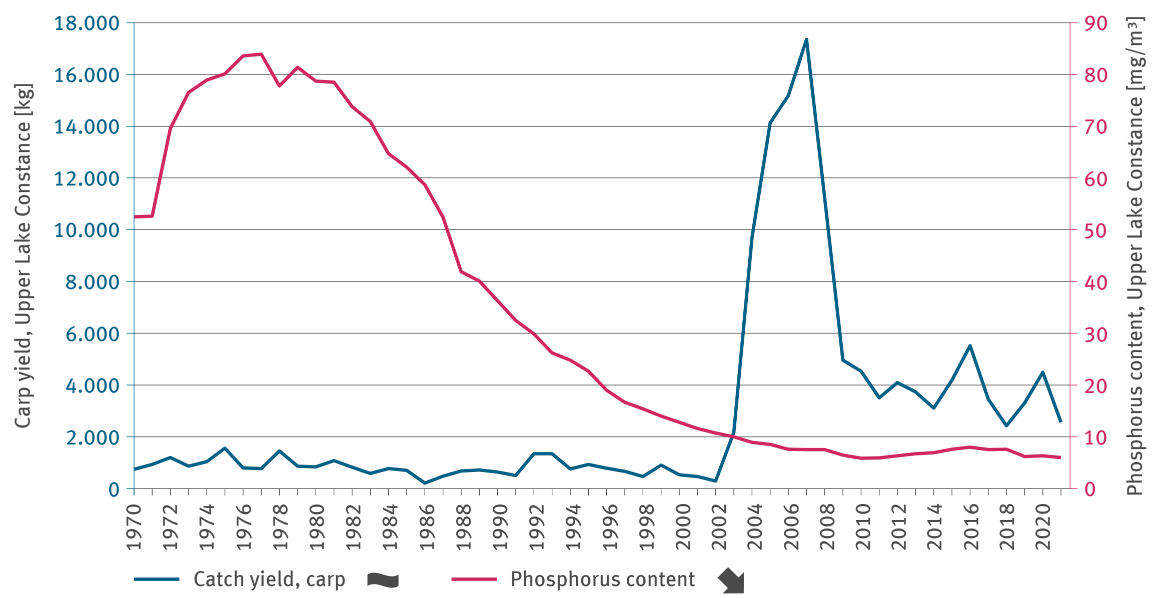
So far, the impacts of climate change are still playing a secondary role compared to other factors impacting freshwater fisheries including aquaculture and pond farming. As far as catch yields in lake and river fisheries are concerned, these are subject to the general conditions governing fishing operations and cost-covering marketing opportunities as well as the availability of selected fish species which are of commercial interest to fisheries. This is why, rather than focusing on the potential impacts of global warming, the discussion is much more intense regarding conflicts arising from increasing tourist exploitation of lakes and rivers, losses of fish to hydropower plants, restrictions on fisheries from conservation-based constraints or changes in the nutrient contents of water bodies. Protracted periods of drought – arising from progressive climate change – pose increasing and clearly visible threats to populations of mussels, crabs and small fish species which occur in small and minute lakes and rivers. The situation is similar in aquaculture, although in this case, the most important influencing factors impacting production are water temperatures affected by climate change, the duration of ice cover on lakes in winter and water flow rates. Basically, fishermen/–women as well as aquaculture operators tend to be more worried about the proliferation of fish diseases and the presence of cormorants which has increased drastically in the course of the past two decades. Nevertheless, there is an increasing number of research projects looking into the impacts of climate change on the fish fauna in Germany's inland waters.

Generally speaking, decentralised production structures and small-scale enterprises predominate in freshwater fisheries including aquaculture. This explains why there is a dearth of nationwide data which would facilitate a systematic identification of climate-related changes regarding shifts in species composition of the fish fauna, not just in lakes and watercourses but also in respect of changes in aquaculture.

As for the future, experts foresee however, that climate change will have increasing influence on fish stocks, yield conditions and proceeds in freshwater fisheries[88]. For example, thermophilic species, distributed by

FI-I-3: Occurrence of thermophilic species in inland waters – case study

Despite a substantial reduction in the phosphorus content of Upper Lake Constance, the hot summer of 2003 led to an explosive increase in carp as a thermophilic species. In particular during spawning and the development of larvae, warm weather conditions provide carp with competitive advantages. The warm summers of subsequent years bestowed record yields on commercial fisheries.



Data source: LAZBW – Fischereiforschungsstelle (catch statistics, commercial fisheries Upper Lake Constance), IGKB (lake monitoring) shipping activities in canals via ballast water, will have better opportunities to become established as water temperatures rise. Thermophilic species such as carp might benefit in terms of competing for habitats, whereas brown trout and other species which can exist only where temperatures are low, are likely to suffer restrictions to their habitats when temperatures rise[89].

Using the example of Lake Constance for which long-term catch statistics exist from commercial fisheries, it is possible to demonstrate that particularly warm years can entail changes in the fish fauna. The upper and to some extent also the lower parts of Lake Constance have in recent years become, and continue to become, nutrient-poor as a result of water pollution control measures. The phosphorus content of Lake Constance, which in the late 1970s and in the early 1980s amounted to more than 80 mg per cubic metre of water is now settling at around 6–8 mg. It is not usually expected that sizeable quantities of carp would exist in such lakes.

Therefore, the surprisingly strong presence of carp in 2003 is obviously due to particularly warm conditions in the spring and summer of that year. In order to ensure successful reproduction, carp are in particular need of warm spring weather every year[90]. Especially in Lake Constance it is rare to have early and prolonged warming of the lake water at the time of carp spawning and subsequent development of carp larvae. In most years, a warm period in early summer is followed by a cooler phase associated with the lake water cooling. Such conditions are not conducive to the emergence of young carp. As a result of favourable conditions caused by higher temperatures prevailing in 2003, subsequent years saw the highest carp yields ever recorded since the compilation of statistics on commercial fisheries in Lake Constance began. Between 1970 and 2003, catch yields for carp oscillated around 800 kg per annum, while in 2007 more than 17,000 kg were caught. Post-2009 catch yields have settled around a distinctly higher level of approximately 4,000 kg annually. By contrast, the warm summers of 2014 and 2015 as well as 2018 and 2019 are reflected in a brief temporary increase in catch statistics. Nevertheless, the steep increase in carp yields experienced at the end of the record summer of 2003 did not materialise again. This may be attributable to various causes. On one hand, carp yield is an indicator which is not just influenced by the availability of this species in Lake Constance. The demand for carp is an equally strong influence that decides whether fishermen / -women target this species of fish. Besides, the number of professional fishermen / -women of Lake Constance has been regressive for years. In 2002, 152 fishing licences[91] were issued, whereas in 2021 the number had dwindled to 66 deep-sea and 17 nearshore licences[92]. for fishing with set nets and pots. The carp yield achieved by professional fishing, as illustrated in the indicator, has been falling in parallel with the number of active fishermen / -women. Furthermore, there are other factors determining the survival chances of carp hatching in warm summers and consequently the carp yield in future years, such as the weather pattern in a subsequent winter and the number of cormorants – a natural predator of carp. Nevertheless, carp is considered a beneficiary of climate change.

When spring and summer seasons are warm, the fishermen/-women of Lake Constance benefit from the thermophilic carp reproducing particularly well. (Photo: © anonym)

Photo: © maxbelchenko / stock.adobe.com

Soil

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

Soils fulfil diverse tasks that are important for ecosystems and human beings. They provide biotopes and habitats where plants, animals and microorganisms live. In particular soils that are nutrient-poor, very wet or very dry, harbour rare species communities worth conserving. It is also true that soils are per se highly complex ecosystems. The amount of living organisms in just a handful of soil easily outnumbers the world's entire human population. In a landscape's water balance, soils play a preeminent role, as they store and filter water in considerable quantities. This makes them natural buffers warding off drought and floodwater hazards while providing us with clean groundwater. Fertile soils are essential for successful agricultural production. Likewise, healthy soils are a basic requirement for producing healthy victuals. In Germany, all these important soil functions have been protected by law since 1999 when the Federal Soil Protection Act (BBodSchG) was passed.

Climate change influences the soil properties, and consequently also the soil's diverse uses. Furthermore, there are interactions with challenges posed by climate change, given that soils are the foremost terrestrial carbon sink on earth. At the global scale, soils currently store roughly 1,460 billion tonnes of carbon. Hence, there is an equally high risk that – when destroyed or used unsustainably – soils become sources of CO_2 emissions. As climate change progresses, with dry and wet periods becoming more frequent and intensifying, it follows that the soils' role as a buffer for water balance is gaining more and more importance.

There are numerous interfaces between the DAS 'soil' action field with other DAS action fields, such as 'Agriculture', 'Woodland and Forestry' as well as 'Water balance and water management' which are referenced below.

DAS Monitoring –what is happening due to climate change

The climate influences numerous soil processes including a soil's formation, its properties and its functions. Soil processes such as weathering, formation of minerals, decomposition, development of humus and structure are strongly dependent on temperatures and availability of water. The diversity of soils is great, and just as diverse are the impacts of climate change.

Where climate change alters precipitation and temperature regimes, this in turn has a direct influence on the water balance of the soils (cf. Indicators BO-I-1, p. 134, and BO-I-2, p. 135), the replenishment of groundwater (cf. Indicator WW-I-2, p. 72) and the temperature scenario (cf. Indicator BO-I-4, p. 138) in the soils affected. Consequently, the mineral balance will also change. Changes in the soil are bound to affect the type of soil utilisation. Any restrictions regarding the availability of soil water will lead to yield losses in agriculture (cf. Indicator LW-I-2, p. 152) and to deterioration of forest condition (cf. Indicator FW-I-3, p. 178); under extreme conditions, such restrictions can also result in more damaged timber accruing in a forestry context (cf. Indicator FW-I-5, p. 180).

Too much water also has adverse effects on soils. Moreover, more frequent and more violent heavy rain events can favour erosion (cf. Indicator BO-I-3, p. 136). Such developments in turn lead to a loss of soil fertility and a decrease in water retention and material storage capacity as typically, this results in the topsoil – rich in humus and nutrients – being removed. Once soils become unable to absorb major volumes of precipitation, this will favour the formation of floodwater (cf. Indicator WW-I-4, p. 76) along with all its associated consequences.

Future climate risks – outcomes of KWRA

According to the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7), the risk of soil erosion by water or wind and the risk threatening the productive function of soils were estimated to become high as soon as the middle of this century. Tied in closely with this, the risks to soil biology, the balance of soil matter and consequently soil fertility, were estimated to become medium by the middle of the century. By contrast, a medium risk for a change in the soils' filtration and buffering functions is not expected to arise until the end of the century.

With a view to the soil water regime, the 2021 KWRA analysis has depicted the following risks: The increase in summer droughts will in future lead to lower seep rates at that time of year. Heavy rain events in summer frequently do not contribute to the formation of seep owing to precipitation running off the surface. Against this background, the replenishment of groundwater occurs predominantly in late autumn and winter, in other words, outside the growth period. This fact increases the risk that inadvertently, the seep transports unused nutrients down into the aquifer. A high risk of water shortages in the soil and a change regarding seep is expected to arise as early as the mid-century. Waterlogging and more frequent landslides and mudslides are regarded as a medium risk expected to arise by the middle of the century.

In assessing the climate risks for the soil action field, the low certainties mentioned almost throughout the 2021 KWRA analysis were adopted for this action field. Particularly low is the certainty in respect of assessing the soil biology. Substantial research would be required to permit making any statements regarding soil biology on a technically reliable basis. Somewhat higher, that is to say medium (within a scale of low- medium – high) is the certainty in assessing soil erosion.

Where do we have gaps in data and knowledge?

Compared to the previous – 2019 – Monitoring Report, the indicator set used in the present – 2023 – Monitoring Report, has been extended and further expanded in terms of contents. Nevertheless, as in the past, it has not been possible to incorporate indicators for certain relevant themes.

As far as the case study on soil erosion is concerned – illustrated in the 2015 and 2019 Monitoring Reports – it was possible to develop the 2023 Monitoring Report further, so that the illustrations apply nationwide. However, as before, it was possible to illustrate the erosion risk only in terms of rainfall erosivity (R-factor). In respect of other effects of climate change influencing the erosion scenario, such as changes in management procedures, the spectrum of crop species or the seasonal distribution of erosive precipitation, this indicator does not permit making any statements. So far, there is no contiguously representative erosion monitoring available, owing to the costs and also the fact that consistently numerous (methodological) issues remain unresolved in Germany. It is, above all, the extreme variability in terms of space and time regarding the erosion scenario, that makes representative surveys difficult. Wind erosion has so far not been included as a theme in the Monitoring Report. Moreover, there are some major uncertainties regarding the potential relationships with climate change. While it is true that, as climate change progresses, the dry condition of topsoils has come to exist more and more frequently, any wind-related projections are still fraught with uncertainty.

Soil biology is influenced significantly by temperature, water balance and soil carbon. It is therefore assumed that – in terms of biological activity – there is a close connection between the composition of soil flora or fauna and climate change. However, the complexity of relationships and influences of land use and land management is high. Hence, it has not been possible to date to propose any suitable indicators. Within the framework of a UBA project and with a view to the new European Soil Monitoring Law, soil-related indicators are currently being developed for the purpose of reporting on climate adaptation and climate protection. In this context, a particular focus is dedicated to soil biology.

It is true to say that there is a DAS Monitoring indicator (cf. Indicator BO-I-1, p. 134). However, that indicator is based on model-derived data. The indicator referring to soil water in forest soils (cf. Indicator BO-I-2, p. 135) is just a case study. There is a problem insofar as the data collection surveys conducted in the Länder of the Federal Republic have so far not been harmonised sufficiently.

So far, climate-change related alterations in the material balance of soils have not yet been covered as a theme in DAS Monitoring. It is important to note that, apart from climate change – especially in respect of soils used for agricultural and forestry purposes – there are many other influential factors. Hence, it has not been possible so far, to establish any straight-forward causal relationships. Without the benefit of some additional scientific insights, the development of meaningful indicators remains impossible.

As before, it is still a major challenge to assess soil data at the nationwide scale. Although there are several nationwide observation programmes such as the Soil Monitoring Sites (BDF) and the Soil Condition Survey for Forestry and Agriculture (BZE), the sampling and analytical methods employed in the Länder still differ despite efforts towards harmonisation. This is because the Länder are keen on maintaining, as much as possible, the stability of their time-series related surveys. Against the background of the problematic data situation, the UBA commissioned several research projects in recent years, with the aim to check the availability of soil-related data for nationwide descriptions of soil condition and any associated changes. As a result, a concept was presented in 2022 in respect of a working group (Klimafolgen-Bodenmonitoring-Verbund) with the remit to lay the foundations for establishing a centre for monitoring soil in terms of climate change impacts nationwide. This is intended to consolidate expertise in the field of soil issues across different government departments, and to ensure that national and international reporting obligations regarding soil can be met in the future with nationally harmonised, quality-assured soil information. In parallel with setting up the soil monitoring centre, work is ongoing regarding the further development of nationwide indicators.

What's being done – some examples

In terms of surface area, agriculture constitutes the most widespread intervention in natural soil structures, because more than half of Germany's surface terrain is used agriculturally. As far as strengthening the resilience of soils is concerned, agriculture therefore plays a key role. In terms of adapting the agricultural use of soil, agricultural funding support is an important lever. With the 'Greening' of the European Direct Payments Regulation, which was in force from 2014 to 2022, support for agricultural enterprises under the Common Agricultural Policy (CAP) was made conditional on those enterprises having to contribute to environmental and climate protection. The Greening stipulations were also used to promote soil protection measures, such as the cultivation of catch crops. The previous Greening stipulations and the general 'Cross Compliance' obligations were consolidated to form the new 'conditionality' as of 2023. This new conditionality is now composed of two parts – the Statutory Management Requirements (GAB) and the compliance with standards for the maintenance of good agricultural and ecological condition (GLÖZ Standards). GLÖZ, on the other hand, encompasses further and, in part, stricter measures which, among other things, are intended to improve soil protection and the resilience of soils. Part of this is, for instance, the conservation of permanent grassland (cf. Indicator BO-R-2, p. 142) and the safeguarding of minimum soil cover at the most sensitive times of the year, which includes the cultivation of catch crops. Both measures provide, above all, protection from erosion while also supporting humus production (cf. Indicator BO-R-1, p. 140). Moreover, the EU member states are obliged, under the new CAP funding period, to voluntarily provide eco-regulations (ER); any beneficiary of this funding must invest part of their direct payments in these measures. The ER catalogue also includes measures intended to improve soil protection while contributing to climate change adaptation.

In principle, forests (including woodlands) are regarded as a soil-protecting type of use. On sites that are particularly at risk from erosion or from becoming overgrown, forests can be designated as soil protection woodlands or forests in order to safeguard permanent soil cover as well as root penetration. That notwithstanding, soil protection is ascribed increasing importance in respect of forest cultivation. The funding programme 'Climate-adapted Forest management' launched in 2022 by the BMEL also provides funding for measures targeting soil protection. This includes providing greater skid trail spacings to limit soil compaction, as well as forest enhancement by means of deadwood for humic enrichment (cf. Indicator FW-R-3, p. 190).

Soils can fulfil their important functions – in terms of ecosystems and in the interest of adaptation to climate change such as water storage and landscape cooling – only provided they are protected from overbuilding and sealing of surfaces (cf. Indicator RO-R-5, p. 310). This is the reason why a reduction in land use conversion is not just a core sustainability objective, but also an objective pertaining to climate change adaptation. The German Sustainability Strategy updated by the Federal government in 2021[93] now intends for the daily increase in the conversion to residential and transport terrain to be reduced to less than 30 ha per day by 2030. The Integrated Environment Programme[94] launched by BMUB in 2016, goes beyond this objective by setting 20 ha per day as an interim target for 2030, from the perspective that by 2050 the transition to circular land use will be completed, thus reducing the conversion of land use to net zero. However, to fulfil this objective will require substantially greater endeavours.

The Federal / Länder Working Group Soil Protection (LABO) coordinates the Länder's concerns in respect of soil protection while also dealing with issues regarding climate change and its impacts on soil. With several position papers, LABO has taken a stand on important challenges, such as in 2017 with the position paper entitled 'Significance and protection of peat soils'[95] and in 2021 – jointly with LAWA – with the position paper 'Degradation of soils – soil erosion by water'[96].

Climate changes relevant to the action field

Precipitation and drought periods

Although the mean precipitation amounts have changed little over recent years, there have been repeated phases regionally of extreme water shortages as well as violent heavy-rain events. Soils can dry out whenever the evaporation in summer increases as a result of high temperatures. Since 2003 there have been particularly frequent incidents of dry phases in summer. As far as heavy-rain events are concerned, high spatial and temporal variability make statistically backed trend statements difficult. However, the general understanding is that heavy rain events have increased as a result of climate change. Especially in warm years, extreme convective precipitation events can occur repeatedly (cf. page 24).

Impacts of climate change

BO-I-1 Soil water in agriculturally used soils

There are critical development phases in the cultivation of agricultural crops which will incur yield losses, if the crops are subject to water shortages during those phases. DWD modelling has demonstrated that the amount of water available to plants during their growth period has diminished in the past 60 years; the trend observed is significant. The decline has been conspicuous above all in the years that have passed since the turn of the millennium.

BO-I-3 Rainfall erosivity

Given the presumably increasing frequency and intensity of heavy rain events due to climate change, the risk of soil erosion by water is rising. Especially in cases where heavy rain falls on to bare or very dry soils, unable to seep through, this situation can rapidly trigger soil removal processes. In particular, erosion leads to the removal of topsoil, which plays an important role regarding the water retention capacity and the nutrient balance of soils. It takes lengthy and complex processes for this topsoil to be replenished. Erosion weakens the resilience of soils towards climate change while strengthening the associated adverse impacts.

Adaptations – activities and results

BO-R-2 Permanent grassland terrain

Under permanent grassland, agriculturally used soils are protected relatively well from adverse impacts of climate change such as erosion or the decomposition of humus. At the same time, moist grassland in particular, helps to stabilise a landscape’s water balance. Since 2013, there has been a precept in force nationwide requiring the conservation of grassland. According to this precept, it is not permitted to plough up grassland unless new grassland is created elsewhere in the territory concerned. Up until 2013 the grassland terrain was diminishing continuously and significantly. After 2013 this trend was reversed. Since then, the grassland terrain and its share of the terrain used for agricultural purposes has been increasing very slowly.

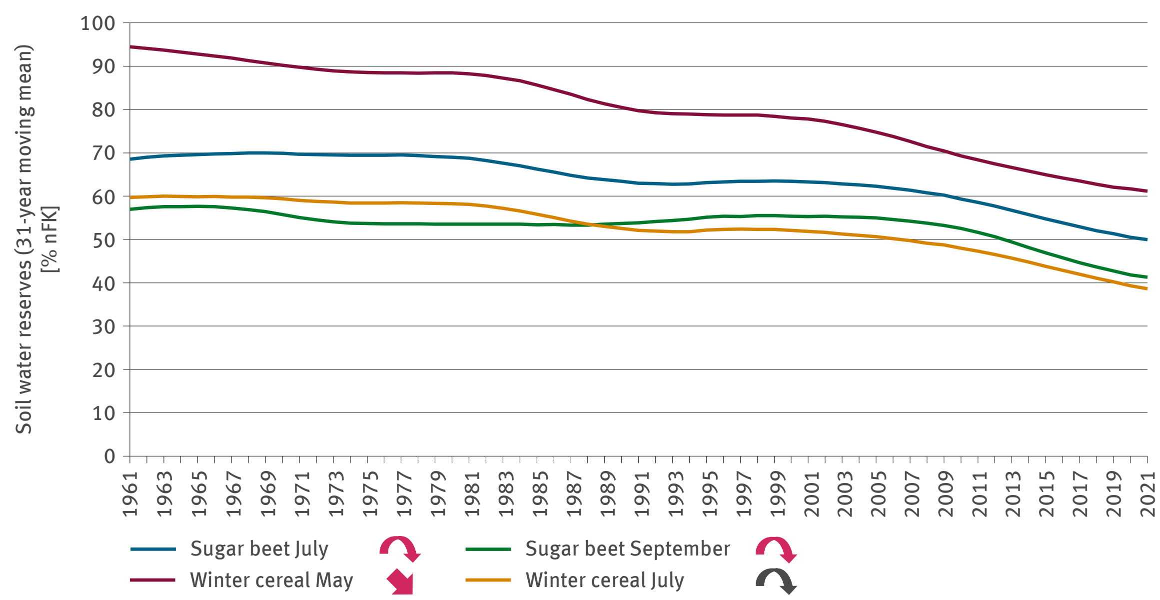
Soil water – diminishing availability

Precipitation and temperature are important factors in the process of soil formation; they have direct influence on both the water balance and mineral balance of the soil. If precipitation scenarios change as a function of climate change, this will have consequences for soils, no matter whether soils are used for agricultural or forestry purposes, or whether urban soils or soils with near-natural vegetation are concerned. It is expected that, depending on soil properties, different amounts of seepage are likely to diminish in summer owing to greater evaporation, whereas they are expected to increase in winter owing to additional precipitation. On one hand, this development impacts groundwater replenishment (cf. Indicator WW-I-2, p. 72). On the other, the actual amount of seepage governs the removal of minerals such as nitrate from the soil. High precipitation levels in winter, especially when the precipitation falls on agricultural land with sparse vegetation cover, can result in repeated leaching of minerals. If soils dry up more strongly in the summer months, their water conductivity diminishes. This process also diminishes the infiltration speed. Increased surface discharge consequently leads to the loss of water from the landscape at the same time as increasing the risks of flash floods and erosion (cf. Indicator BO-I-3, p. 136). Furthermore, dry soils and dry vegetation increase the hazard of vegetation fires. In cases where there is a lot of dry litter in a forest, a fire can start even in a scenario – meteorologically speaking – of a medium forest fire hazard (cf. Indicator FW-I-8, p. 184).

The soil moisture is stated in the indicator as a percentage of usable field capacity (nFK). This variable identifies the water reserves in a soil which are available for use by plants. Where soil moisture drops below a value of 50 % nFK owing to low precipitation and high evaporation levels, drought stress is bound to arise affecting numerous plant species in these circumstances. Where soil water reserves drop below 40 % nFK, this situation is assumed to be a medium to high drought stress hazard, whilst below 20 % this is assumed to be a very high to extremely high drought stress hazard. Values in excess of 100 % nFK will occur in cases when there is more water in the soil than it can hold. This surplus water can subsequently seep away, run off laterally or evaporate.

BO-I-1: Soil water in agriculturally used soils

The availability of soil water influences plant development in a fundamental way. In farmland cultivation both drought stress and waterlogging during critical development phases can adversely affect yields. The soil moisture modelled for selected arable crops during the growth period has diminished, indicating a significantly falling trend. The decline has been particularly conspicuous during the years since the turn of the millennium.

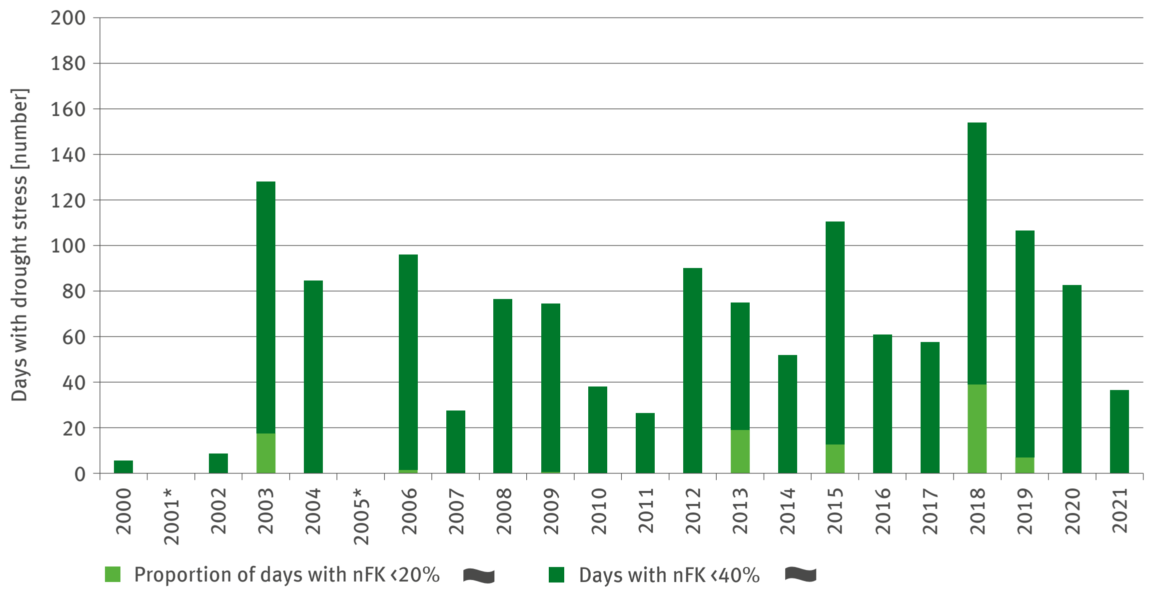


Data source: DWD (data from DWD Bodenfeuchteviewer)

For the development of agricultural crops, the availability of water in the soil is a highly relevant, influential variable. When in the spring and summer months, periods of high temperature and low precipitation coincide with increased water demand by vegetation, it can occur that the soil water available to plants is soon exhausted. For annual crops (in particular cereal species) that develop their flowers mostly in the months of April till June when they grow fastest, drought stress in this phase is particularly critical. In respect of crops such as sugar beet, which remain in the field for longer periods, lack of soil humidity usually has adverse effects even as late as September. Sugar beet – as indeed other root vegetables – is able to increase in biomass until shortly before harvest, provided the crop can draw on ample water supplies. By contrast, a poor water supply in July is less serious in respect of cereal crops, as this is the time when cereal ripens. Excessively high soil moisture in this phase might even have adverse effects on yields, partly because excessively high-water contents might limit the use of vehicles on cultivated ground, thus making timely harvesting impossible. The DWD uses models of soil moisture in respect of agricultural crops on the basis of a 1 km x 1 km grid, taking into account the soil information from the Soil Overview Map (BÜK) 1000. This is done on the basis of interpolated meteorological data and the observed development status of the plants, prevailing at the time. Given the regional differences in soil properties and precipitation scenarios, nationwide observations of mean values should be interpreted with caution. Nevertheless, it is possible to discern longer-term development trends. The time series so far demonstrates that the models indicate – both for wheat and sugar beet – significantly diminishing availability of water during the growth period[97]. The measuring data from intensive monitoring in the forest, in this case from a case study at Bavarian Forest climate stations, do not indicate a trend. The massive drought stress which in 2018 prevailed also in Bavarian forests, entailed severe forest damage (cf. Indicator FW-I-3, p. 178). In agriculture, it is possible to respond to drought by means of cultivating drought-tolerant species and varieties (cf. Indicator LW-R-2, p. 160), by adapted (for instance ploughless) soil tillage or by irrigation (cf. Indicator LW-R-6, p. 166) In forestry, by comparison, the composition of tree species is the most important lever.

BO-I-2: Soil water in forest soils – case study

Measurements taken at climate stations in Bavarian forests demonstrate that years with precipitation deficits lead to persistent phases of drought stress. In 2018 extreme drought stress was measured for almost 40 years in terms of the five-year mean for stations distributed across Bavaria. During most of the growth period, the soils were undersupplied with water. In the precipitation-rich year of 2021, the situation eased.



* no data

Data source: TI für Waldökosysteme (LEVEL II monitoring network)

Climate change increases the risk of soil loss

Soils usable today is the result of thousands of years of development, because the formation of a soil layer of just one centimetre thickness, arising from the weathering of rock and the decomposition of organic matter, takes at least a hundred years. Soil losses, for instance resulting from erosion by water or wind, are therefore usually irreplaceable. They constitute severe ecological and economic damage.

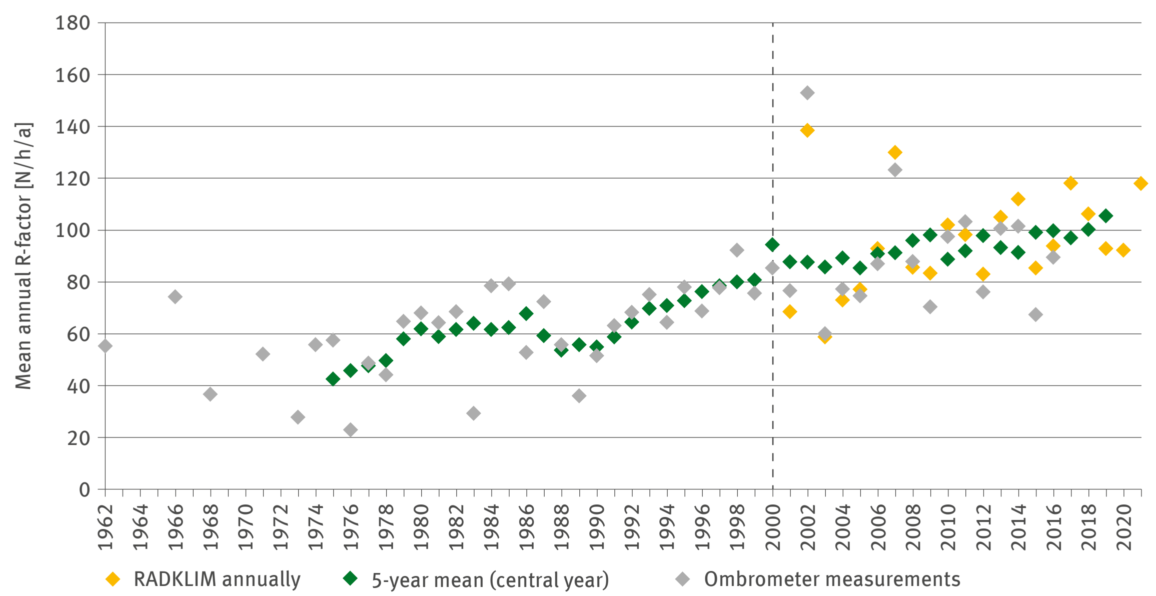
The impacts of climate change increase the risk of soil loss. Erosive, extreme weather events as well as heavy rain events have been occurring more frequently and with greater intensity. Moreover, soil loss can be favoured by increasing precipitation in winter. When winter precipitation increasingly falls as rain, and when this rain falls on patchy vegetation cover on soils under agricultural use, the outcome may involve substantial soil losses. Furthermore, temperature increases lead to shifts in the development phases of plants, including agricultural crops (cf. Indicator LW-I-1, p. 150). Presumably, any resulting changes in ground cover are likely to increase the risk of erosion even more. Gaps in the vegetation – apt to assist erosion – and desiccated topsoil are to be expected as a result of increased drought periods in spring and summer. This development also increases the risk of wind erosion. On the predominantly sandy soils in northern Länder near the coast, wind is one of the foremost causes of erosion.

Primarily, soil erosion signifies a reduction in soil depth and thus in the usable field capacity (cf. Indicators BO-I-1, p. 134, and BO-I-2, p. 135) It also signifies the loss of topsoil particularly rich in nutrients and humus. Eroded soil material is shifted to lower lying areas including housing estates and transport routes. In those locations the material inputs lead to siltation (colmation) thus producing undesirable pollution of water bodies with nutrients and pollutants. Such developments counteract the efforts to improve the condition of water in the spirit of the European Water Framework Directive (WWRL).

Erosion monitoring that would cover the whole of Germany contiguously is not yet available. So far, soil erosion monitoring conducted in existing BDF is the only measuring

BO-I-3: Rainfall erosivity

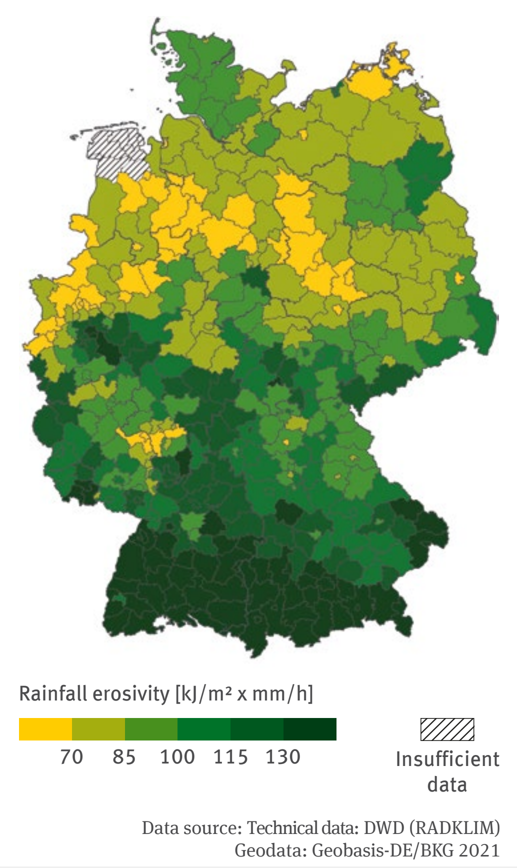
In Germany, rainfall erosivity doubled over the past 50 years. High levels of rainfall intensity increase the risk of soil loss. In years with violent heavy rainfall events such as 2002 or latterly 2021, the mean annual R-factors were particularly high. Targeted anti-erosion measures taken on vulnerable soils and on steeply sloping terrain can help to reduce soil loss even where high rainfall erosivity prevails.



Data source: literature research up until 2000 (Auerswald et al. 2019a and b), from 2001 onwards DWD (RADKLIM) approach to cover all of Germany's Länder for the purpose of long-term data collection on soil erosion nationwide. However, neither the procedures nor the intensity involved in those surveys have been adopting a homogeneous approach. Consequently, there is a lack of representative monitoring data on the actual erosion scenario. However, it is possible to calculate rainfall erosivity (the R-factor) on the basis of ombrometer and radar data thus facilitating an estimate of the risk potential. The R-factor is an input parameter contained in ABAG, the Allgemeine Bodenabtragsgleichung (General Soil Erosion Equation) which is used to illustrate climate-relevant influences on erosion. Rainfall erosivity results from the volume and intensity of erosive rain. It describes the ability of precipitation to detach particles from their aggregates (splash effect) by means of the rain's kinetic energy, thus displacing these particles as a result of surface discharge.

The indicator shows the mean annual R-factor for Germany: from 1962 to 2016 on the basis of ombrometer data[98], from 2001 to 2021, additionally, on the basis of RADKLIM, radar-based precipitation data[99]. As is typical of time series characterised by extreme events, the development of the mean annual R-factors in Germany indicates a fluctuating course. Both the ombrometer data and the radar data indicate peak values of rainfall erosivity for the years of 2002 and 2007. Especially the year of 2002 was characterised by heavy rainfall events. In summer, violent precipitation led to severe flooding in eastern and western Germany. The year of 2021 had, according to RADKLIM data, the fourth highest mean rainfall erosivity so far. In that year, one of the most severe flood disasters in Germany's history occurred in North Rhine-Westphalia and in the Rhineland-Palatinate as a result of heavy rainfall. The moving 5-year mean demonstrates that over the past 50 years, the R-factor has increased distinctly. In 2019, the 5-year annual mean was roughly 2.5 times higher than in 1975.

In Germany, rainfall erosivity is essentially in line with the distribution of precipitation. As far as the mean of 2017 to 2021 is concerned, the lowest R-values (RADKLIM radar data) were centred on Saxony-Anhalt and Lower Saxony, on North Rhine-Westphalia and on the coast of Mecklenburg-Western Pomerania. In the North German Plain, erosive precipitation volumes generally occur less frequently than in central Germany and the south of the country where, in orographical terms, the topography is more differentiated thus favouring elevating and convective processes in the atmosphere. Accordingly, the highest R-factor values occur in the ridges of upland areas and in the Alpine region.



Rainfall erosivity – district mean for 2017-2021

In Germany, the rainfall erosivity factor is essentially in line with the distribution of precipitation, with higher values indicated for the uplands and the Alpine region.

Apart from precipitation, the slope of the terrain, the soil properties, and especially the ground cover play an important role in the erosion scenarios: Types of crops with a particularly high potential for soil loss include potatoes, maize and sugar beet as well as numerous special crops and vineyards on steep slopes. There is a diverse range of measures available for preventing erosion, in particular in arable fields. The options range from site-adapted crop rotation which ensures continuous ground cover for the entire year, to nurse crops and the use of mulches, to adapting the management direction as well as practising permanently ploughless, conservation-oriented soil tillage for the purpose of maintaining a natural soil structure and in order to achieve particularly thorough soil cover by leaving protective plant residues on the ground.

Soil temperature on the rise

In the same way as air temperature, soil temperature is rising too. This scenario has effects on the chemical and biological processes in the soil and on soil development. The chemical weathering of rock is accelerated at high temperatures, because the temperature influences the speed of reactions as well as the chemical solution equilibria. The decomposition of organic matter also accelerates because soil organisms are more active as a result.

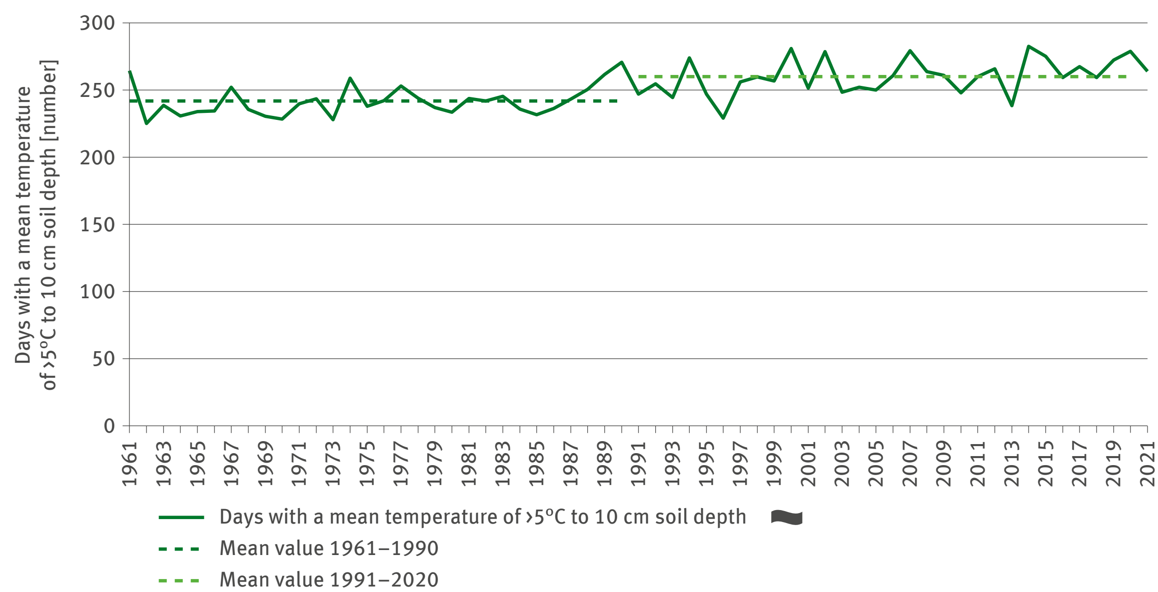
Furthermore, the soil temperature is a major factor in determining the length of the growth period and the mobilisation of nutrients in the soil. Whenever a daily mean temperature of 5 °C in the topsoil is exceeded – more precisely, down to a depth of between 5 and 10 centimetres – this will trigger the mobilisation of nutrients and the development of most plant species. Once this temperature threshold is undercut, the development process will come to a standstill. In Germany's lowlands, soil temperatures of more than 5 °C prevail roughly between the beginning of March until the end of November. There are regional differences depending on altitude and geographical latitude. In the course of a year, values of 5 °C are typically first exceeded in southwest Germany. Subsequently, values of 5 °C and more in the soil gradually begin to be reached also in a north-easterly direction.

A prerequisite for temperature-driven processes in terms of the conversion and displacement of matter is the sufficient supply of water in the soils (cf. Indicators BO-I-1, p. 134, and BO-I-2, p. 135). If conditions are too dry, many chemical processes and plant growth are inhibited. The same applies when soils are saturated with water and anaerobic conditions prevail – in other words, when either the concentration of oxygen is too low or there is none at all.

Given that soil temperature is directly dependent on sun irradiation, soil temperature usually moves in line with the daily or annual course of the radiation regime, albeit with certain temporal delays. It must be noted, however, that there can be major differences between air temperature and soil temperature. For instance, in comparatively dry conditions – contrary to air – bare soil can heat up more stronglyw. By contrast, moist soils warm

BO-I-4: Temperature in the topsoil

At a soil temperature of greater than 5 °C in the topsoil (daily mean), the nutrient mobilisation and the development of most plant species set in, whereas at 5 °C and less, these processes revert to a standstill. The number of days with a soil temperature greater than 5 °C has increased significantly over the past 60 years. In particular, an early onset of a warm spring and a warm autumn, lead to high indicator values.



Data source: DWD (DWD measuring network) up more slowly and can impart a cooling effect to their environment. Owing to their higher reflection capacity, light-coloured soils do not warm up very strongly, whereas in dark-coloured soils, temperatures can rise quickly and strongly. Soils covered with vegetation warm up with some delay, and they also cool off with delay.

The fact that soil temperatures rise in line with climate change also entails impacts on the humus regime (cf. Indicator BO-R-1, p. 140). A warmer soil temperature can further humus decomposition on account of the resulting high biological activity. This decomposition has adverse effects, not just on the water-storage capacity of soils and their ability to bind nutrients; it also reduces the structural stability of soils, and – given the risk of coinciding (rain-related) erosion – this scenario is problematic (cf. Indicator BO-I-3, p. 136).

Soil temperature is the foremost driver of soil respiration. An increase in soil respiration can lead to an additional release of CO_2 from the soils thus resulting in positive feedback and further accelerating global warming. However, temperature rise can also favour the sequestration of atmospheric carbon in the soil. This is because at higher temperatures with associated longer growth periods, plants produce more biomass by absorbing CO_2 from the atmosphere – provided there is adequate availability of water. As a result, more carbon is sequestered in the soil. In this way – contrary to the humus decomposition outlined above – it is possible for humus enrichment to occur. These complex – and in some respects counteractive – developments demonstrate that a change in soil temperature per se is not a suitable basis for drawing straightforward conclusions in respect of potential changes in soil processes.

The measuring data underlying the indicator emanate from standardised measuring fields operated by DWD. These fields are continuously kept free of vegetation. It is therefore not possible to apply or transfer these measuring results directly to soil conditions prevailing on land in agricultural use or even to forest soils. The indicator illustrates the number of days on which the threshold of 5 °C of the daily mean temperature in topsoil was exceeded. The nationwide value represents the mean of measurements recorded at 15 stations spread geographically across Germany. In the course of the past 60 years, this nationwide mean has increased significantly. While the mean of the years 1961 to 1990 amounted to 242 days with greater than 5 °C, the mean for the period of 1990 to 2020 amounted to 260 days already. However, there is no statistical change point in the time series. The increase proceeded relatively continuously. However, the values clearly fluctuated from year to year. High values occurred above all in cases when autumn remained warm and dry for a long time (cf. Indicator BD-I-1, p. 202) and the warmth was retained in the soil for a lengthy period. High air temperature in summer is of no consequence regarding the course of the indicator. This is demonstrated by the year of 2018. In that year, the highest mean air temperature to date was recorded – a value of 10.5 °C. However, the number of days with a soil temperature mean of greater than 5 °C, amounting to 259 days, was comparatively low. This is due to the fact that the winter of 2017 / 2018 was characterised by comparatively high precipitation levels. In other words, the soils started out with high water contents in spring and consequently required a long time to warm up. By contrast, the year of 2020 produced distinctly higher indicator values. Although the mean value for winter 2019 / 2020 in Germany was also very wet, it was nevertheless the second-warmest winter since records began in 1881. That winter was followed by an extremely sunny spring which was far too dry. This, in turn, led to rapid warming of the soil. Consequently, the number of days with a soil temperature mean of greater than 5 °C was only higher by 20 days compared to 2018.

With soil temperatures rising beyond 5 °C, plants begin to sprout and grow. (Photo: © sandra zuerlein / stock.adobe.com)

As far as the planning of agricultural management is concerned, the warming of the soil in spring is of major importance, as it is a crucial factor for scheduling the optimal point in time when to sow / drill summer crops (cf. Indicator LW-R-1, p. 158).

Humus strengthens soil resilience

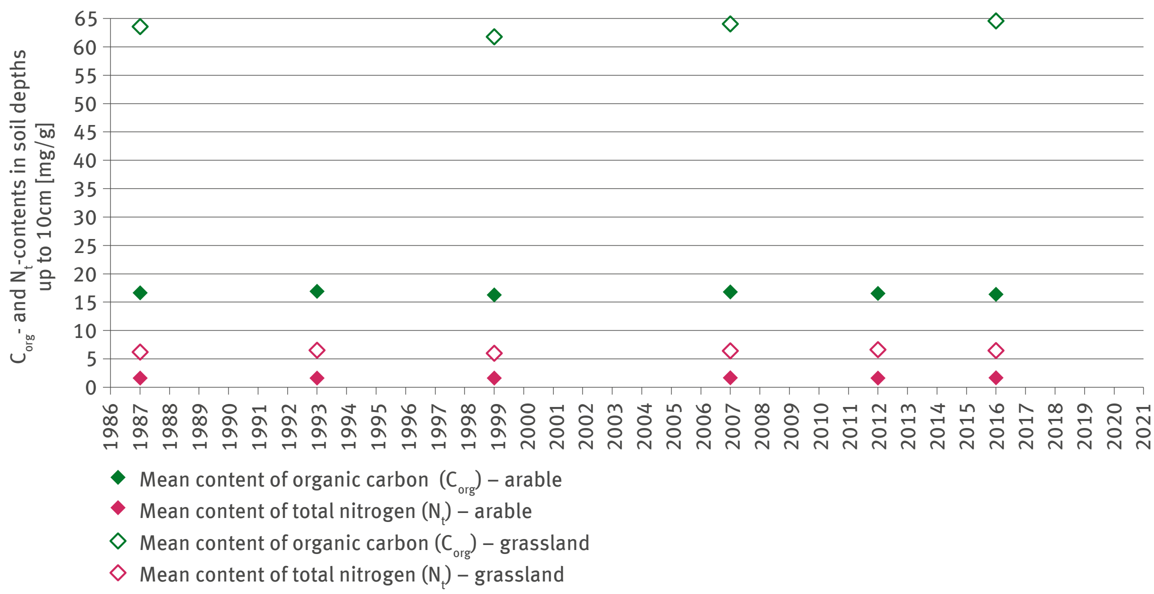
EAn important adaptation strategy aiming at soil protection consists in making soils more resilient towards hazards such as desiccation and / or erosion. Humus plays a major role in the resilience of soils, as it influences nearly all soil properties and functions. Humus is the entirety of organic matter in the soil, composed of all dead vegetable and animal remains as well as their organic conversion products. It is an important storage medium for nutrients and water and facilitates a favourable soil structure. This has a beneficial effect on the air and water balance in the soil and reduces soil compaction and erosion. Moreover, humus reduces desiccation in summer and furthers the activity of soil organisms. Therefore, conserving and augmenting site-adapted humic content, are important adaptation measures in safeguarding the health of soils.

With a view to the diverse relationships between climate change and humus, it is important to remember that also climate change has a direct bearing on the humus contained in soils. On one hand, higher temperature can accelerate mineralisation processes in the soil and the decomposition of organic matter, while on the other hand, it can also have humus-increasing effects, for example when plants form more biomass owing to the higher temperature, thus increasing the availability of more material for conversion to organic soil matter (cf. Indicator BO-I-4, p. 138). Changed precipitation scenarios also affect humus formation. For the time being, it is not possible to make any statistically-assured statements on climate-change dependent alterations in the contents and reserves of organic matter. However, it is assumed that weather patterns and climate play a subordinate role in terms of humus condition. The most severe changes are induced by changes in land use[100].

The contents of organic matter in soils are essentially dependent on site-typical circumstances (such as type of soil and the distance from groundwater levels) and therefore they cannot be augmented wholesale by adding organic materials. However, a useful control mechanism is the choice of land use practices. In forests and woodlands, the composition of tree species and the amount of residues from timber harvesting are crucial factors in the formation of humus (cf. Indicator FW-R-3, p. 190). On agricultural

BO-R-1: Humus contents in soils of arable land and grassland soils – case study

On average, the humic soil contents in permanent soil monitoring areas in Bavaria have not changed to any relevant extent since the mid-1980s. It must be said, however, that depending on site and land use, developments can vary substantially. In grassland, humic contents are generally higher. In arable fields, an increased cultivation of catch crops and the additional organic fertilisation promote the build-up of humus.



Data source: LfL (analyses of soil monitoring sites in Bavaria) soils, options include utilisation as grassland, application of farmyard manure, cultivation of catch crops or incorporating / leaving harvest and root remnants on site for the conservation and accumulation of humus. However, doubts have been raised in respect of any long-term humus-enriching effects from reduced ploughing and tilling of the soil. Long-term trials have demonstrated that humus reserves hardly change, and that it is merely a matter of humus being distributed differently in the soil profile[101].

With the 'Greening' stipulations contained in the European Direct Payments Regulation, the funding within the framework of the CAP from 2014 to 2022 was made conditional on agricultural businesses contributing towards environmental and climate protection. Thanks to those stipulations, it was possible to achieve a significant increase in the cultivation of catch crops in Germany in recent years[102]. Humus enrichment benefits from catch crop cultivation, not only thanks to the formation of biomass above ground, but also from the soil-borne input of organic matter. In the course of the new CAP funding period which started in 2023, the conditionality in relation to Greening has been expanded. The standards in respect of good agricultural and ecological condition of surface areas (GLÖZ) that have been in force since 2023, include measures such as the conservation of permanent grassland (cf. Indicator BO-R-2, p. 142) and a minimum of ground cover at the most sensitive times, which also serves the purpose of humus enrichment. Furthermore, EU member states are beholden to offer voluntary eco regulations (ER). The ER catalogue includes the 'retention of an agroforestry management approach in respect of arable land and permanent grassland'. This combined use of land for trees and arable fields or grassland is another method of contributing to humus enrichment. Furthermore, several Länder are in the process of preparing targeted funding programmes for agroforestry.

As far as restricting the decomposition of humus is concerned, organic soils are of utmost relevance. Substantial amounts of carbon are sequestered in moorlands. In cases where moorlands are under agricultural and forestry management, drainage is practised, thus allowing oxygen to penetrate the peat which causes a strong acceleration of microbial conversion and leading to decomposition of organic matter. In terms of the national greenhouse gas inventory, drained moorlands in the agricultural and forestry sectors account for roughly 40 % of emissions and roughly 7.5 % of the total of national greenhouse gas emissions in Germany.[103] By means of moorland renaturation or the transformation to wet management regimes by means of paludiculture, it is possible to halt humus decomposition, thus ideally leading to the moorland reverting to peat replenishment.

Humus is regarded as 'black gold' which protects soils efficiently from desiccation and erosion.
(Photo: © 994yellow / stock.adobe.com)

Regular surveys of humus contents in agricultural soils are carried out by the Länder within the nationwide network of BDF. As shown by results from the Bavarian BDF, the mean contents of the most important humic components such as organic carbon (C_{org}) and total nitrogen (N_t) in soil depths of 0 to 15 cm remained almost consistent for the past few years. Throughout the Bavarian BDF areas, decrease and increase figures remained roughly in balance over the past 35 years. As far as arable land is concerned, the mean value indicated a slight decline in C_{org} contents by 3 % compared to the baseline condition. However, most of the sites examined did not indicate any changes. In BDF areas where a deviation in terms of an increase in C_{org} contents occurred, it was possible to provide evidence for a connection with the transformation to ecological farming and organic fertilisation as well as the retention of harvest residues in the fields. However, more apparent is a general tightening of the C / N relationship as Nt contents tend to increase at the same time as C_{org} contents are slightly declining. The situation is similar in respect of grassland BDF. In this case too, a major part of the sites examined did not indicate any striking C_{org} changes, and the mean value for the observation period did not indicate any significant change in C_{org} contents.[104] Generally speaking, humus replenishment proceeds very slowly, and there are measuring inaccuracies. Hence, long time series would be required to draw any statistically assured conclusions.

More permanent grassland for the protection of agricultural soils

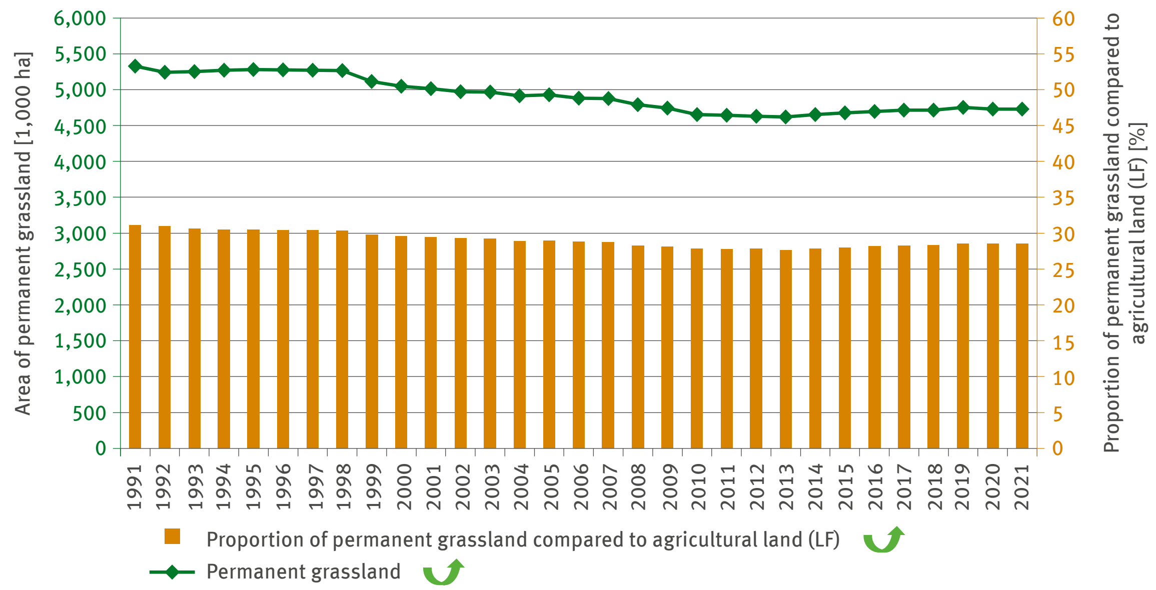
Permanent grassland refers to meadows and pastures which are either harvested by mowing or grazed by livestock. This is where grass is cultivated and herbaceous plants are cultivated as permanent crops. As a result of permanent ground cover, humus enrichment and species diversity, permanent grassland provides – especially compared to arable land – numerous favourable impacts, and it protects soils from the projected adverse effects of climate change. Especially the risk of soil loss from impacts of wind and water (cf. Indicator BO-I-3, p. 136) is considerably reduced where soils are under grassland. In cases of heavy precipitation, the precipitated water has a much better chance of penetrating a field with permanent grassland cover than a field of arable soils devoid of vegetation. Moreover, humic contents in grassland are higher (cf. Indicator BO-R-1, p. 140). Consequently, the conservation or even expansion of permanent grassland, especially on sensitive sloping ground used for agricultural purposes or in floodplains, constitutes a suitable measure for protecting soil even where it is affected by climate change.

Likewise, the loss of soil owing to converting grassland to arable land is to be viewed very critically, for reasons such as protection from climate change. Whenever grassland is ploughed up, a considerable part of carbon stored in the soil is released to the atmosphere in the form of greenhouse gases. This applies above all to grassland on organic soils which are particularly rich in high proportions of organic matter. The conservation of grassland is therefore highly relevant also in terms of climate protection. Furthermore, grassland plays a major role in species protection, the conservation of biological diversity and the protection of soils and water bodies.

The total of Germany's grassland terrain decreased between 1991 and 2013 by roughly 700,000 ha. Of 5.3 million ha originally, only some 4.6 million ha were left by the beginning of the 2010s. This development – apart from the task to make use of terrain with unfavourable production conditions – was the outcome of grassland conversion in favour of the cultivation of food crops,

BO-R-2: Permanent grassland terrain

The conservation of permanent grassland is intended to protect soils under agricultural use from the adverse effects of climate change. Between 1991 and 2013 grassland areas were experiencing a continuous and significant declining trend. Since 2013 the areas and the respective proportion of land in agricultural use have been increasing again gradually. From 2019 to 2021 the proportion remained consistent amounting to 28.5 %.



Data source: StBA (Bodennutzungshaupterhebung, Agrarstrukturerhebung) animal feed or the cultivation of renewable raw materials. Regions which in those days suffered the greatest absolute losses of grassland – such as Bavaria and Lower Saxony – are in part characterised by intensive livestock farming. However, the relative losses were partly also significant in other Länder where grassland use is less widely distributed. The intensification of dairy farming and low milk prices prompted agricultural businesses to tend predominantly high-performance dairy cows. Their basic food consists of grass, hay and silage, with the addition of major quantities of concentrates by means of cereals and protein carriers such as soy- and rapeseed meal. Moreover, the regions affected also experienced the most extensive increase in biogas capacities – with impacts on the conversion of grassland terrain by ploughing. It can therefore be argued that up until 2013, the nationwide decline of grassland was almost proportionate to the decline of agricultural land in Germany overall. Presumably, this occurred because a great deal of moist grassland was ploughed up and then drained. It can be said that ploughing activities on wet soils or moorland soils have therefore been particularly alarming in terms of climate protection.

Under use as permanent grassland, the soil loss risk is reduced, and the soils are better able to absorb heavy rainfall than arable land devoid of vegetation.
(Photo: © Superingo / stock.adobe.com)

Since 2013, there has been an increase in the terrain of permanent grassland. Likewise, the proportion of grassland compared to the total agricultural terrain increased by 2019. Over the last three years of the time series, this proportion consistently amounted to 28.5 %. The EU's agricultural reform is seen as one of the reasons for the reversal of this development in the mid-2010s. This reform was adopted by the Council of Europe and the European Parliament at the end of 2013. In subsequent years, the new regulations were incorporated by the individual member states into their respective national legislations. In Germany, for example, the permanent grassland conservation precept was in force from 2015 to 2022 within the framework of 'Greening'. It continues to be in force for the new CAP funding period which began in 2023 within the framework of the GLÖZ Standard. This means that any funding disbursed to agricultural businesses from the CAP is conditional on ensuring that the permanent grassland terrain as a proportion of agriculturally used terrain in a defined region does not suffer any decline. The conversion of permanent grassland to arable land should in principle be allowed only with official authorisation and, depending on the site's location and age of the permanent grassland, this should only be tolerated on condition that new permanent grassland be created elsewhere. In some Länder such as Schleswig-Holstein, Mecklenburg-Western Pomerania and Baden-Württemberg, there are specific legal regulations in force, passed by each of these states which prohibit in principle any conversion of permanent grassland to arable land. As of 2023, the new CAP funding period is valid not just in areas designated according to the Habitats Directive (FFH areas). This means that a strict ban on ploughing and conversion is in force, not just for permanent grassland but also for bird sanctuaries, wetlands and moorlands.

Any newly created grassland can contribute to the additional sequestration of carbon, as a rule regardless of its composition, as this grassland is certain to further humus production. However, with a view to biodiversity it has to be borne in mind that newly created grassland is typically more species-poorer than long-established grassland terrain. It follows that within the framework of the grassland conservation precept, the newly created grassland is less significant than the conservation of older terrain of this kind[105].

Photo: © Johan Larson / stock.adobe.com

Agriculture

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

More than half of Germany's terrain is used for agriculture. This means that – given its expanse alone – Germany possesses a huge potential for creating landscape and biotope structures in keeping with the concept of 'good' adaptation to climate change. At the same time, the agricultural sector with its associated preliminary work and investments – as well as the nutrition industry closely bound up with agricultural production and bioeconomy – is of major importance to the national economy. At a global scale, climate change has become a relevant risk factor for food security. In many countries located in both the European and the global south, farmers are wrestling with severe drought and other extreme events. However, in Germany too, there are now regions in which it is no longer possible to farm as productively and sustainably as in the past.

For agriculture to remain productive under conditions of ongoing climatic changes, it is essential to adapt, not only in many agricultural subsectors, but also in terms of maintaining nutritional values and in terms of food processing.

Given the close links between agriculture, (high-quality) nutrition and health, the UN organisations for health (WHO), animal health (WOAH), environment (UNEP) as well as food and agriculture (FAO) are involved in the propagation of the concept of 'One Health'. This concept has become a guiding principle for action taken in respect of global health policies, at the same time as acting as a lever to make agricultural production and, in particular nutrition, more sustainable at the global scale.

DAS Monitoring –what is happening due to climate change

Agricultural management is largely influenced by European and German agricultural policies and by international agricultural and input markets. It is therefore not usually possible in this sector to identify – on the basis of collectable data – a distinct causal relationship with climate change. Monitoring data will always have to be interpreted against the background of the framework of the prevailing agricultural policy, as well as market conditions and individual business decisions.

The fact that climate change is relevant to agriculture is demonstrated directly by the shift in agrophenological phases (cf. Indicator LW-I-1, p. 150). For example, during the past ten years, winter rapeseed – based on Germany's national average – started to flower roughly 18 days earlier than the mean for the period of 1971 to 1980; while apple trees started to flower roughly 15 days earlier. Likewise, vines also start sprouting earlier in the year. The vegetation period is becoming longer. These changes harbour both risks and opportunities for agriculture and horticulture.

Farmers have always 'worked' according to the weather pattern and tried to adapt to current conditions and observed changes as best they could. In the face of climate change too, there are countless adaptation options available to avoid or mitigate impacts on cultural traditions, reduce risks or to exploit new opportunities. This is why many developments of climate change impacts in agriculture – illustrated by means of impact indicators contained in the DAS Monitoring Report – are already the result of preventative and prudent adaptation efforts and not just a description of isolated climate change effects. The fact that insured damage from hailstorms – adjusted for inflation effects and increases in insured amounts – in sensitive agricultural crops did not increase between 1980 and 2021 (cf. Indicator LW-I-3, p. 154), may be due to a lack of increases in severe hailstorm events in that period, or indeed that hailstorms did not hit agricultural crops. It may also be due to agricultural businesses having taken protective measures – such as installing hailstone protection nets – thus effectively avoiding or reducing damage.

Above all, it is the unpredictability of annual weather patterns which makes it difficult for agricultural businesses to adapt adequately or in good time. Extreme events or unexpected weather conditions can overwhelm even the most solid and provident forward planning. Foreseeable medium and long-term trends such as rising temperatures and increasingly dry conditions in spring, or conditions favouring certain pest organisms as a result of changing weather patterns (cf. Indicator LW-I-4, p. 156) can be integrated in business strategies by selecting crop varieties that are adapted better. In respect of some crop species, yields continue to increase – partly owing to the continuing intensification of agricultural processes and as a result of provident business management. On the other hand, there are now some crops for which yields are stagnating. Time and again, there are more or less strong fluctuations in the quantity and quality of yields (cf. Indicator LW-I-2, p. 152). In one year, yields might be unexpectedly high due to surprisingly good weather patterns, whereas in another year, extreme weather events lead to substantial yield losses. Both situations present agricultural businesses with challenges as they make it (increasingly) more difficult to schedule farming processes.

Future climate risks – outcomes of KWRA

Research carried out within the framework of the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7) as covered in the agriculture action field indicated – already for the middle of this century – a high risk of abiotic stress and yield losses. In addition, a high risk of a heat-related reduction in health and performance of livestock is to be expected by the end of the century. As far as the risks for a decline in the quality of harvested crops is concerned, a medium risk (according to a grid of low – medium – high risk) was estimated owing to stress from pests and diseases as well a shift in cultivation areas and agrophenological phases is to be expected to arise by the middle and towards the end of this century. The certainty of risk assessments regarding nearly all climate impacts ranges from medium to high. However, whether there will be any stress from pest organisms and diseases and also in respect of yield losses is subject to major uncertainties.

In future, conflicts regarding the utilisation of terrain and water will have a crucial influence on the framework conditions governing agricultural production.

Where do we have gaps in data and knowledge?

So far the DAS Monitoring Indicators have not managed to provide adequate illustrations of many relevant impacts of climate change on agriculture and horticulture. Despite regular agro-structural surveys, the data basis underlying some of the themes is just not adequate. Moreover, many business-related data (such as insurance data) are subject to data protection, or the assessment of data would have required major efforts (for instance regarding the documentation on the application of pesticides by agricultural businesses).

So far, agricultural damage resulting from floods, storms, droughts and late frosts have not been documented either systematically or nationally. This is due to the lack of high-resolution, comprehensive yield data from research, as well as the insufficient cover of agricultural multi-risk insurance nationwide which would make it possible to derive representative statements from insurance data. Even with a significant increase in the density of insurance cover, it will take several more years to make any statistically valid statements.

There are knowledge gaps regarding the quality of harvested products that can be affected by climate change impacts. Apart from heat and drought, CO_2 concentration also plays a role. It might reduce a plant's nutritional value. As far as wheat is concerned, CO_2 concentration presumably also influences the baking quality. This subject is increasingly becoming a matter of scientific interest. Every year, the 'Besondere Ernte- und Qualitätsermittlung' (special survey of yield and quality data), is carried out in respect of agricultural businesses. As far as cereal crops and rapeseed are concerned, additional assessments are made regarding ingredients and processing properties. However, in order to interpret such data in the context of climate change, it would be necessary to have better access to data for research purposes and would also require more knowledge.

A particularly large knowledge gap exists in respect of climate change impacts on livestock farming. Especially with regard to animal health, there is a nationwide lack of data sources. Data collated by veterinary inspection offices, slaughter houses or even rendering plants cannot be retrieved and assessed centrally. Performance parameters – such as the actual milk yields achieved – can be interpreted in relation to specific weather events and weather patterns insofar as details are known regarding the pertaining animal husbandry. Analyses carried out within the framework of the 2021 KWRA demonstrate that the number of days with heat stress expected to affect dairy cows, pigs and poultry might be distinctly higher in future. Especially with regard to livestock kept indoors, it is not possible to make any statements on actual impacts as many byres, barns and pigsties are air-conditioned. Furthermore, improvements made to animal welfare are apt to counteract any adverse impacts from heat.

What's being done – some examples

Agriculture provides numerous possibilities for responding to climate change. What is crucial is the choice of crop types and varieties (cf. Indicators LW-R-2, p. 160, LW-R-3, p. 161, and LW-R-4, p. 162) as well as the type of management practised (cf. Indicators LW-R-1, p. 158, and LW-R-5, p. 164). Short-term adaptation in respect of permanent crops is more difficult, as in these cases provident business decisions have to be made a long time in advance. The situation is similar in respect of annual crop species, in cases where these require specific management techniques and associated investments or if they are bound up with specific processing and marketing structures. In fact, the installation of an irrigation infrastructure (cf. Indicator LW-R-6, p. 166) also requires carefully considered investments, and not least, the availability of and access to water resources.

At Federal level, adaptation activities are aimed at improving the knowledge base available to agricultural businesses. With the establishment of Federal soil information systems and the enhancement of agricultural meteorological advisory services (including the Agricultural Meteorological Advisory Software AMBER), the objective is that agricultural businesses receive differentiated information. This information is intended to enable agricultural businesses to adapt their management in a more targeted way to changing conditions. In Mission 2 'Klimaschutz, Klimaanpassung, Ernährungssicherheit und Bewahrung der Biodiversität voranbringen' (Advancing climate protection, climate adaptation, food security and the conservation of biodiversity), contained in the 'Zukunftsstrategie Forschung und Innovation' (Future strategy, research and innovation) adopted by the Federal government, a particular focus was placed on promoting plant research. Resistant varieties which are yield-assured even under drought conditions are required in order to safeguard global food security[106]. The support initiative entitled 'Agricultural systems of the future' is used by the BMBF for the development of new avenues to a sustainable design of agricultural production under the conditions imposed by climate change[107].

Agricultural aid is an important lever for use at Federal and Länder level. The new funding period of the Common Agricultural Policy (CAP) started in January 2023, after the two transitional years of 2021 and 2022. In accordance with the regulation laid down in the CAP Strategic Plan, each EU member state first had to submit its own CAP Strategic Plan in conformity with the framework adopted at EU level, which stipulates what the funding is to be used for. The BMEL developed this plan in close cooperation with Federal government departments, the Länder, associations and stakeholder groups. A new conditionality was introduced for the current CAP funding period. This conditionality relates to general basic requirements. It is incumbent on all agricultural businesses to fulfil these requirements, if they wish to obtain agricultural funding support. These basic requirements include the compliance with standards for the maintenance of good agricultural and ecological condition (GLÖZ Standards). These standards are intended to provide additional support for climate protection, as well as the adaptation to climate change, coping with numerous problems in respect of water, the protection of the soil and soil quality, and not least for strengthening biodiversity.

Likewise, the funding of ecological farming can support adaptation, as eco-farming practices include diversified plant cultivation systems, diverse crop rotation and continuous ground cover – all apt to strengthen the resistance and resilience of agricultural ecosystems. However, for agriculture to cope with climate risks, there is also a need for far-reaching change in respect of the markets and for the demand side to embrace changes in terms of product selection and pricing, not least because agricultural businesses will incur higher costs.

One approach to reduce economic risks in agriculture is the development and offer of insurance solutions that match requirements. By granting a significantly reduced tax rate of only 0.3 per mille of the amount insured in 2013, more favourable conditions for multi-risk insurance in agriculture have been established already. These conditions covered not only the risks of hailstorms but also tempests, severe frost, heavy rain and floods. In early 2020, the regulation was amended to include drought as a natural hazard. Given that the premiums for multi-risk insurance policies are mostly very high, there are now grants to assist with insurance policies available to agricultural businesses in several EU member states. In Bavaria, Baden-Württemberg, North Rhine-Westphalia and Thuringia there is currently funding available from Länder- or EU resources for multi-risk insurance policies, particularly in respect of special crops, which means that part of the insurance premium is paid from the public purse. Lower Saxony, along with Bremen and Hamburg, are planning to introduce such funding as of 2024.

State

Photo: © Volodymyr / stock.adobe.com

Climate changes relevant to the action field

Air temperature and fluctuations in weather patterns

The annual air temperature as an aggregated mean for Germany between 1881 and 2022 was determined statistically to have risen by 1.7 °C. Furthermore, in the course of the past 50 years, the speed of this temperature rise has distinctly increased. Prior to 2014 Germany had never had an annual mean temperature of more than 10 °C. By contrast since 2014 this value has been exceeded five times. However, as in the past, there is still a considerable range of fluctuations in weather patterns as well as many incalculable developments from year to year (cf. page 19).

Impact

Photo: © Mariusz Switulski/ stock.adobe.com

Impacts of climate change

LW-I-1 Agrophenological phase shifts

Climate change alters the seasonal flow of development in respect of agricultural crops. There are shifts occurring in agrophenological phases. This can have various consequences for various agricultural and horticultural crops. When there are late frosts after warm spring temperatures, this can affect quite well developed crops (for instance in fruit-farming), thus causing massive losses incurred as a result of frost. In other cases, however, for instance regarding winter cereals and winter rapeseed, an earlier development can entail advantages, for example in respect of managing pest organisms, or in crop rotation or the exploitation of residual moisture left over from the winter months.

LW-I-2 Yield fluctuations

The absolute yield levels achieved in Germany’s agriculture depend on many factors, not least (and in fact essential) on market-related circumstances. Nevertheless, at least in some regions of Germany, the climatic limits to any further increases in yields might be reached in the future. There is a more immediate relationship between weather patterns and interannual fluctuations, because there are limitations to the degree in which agriculture can adapt to extreme weather patterns. Since the turn of the millennium, strong interannual fluctuations have been observed regarding wheat and maize yields.

Impact

Photo: © zoteva87 / stock.adobe.com

Adaptations – activities and results

LW-R-4 Cultivation of thermophilic crops

In respect of arable crops, there are opportunities to respond to changing climate and weather conditions by means of selecting suitable crop species and varieties. Apart from preventing yield losses, the changing conditions also open up new business options for agricultural businesses. In that context, the cultivation of soy, durum wheat and grain maize is becoming increasingly attractive in Germany where temperatures are rising, and the terrain used for these crops is expanding. As far as pulses such as soy are concerned, the agropolitical framework conditions are currently favourable, as the cultivation of these crops is being sponsored heavily by the Federal government’s protein plant cultivation strategy.

Response

Photo: © Johannes Wilke / stock.adobe.com

Spring crops starting earlier year by year

Hardly any other form of land use is as tied to natural seasonal rhythms as agricultural land use. People who work in agriculture always need to adapt the management of their specific crop to the annually changing weather patterns prevailing at any particular time. Changes in weather patterns can impact on crops in both positive and negative ways. On one hand, greater accumulations of warmth in the presence of adequate availability of water further the growth of certain types of crop. On the other, excessively high temperatures or drought can entail losses in yield or quality, when for instance a cereal crop ripens too early.

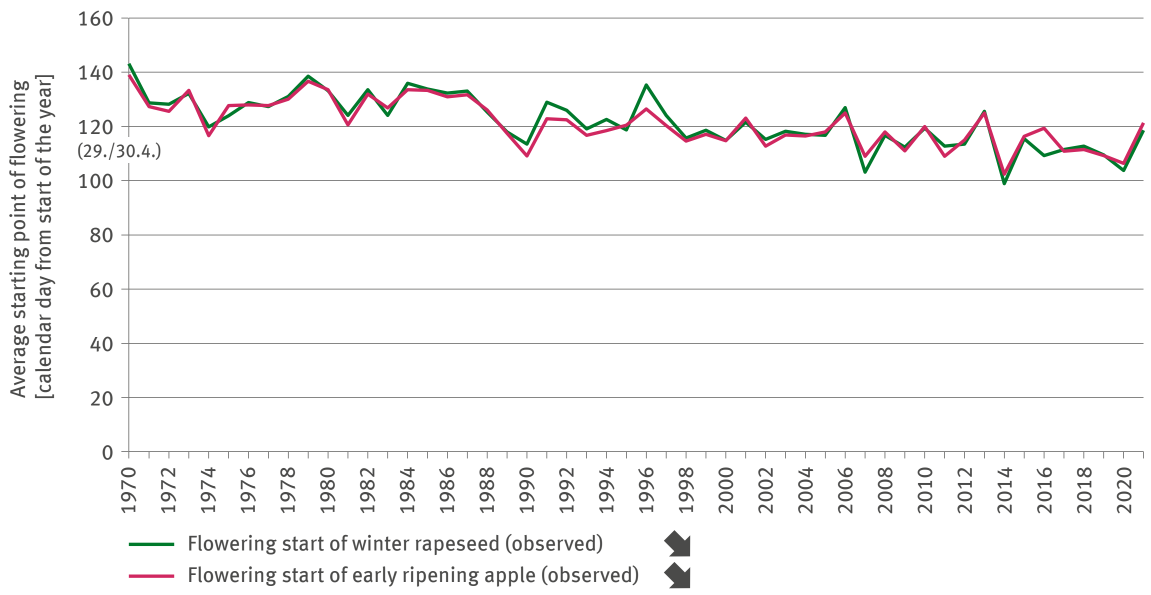
Climate change influences seasonal weather patterns which in turn impact the seasonal development processes of agricultural crops. Spring is expected to bring rising temperatures, summers are likely to become drier and hotter while winters have already become milder and wetter. Such circumstances make it impossible to infer any simplified conclusions regarding volume, quality or stability of yields, because the impacts of climate change can vary subject to the crop cultivated and to crop rotation. Above all, there are regional differences to be taken into account.

Changes in natural seasonal rhythms and associated temporal shifts in the development of plants have been studied and documented for years by means of phenological observations. These nationwide studies involve the onset of certain biological phenomena recurring periodically such as leaf and bud formation, flowering, maturity of fruit or leaf fall. The phenological observation network operated by DWD extends to wild plants, agricultural crops and management operations, thus providing indications regarding impacts on agricultural management, because changes in seasonal weather patterns confront agriculture with new challenges. Farming businesses have to adapt their choices of crop and crop variety, crop rotation and the scheduling of management operations according to new circumstances arising.

In Germany the onset of spring is marked by the flowering of apple trees and winter rapeseed. Both flowering periods are independent of the influence of preceding

LW-I-1: Agrophenological phase shifts

Changes in seasonal weather patterns result in new challenges facing agricultural businesses in terms of scheduling their management operations. Owing to higher accumulations of warmth in spring, both apple trees and winter rapeseed flower earlier and earlier.



Data source: DWD (phenological observation network)

agricultural operations such as the date of sowing. Apples belong to the category of permanent crops, while winter rapeseed is sown the previous year, no later than September. The flowering period is therefore linked directly to climatic factors, especially accumulations of warmth occurring in the first few months of the new year.

Depending on the progress of weather patterns, the start of flowering in respect of apple trees and winter rapeseed tends to fluctuate from year to year, and in some cases such fluctuations are considerable. The differences from year to year can be as much as up to three weeks. However, looking back over a little more than the past fifty years, both crop types show a significant trend towards an earlier onset of flowering. Compared to the 1970s, winter rapeseed started to flower 18 days earlier – as indicated by the mean calculated for the past ten years – while apple trees started to flower roughly 15 days earlier.

As far as fruit-growing is concerned, early flowering can increase the risk of damage from late frost. In cases where warm spring temperatures have led to flowering and fructification being well advanced, only to be hit by late frost, this is possible to cause frost damage leading to substantial yield losses and possibly even to the loss of the entire harvest. In 2016, winter returned with a vengeance in late April, with snow falling all the way from Scandinavia to the Alpine region. Even though that year does not stand out in terms of the phenological time series for apple blossom, the resulting damage was immense, owing to the very late occurrence of frost. Likewise, in 2017 (the subsequent year), the late onset of cold weather – with numerous frosty nights – descended on large parts of Europe between 17th April and 10th May. Owing to the previous warm weather pattern which had prevailed from March until the beginning of April, the vegetation was already comparatively far ahead in that spring. As far as fruit-growing is concerned, the blossom had already partly gone in that year, whereas there were already young fruit which are even more vulnerable to frost than the blossom. In respect of fruit growing on trees, the extent of damage reached devastating proportions. 2020 was another year in which late frosts caused yield losses as a result of a frosty May; whilst in 2021 several successive frosty April nights did the damage.

In many locations the orchardists are already responding to this development by increasingly applying targeted anti-frost irrigation, in other words, spraying plants with very small water droplets. While the water freezes, crystallisation heat is released, which protects both leaves and blooms from frost damage. Nevertheless, frost protection irrigation requires massive quantities of water

Agrophenological phase shifts can have both positive and negative impacts on agricultural crops.
(Photo: © Mariusz Świtulski / stock.adobe.com)

amounting to 30,000 per hectare and hour. This factor naturally limits the application of frost protection irrigation, not least for sustainability reasons. A more sustainable solution might be the planting of less frost-sensitive varieties in locations vulnerable to frost.

The situation is quite different, however, with regard to winter rapeseed. In this case, early flowering can entail benefits for the management of pest organisms and crop rotation. The infestation of winter rapeseed with rape beetle is apt to increase owing to rising winter and spring temperatures (cf. Indicator LW-I-4, p. 156). The use of early-flowering varieties can provide a tool for the prevention of this infestation in the vulnerable stage of budding. This is indeed one of the reasons why agricultural businesses increasingly give preference to early-flowering winter rapeseed. However, phenological observation is unable to take a specific variety into account. This circumstance is the reason why the effects of using different varieties are also reflected in the flowering periods observed within the framework of phenological analysis. Hence, the relevant indicator fulfils two purposes at the same time: it is both impact and response indicator. In fact, it clearly illustrates the combined effects described.

Drops in yield owing to extreme weather patterns

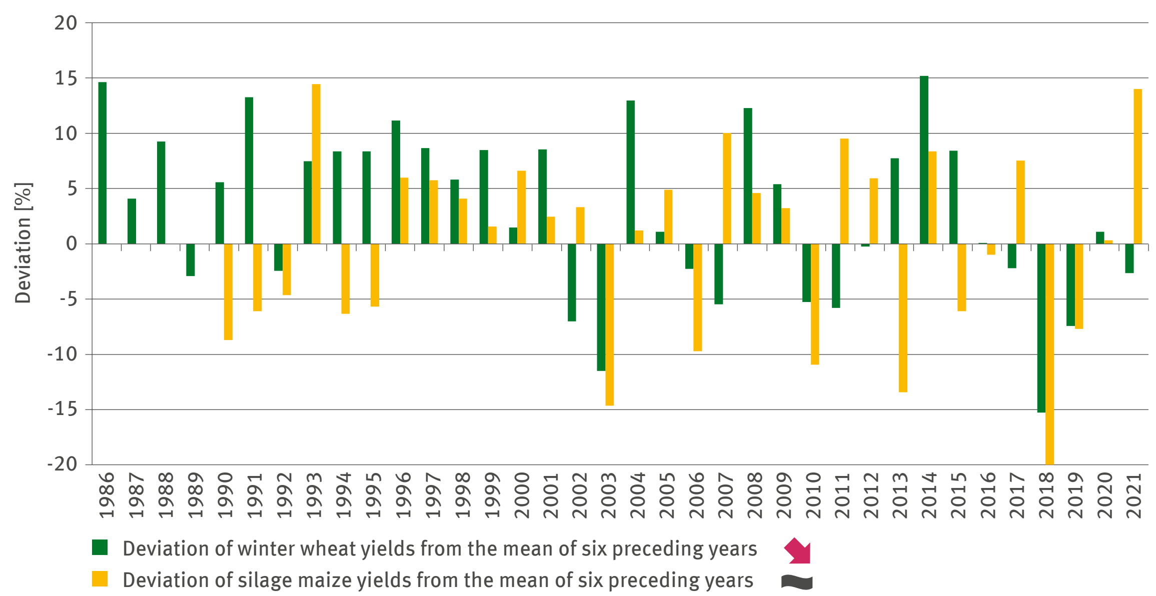
An extended vegetation period, higher temperature totals and higher CO_2 concentrations in the atmosphere are apt to stimulate photosynthesis and plant growth. On the other hand – droughts, storms, heavy rain, hailstones and floods can entail increasing risks of yield losses.

Over the past fifty years, advances in plant breeding and technical progress have brought about increases in agricultural yields for important crop species in Germany. Breeding efforts have produced new varieties with improved properties in terms of amounts and stability of yields, quality, resource efficiency, stress tolerance and disease resistance. Likewise, there were improvements in terms of sowing, plant care and harvesting methods as well as fertilising and plant protection. It is true to say, however, that yields are dependent on several other factors besides. In respect of wheat, it was possible to observe stagnation in yields, especially since the turn of the millennium, and in recent years even a slight decline. This development was due to a complexity of causes that will have to be examined more closely. Apart from factors already mentioned, it is possible that cultivation on less fertile soils, so-called marginal sites, may be one of the causes; another factor may be crop rotation at closer intervals. With regard to silage maize, the yields recorded in the time series concerned indicate stronger fluctuations; there is no distinct trend discernible regarding yields. It is important in agriculture to optimise operational management and use of resources. To what extent yield-enhancing measures are taken continues to depend largely on the achievable level of product pricing. The higher the price level, the greater the benefit from the use of yield-enhancing or yield-safeguarding materials such as mineral fertiliser and pesticides. In the past two years, it was above all the high price increases in respect of fertilisers which impacted management operations.

For the time being it is difficult to estimate to what extent climate change influences the absolute yield levels in Germany. Some participants in the debate argue that at least regionally the climate might impose limitations on a further increase in yields. Others argue that the CO_2 fertilising effect is making itself felt, and those individuals expect that the agricultural sector will be able to cope with

LW-I-2: Yield fluctuations

Yields fluctuating from year to year can be attributed more directly to changes in weather patterns than to long-term yield trends. Any increase in yield variability increases the production risk for agricultural businesses. Extreme years tend to result in substantial deviations – either positive or negative – from yields achieved in preceding years.



Data source: BMEL (Ernte- und Betriebsberichterstattung, Besondere Ernte- und Qualitätsermittlung) long-term climate trends. In particular regarding the cultivation of annual crops, there are many options available for responding to the changed framework conditions, for instance by choosing appropriate crop species and varieties, by crop rotation and by adapting management planning accordingly. Such adaptive responses have already been in use for decades in agricultural practice, because changing market conditions have always meant that businesses have had to be highly responsive.

It is to be expected that increasing weather- or weather-pattern – fluctuations will occur from year to year, associated with climate change, and these are less easy for agricultural businesses to prepare for. On one hand, weather extremes such as long drought periods, but also heavy rain (for instance during harvest) can lead to unpredictable drops in yield. On the other hand, it is also conceivable that unexpectedly favourable weather scenarios entail surprisingly high yields. Both versions make forward planning difficult and entail production risks, because any calculation will have to be inclusive of the materials to be used and the storage capacities required, based on the yields expected.

Looking at the example of winter wheat – currently the most important cultivated crop in Germany – in respect of the deviations of annual yield from the average yield achieved in the six preceding years, it becomes clear that the yields in this sector – from the turn of the millennium onwards – went through a lot of ups and downs. The trend towards more frequent and more negative impacts on yield outliers has become significant too. The situation is similar in respect of silage maize, but so far it is not possible to see a statistically distinct trend. A possible explanation for the reduction in the yield capacity of winter wheat is above all the shortened phase of grains filling as a result of heat and drought in June. If the harvest month of August turns out to be too wet, this will lead to damage during storage and to pre-harvest sprouting. As far as silage maize is concerned – which as a summer crop is sown and harvested later – other development phases might be vulnerable to weather patterns. In the hot and dry year of 2003, the wheat yield amounted to 65.5 dt / ha which was 14.6 % below the mean yield calculated for the preceding six-year period. Apart from heat and drought, regional outwintering damage owing to black frosts also impacted the yields. In respect of maize, the hot and dry weather pattern in July and August 2003 triggered premature ripening in many locations which enforced early harvesting. In 2010, many locations suffered persistent rain in August, and harvesting conditions remained poor well into September. Both factors entailed adverse effects on maize yields. There is also striking evidence for decline regarding maize yields in 2013. At the end of May flooding occurred throughout Germany, whilst there were also late frosts in some localities. Subsequently, there was a delay in flowering, and there were problems with weed control. In early August, hailstorms and stormy bouts of heavy rain resulted in harvest losses. The extreme drought years of 2018 and 2019 badly affected both winter wheat and silage maize. 2018 was the year with the most significant average drops in yields so far. The difficulties in respect of winter wheat – especially in northern Germany – already began in the autumn of the previous year. Owing to large amounts of rain, the autumn sowing of winter cereals was practically impossible in many cases, and in spring 2018 summer cereals were sown that produced very poor yields. High temperatures and low precipitation levels from April 2018 onwards resulted in an unusually early onset of harvest. Wheat yields for 2018, amounting to 67.7 dt / ha – that is higher than the total of yields for 2003. However, compared to the extraordinary wheat yields of the years of 2013 to 2015, it nevertheless signified a major decline. However, in respect of silage maize, the lowest yield to date was produced in 2018, amounting to 352.9 dt / ha.

Extreme weather patterns can lead to massive yield fluctuations from year to year. (Photo: © zoteva87 / stock.adobe.com)

It should also be borne in mind that there are, of course, distinct differences between Germany's regions. In particular in eastern Germany – with its light and sandy soils which react especially fast and strongly to extreme precipitation levels – the interannual yield fluctuations were more pronounced than for instance in the central and western parts of Germany where soils in rather moist and cool upland regions produced more stable yields generally.

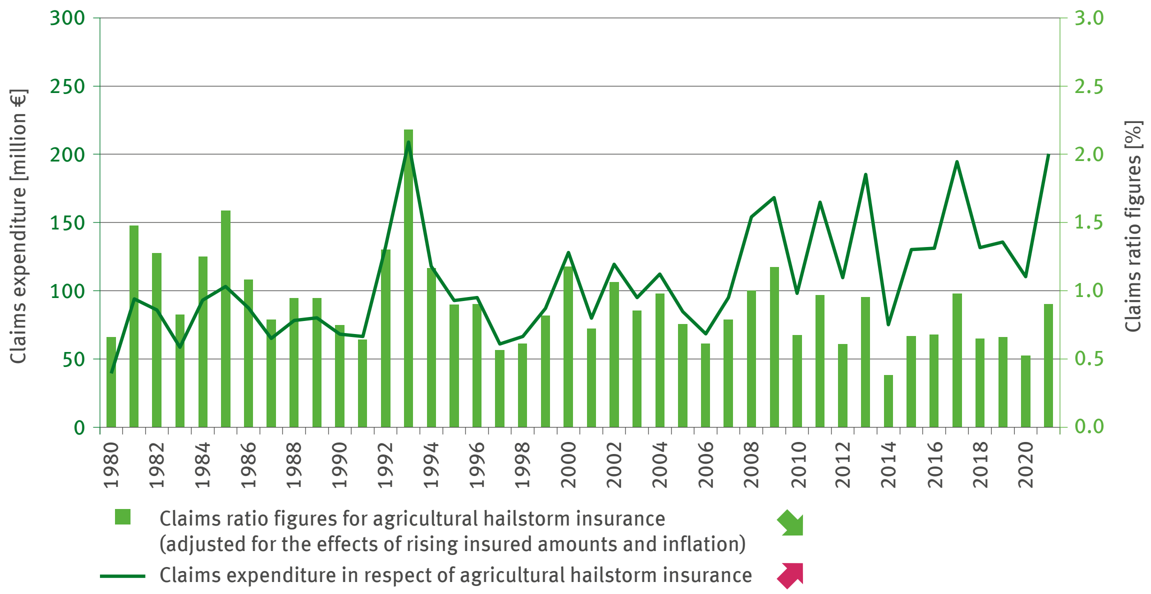
Yield losses caused by extreme weather events

As a result of weather extremes, Germany's plant production has repeatedly suffered some considerable yield losses in the course of recent years. A study carried out by the German Insurance Association (GDV) regarding insurance for agricultural multirisks (Landwirtschaftliche Mehrgefahrenversicherung) for Germany, estimated that annual harvest losses caused by weather-related risks in Germany between 1990 and 2013 amounted to roughly 510 million Euros per annum. 54 % of harvest losses in this period – that is to say, prior to the drought years of 2018 to 2020 – can be attributed to drought, 26 % of damage to hail storms and just 20 % to tempests, heavy rain, flooding or outwintering and frosts.[108] If extreme events increase as a result of climate change, agriculture is liable to have its fair share of harvest damage or harvest losses. The drought summer of 2018 has demonstrated that the average yield losses mentioned above can sometimes be much more severe. Many agricultural businesses struggled to survive. The businesses affected obtained financial support totalling 340 million Euros from Federal and Länder sources[109].

Typically any statements regarding weather-related harvest losses are made in terms of approximated values. Basically, the most reliable data on insured damage might be disclosed by insurance companies themselves, as funding disbursed from aid programmes on a case-by-case basis covers only part of the damage incurred. So far, however, only few agricultural businesses have comprehensive insurance protection from harvest losses which result from extreme weather events such as drought. According to a recent BMEL survey among German insurance companies in the years of 2020 to 2022, roughly just 1 % of arable ground in Germany was insured for drought. One reason for the hitherto low insurance density is the fact that insurance premiums continue to be very expensive. In particular drought, but frost too, are among the so-called accumulation risks, which means that several regions can be affected at the same time. The high amount of damage associated with such situations thus increases the premiums charged. In fact, in several EU member states, there has been government part-funding available for many years for multi-risk insurance policies, in order to make insurance premiums more affordable. Since multi-risk insurance for

LW-I-3: Hailstone damage in agriculture

Extreme weather events such as drought, hailstorm, tempest, heavy rain, flooding, frost and damage from outwintering can cause yield losses in agriculture. Typically, the insurance policy covers only damage from hailstones. Increases in claims expenditure are essentially caused by increases in the amounts insured. Claims ratio figures make it possible to infer more direct conclusions regarding hailstorm events. These figures show a falling trend.



Data source: GDV (branch statistics)

orchards and vineyards in Baden-Württemberg was first subsidised by state funding in Germany in 2020, the Länder of Baden-Württemberg, Bavaria, Thuringia and North Rhine-Westphalia currently provide subsidies including state and / or EU funding for multi-risk insurance policies in respect of specific crops and risks, covering up to 50 % of the insurance premium. For the first time in Germany, Bavaria in 2023 also subsidised multi-risk insurance for arable and grassland areas including the risk of drought. Lower Saxony, along with Bremen and Hamburg are planning to introduce funding for multi-risk insurance as of 2024.

Compared to multi-risk insurance, insurance for hailstone damage is already in wide-spread use in agriculture. More than two thirds of all farmland is insured for hailstone damage[110]. Regarding reports from hailstorm insurance companies in respect of expenditure insurance claims, it is therefore possible to make statements on at least part of the losses.

The claims expenditure, that is to say, the gross expenditure arising from insurance claims for hailstone damage, has increased significantly between 1980 and 2021. However, this is not exclusively due to increased incidents entailing claims. In fact, it is also a result of increases in insured amounts. In Germany, the market for agricultural hailstorm insurance is not considered saturated and the values insured are on the increase.

Contrary to claims expenditure, claims ratio figures for agricultural hailstorm insurance are adjusted for the effects of rising insured amounts and inflation. In order to infer some more direct conclusions, it is therefore possible to use the claims ratio figures to identify the driving force underlying the claim – in this case hailstorm events. The trend indicated for the claims ratio is falling. So far, 1993 was the year with the greatest incidence of damage during the period examined. In 2002 major hailstorms, especially in south-west and eastern Germany, caused total losses in many locations, while in 2009 the north and south were affected most severely between late April and mid-August by a sequence of thunderstorms of extraordinary violence. In 2017 there was substantial damage caused by changeable weather patterns with regional hailstorm events.

Despite some regionally substantial damage, 2018 was overall a year with comparatively moderate damage, although between the end of April and mid-June, not a day went by without damage being reported to hailstorm insurers. In the south and south-west of Germany, August hailstorms damaged maize crops just before harvest – a crop which, in that drought year, had still promised to deliver good yields. Likewise, in 2019 the great heat was accompanied by heavy thunderstorms. The month most affected by hailstone damage was June. Thunderstorm 'Jörn' which afflicted the south and south-east of Germany, brought some of the ten most severe hailstorms known to property insurers since 1997. Other hailstorm events in June in Lower Saxony and in July in Hesse, northern Bavaria, Thuringia, Mecklenburg-Western Pomerania, among others, struck many rapeseed, peas and cereal crops that were ready to be harvested at that time.

In agricultural cultivation, damage can be caused by hailstorms, tempests, heavy rain, flooding or outwintering and frost. (Photo: © brunok1 / stock.adobe.com)

There were no major hailstorm events in 2020. In June 2021, however, thunderstorm supercells – these are rotating and very long-lasting thunderstorm clouds – emitted huge hailstones thus causing enormous damage, especially in agricultural areas of Baden-Württemberg and Bavaria. It is true that in 2021 the claims ratio in Germany nationwide was higher than in the three preceding years and also higher than the mean of the past 30 years. However, it was not as high as the peak values recorded for the 1980s and 1990s.

Although hailstorm insurance compensates agricultural businesses for tangible harvest losses, it does not cover any associated consequential losses incurred by an agricultural business as a whole. The insurance does not cover any losses in terms of market presence in a hailstorm year, or underused capacity of operational infrastructure or even increased expenditure arising from product harvesting and sorting efforts. This is another reason why many companies do not regard concluding a hailstorm insurance as their only option. Especially in orcharding, farmers increasingly use safety nets for product protection from hailstones.

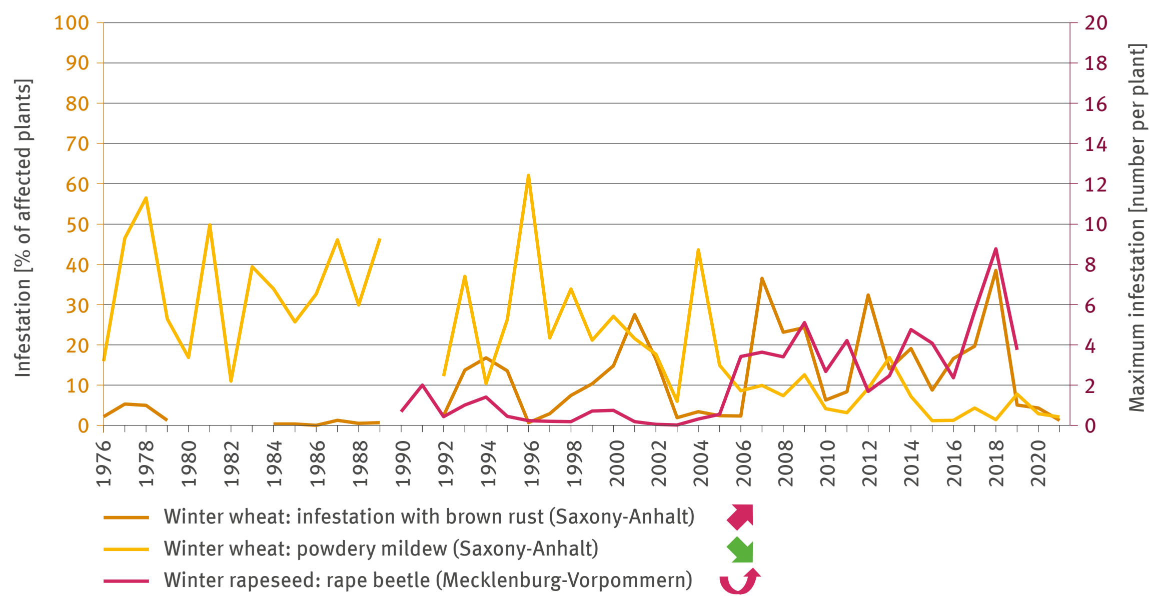
Increased pressure from harmful organisms is possible

Climate change does not just alter the conditions for agricultural crops but also for pest organisms and plant diseases. Warmer weather patterns and the extension of the vegetation period improve the opportunities for some pest organisms to increase their range and to produce several generations per annum. However, other pest organisms which depend, for example, on extended moist periods might decline. Given the progress of climate change, it is to be expected that in the next few years, this development will bring about shifts in the species range of organisms harmful to plants. Damage caused by fungal diseases – apart from diseases triggered by thermophilic fungi such as Pucciniales (types of rust) – will probably diminish in many areas. On the other hand, thermophilic grass weeds and other weeds, animal pests and non-parasitic diseases might increase. Furthermore, insects basically always benefit from warmer temperatures. It is to be expected that new risks will arise from pest organisms which have so far not occurred in our latitudes. Once introduced, these alien species will be able to establish themselves and spread owing to the changed climatic conditions in our regions. However, observations so far do not permit to draw any conclusions as to the increase or decrease of infestations with pest organisms. It is not possible yet, or at least very difficult, to make any detailed prognoses at this stage. It is undeniable, however, that numerous pest organisms can respond very sensitively and spontaneously to changed weather patterns; this requires the agricultural sector to respond flexibly and with utmost speed in order to get problems with pest infestations under control.

It is essential to conduct a systematic assessment of infestation data for a broad spectrum of different pest organisms in order to make overarching statements on the influence of climatic changes on pest organisms possible. In respect of brown rust (*Puccinia triticina*) affecting wheat, barley and triticale, a hybridised form of wheat crossed with rye, and in respect of the rape beetle (*Meligethes aeneus*), the current state of scientific consensus is that climate change entailing warmer winters and drier, warmer springs will benefit the development or even mass reproduction of such pest organisms. As far as powdery mildew (*Erysiphe gramins*) infestations on wheat are concerned, the relationships are not quite clear yet. So far

LW-I-4: Infestation with pest organism – case study

As far as brown rust, powdery mildew and rape beetle are concerned, it is understood that climate change will alter the course of infestations. The two first-named species may become increasingly relevant. That notwithstanding, it is important to note that the development of pest organisms takes place in very specific ways. On the basis of currently available data it is not possible to make any generalised statements on the impact of climate change on the infestation scenario.



Data source: JKI (analyses of infestation-data of the federal states) there are no analyses available in Germany nationwide of any long-term data series in respect of the relationships. However, it was possible to process data from two Länder (Saxony-Anhalt and Mecklenburg-Western Pomerania) which provide a first glimpse into temporal development trends for the three pest organisms mentioned above. Unfortunately, it has not been possible to date to derive any distinct information of the influences of climate change.

In respect of brown rust observed in Saxony-Anhalt and rape beetle in Mecklenburg-Western Pomerania, it has been possible to discern a significantly rising trend towards higher infestation since the 1970s. As far as powdery mildew is concerned, for which there are also data available from Saxony-Anhalt, there have been, since the 1970s, recurring years of high infestations. However, it must be said that judging by the time series illustrated, the infestation seems to be in decline. The data also show that the degree of infestation with a specific pest organism can vary considerably. There is no singular definitive weather pattern discernible which furthers pest infestations.

However, the situation in the particularly hot and dry year of 2018 demonstrates that specific weather scenarios can entail a massive spread of pest organisms. For example, 2018 was a pronounced brown-rust year. Most fungal-type pathogens do not play an important role under such difficult circumstances, but brown rust does not need any rain – dew is sufficient for causing infection. This fungus which in the past was mostly found in warm agricultural areas, has now become relevant throughout Germany and is increasingly becoming the predominant disease afflicting winter wheat. The earlier in the year high temperatures are reached, the earlier the point when brown rust can become infectious and the more favourable the conditions for the continued development of this infection. The rape beetle likewise benefits from high temperatures. It overwinters in beetle form in loose soil layers at woodland edges or in hedges, thus enabling it to start its 'season' as soon as warm spring temperatures set in. The beetle lays its eggs in the buds of rapeseed blossoms. Basically, the use of early-flowering varieties (cf. Indicator LW-I-1, p. 150) can reduce the infestation in the sensitive budding stage, but in very warm spring temperatures even this preventative measure may lose its effectiveness. When interpreting the trend towards increased rape beetle infestation, it has to be borne in mind that by now the species has developed increased resistance towards the usual insecticides. The decline in infestations with powdery mildew can be attributed (among other factors) to lower demands on temperatures compared to brown rust. It is conceivable that in the course of climate change, its optimum temperature range of roughly 17 to 18 °C might be exceeded more frequently.

With regard to the impacts of climate change on pest organisms, there are many questions that remain to be answered. (Photo: © Aleksa / stock.adobe.com)

This might have adverse effects on its development and the infestation conditions.

Representative statements regarding infestation issues are not yet possible on the basis of the data presented here. There are major differences in the infection risk and the infestation between different pest organisms, from region to region and from year to year. In recent years, it has been possible to increase the resistance level to fungal diseases in particular. The frequency and intensity of infection, at least for some crop species, have therefore become very dependent on the varieties grown. It is worth mentioning that also the ways in which plant protection measures are carried out vary considerably from one crop species to another.

The Julius Kühn Institute (JKI) carries out analyses on the climate and weather-related dependence of infestations with pest organisms, which means that in future it may become possible to make more comprehensive and representative statements on the development of infestations with pest organisms. A further development of the indicator – where possible towards a nationwide illustration – is planned for the next DAS Monitoring Report in 2027. It is expected that extensive synergies will evolve – both at contents and organisational level – with the aid of findings from surveys for the indicators contained in the 2013 National Action Plan for the sustainable application of pesticides (cf. Indicator LW-R-5, p. 164) and activities carried out within the framework of the national monitoring of biological diversity in agrarian landscapes (MonViA).

Adaptation of management planning

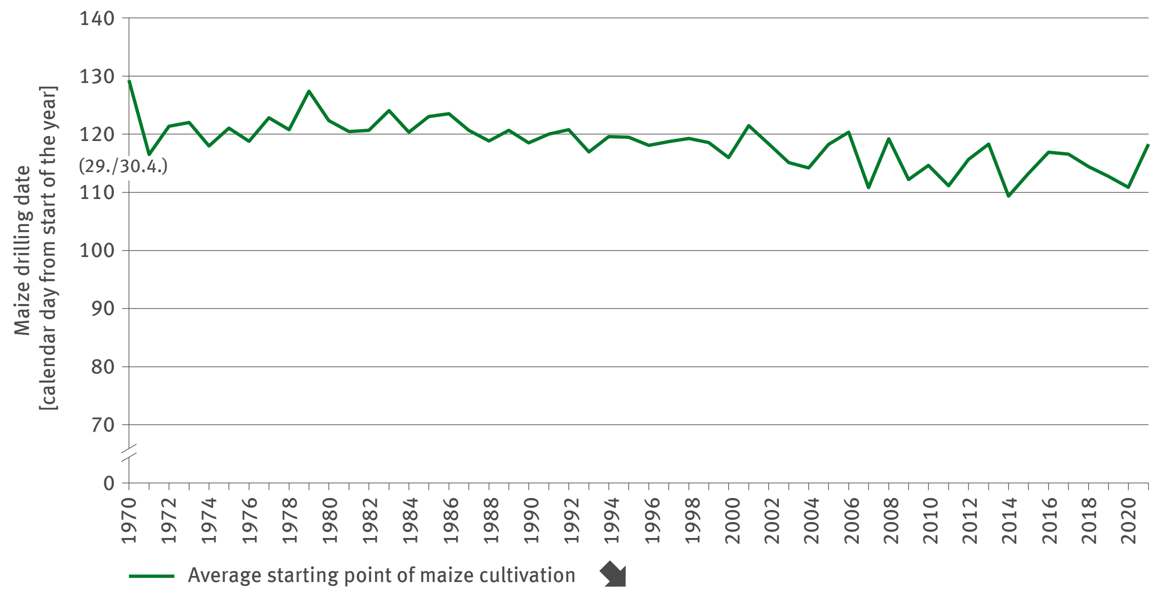
Owing to changes in seasonal weather patterns associated with climate change, agricultural businesses are forced to adapt their management planning accordingly. The most favourable times for tilling, sowing and harvesting and for the application of fertiliser and pesticides have to be redetermined specifically for every year. Both direct and indirect effects of weather patterns play a crucial – albeit not the only- role in deciding which management operations should be continued and which should be terminated. As far as the direct effect of weather is concerned, it is, for instance, important to determine the most favourable time for tilling, and this timing is heavily dependent on soil moisture. Another example is the scheduling of sowing (drilling) in spring, because specific crops such as maize should not be sown until and unless the soil has reached a certain temperature. Indirect effects of changed weather patterns play a role in the choice of crop species and varieties (cf. Indicators LW-R-2, p. 160, and LW-R-4, p. 162) and the selection of crop rotations made by agricultural businesses in order to adapt to changing climatic framework conditions.

Such adaptation practices are basically nothing new in agriculture, as these challenges have always had to be addressed in carrying out management operations as they had to respond to the seasons and phenological development phases of crop species. Nevertheless, it is conceivable that the incidence of unpredictable weather patterns or weather scenarios is on the increase.

Apart from data on temporal changes in the development of plants, the DWD‘s nationwide phenological observation network also collates data on changes in management operations carried out in respect of agricultural crops. Depending on the management operation concerned, the influences on scheduling vary. Apart from weather patterns, there are usually several other factors to be considered. Of foremost relevance is the selection of varieties and crop rotation. Sowing can only commence after the previous crop – cultivated as part of crop rotation – has been removed. Organisational requirements in individual agricultural businesses may also play a crucial role. Depending on the cultivated area and the extent of a farm’s own machinery or the contractor’s machinery,

LW-R-1: Adaptation of management rhythms

With regard to individual management operations for crop cultivation, agricultural businesses respond by scheduling these tasks according to changing weather patterns. In the course of the past fifty years, maize cultivation (drilling) was brought forward by more than a week. The trend towards this early start is significant. For maize cultivation in particular, this earlier sowing is advantageous as it improves the ripening conditions.



Data source: DWD (phenological observation network)

management operations may have to be rescheduled. In other words, such decisions on rescheduling management operations in agriculture are not exclusively dependent on weather patterns. Nevertheless, relevant observations may provide useful pointers for adaptations in respect of management planning.

The cultivation of maize takes place typically in the course of April and May once the soil is warm, well dried and resilient, while the soil temperature amounts to roughly 8 to 10 °C. Sowing at the right moment is crucial for plant development, healthy growth and thus ultimately also for yields. In spring any effects due to management operations will be comparatively minor, and the influence of weather patterns play a more important role at that time, rather than at a time when management operations are scheduled for summer and autumn. Therefore the changes regarding cultivation dates in spring are a suitable subject for indication in the context of climate change, especially for summer crops.

Apart from the weather pattern in spring, the decision to sow summer crops also depends on whether and to what extent the catch crops were killed by frost during the winter months or by the end of winter. In cases where this cannot be safeguarded, additional work may be necessary in the preparation of seedbeds for the main crop of maize.

Over the past fifty years, maize cultivation started earlier and earlier. Judging by the mean of the past ten years, maize was sown more than a week earlier than in the 1970s, . It is also remarkable that since the turn of the millennium, there have been distinct fluctuations from year to year. Extremely early sowings occurred in the years of 2014 and 2020. At the same time, those years were characterised by an extraordinarily high number of days with soil temperatures of more than 5 °C (cf. Indicator BO-I-4, p. 138).

Sowing maize early is advantageous insofar as maize requires specific amounts of warmth to become ripe enough for ensiling or to reach grain maturity for use as corn. Under these circumstances, the optimum harvest dates for silage maize can be reached earlier. As far as grain maize is concerned, a longer vegetation period usually results in lower water contents in the grain, thus achieving higher market values (cf. Indicator LW-R-1, p. 162). Furthermore, sowing maize early can help significantly in curbing competition from weeds. Besides, early in the year the soil is protected better from erosion.

In order to schedule management operations successfully, it is essential to observe plant development and weather patterns closely. (Photo: © encierro / stock.adobe.com)

Apart from the planning and scheduling of management operations, there are other measures which play an important role in terms of soil protection and improving the growth conditions for crops: In order to buffer the worst of the impacts of extreme weather events, to avoid erosion, and to safeguard the replenishment of water and nutrients in dry periods, management operations have to maintain high infiltration rates as well as storage capacity for water and nutrients and a good aggregate structure in the soil. It is essential to maintain the organic soil substance or – where necessary – to improve it as required by site-specific circumstances (cf. Indicator BO-R-1, p. 140). Stabilising measures in individual agricultural businesses can include the cultivation of catch crops, nurse crops, various species combinations, incorporation of harvest remnants, cultivation of perennial crops, organic fertilisation and adaptation of soil tillage. At a higher organisational level, the following elements are considered essential for adapting agriculture to climate change: feed and farm manure synergies, the integration and utilisation of perennial fodder plants in crop rotations, the conservation of grassland (cf. Indicator BO-R-2, p. 142), maintaining the stability of mixed livestock-cum-arable farms as well as ecological farming and landscaping (such as agroforestry systems, contour management and beetle banks).

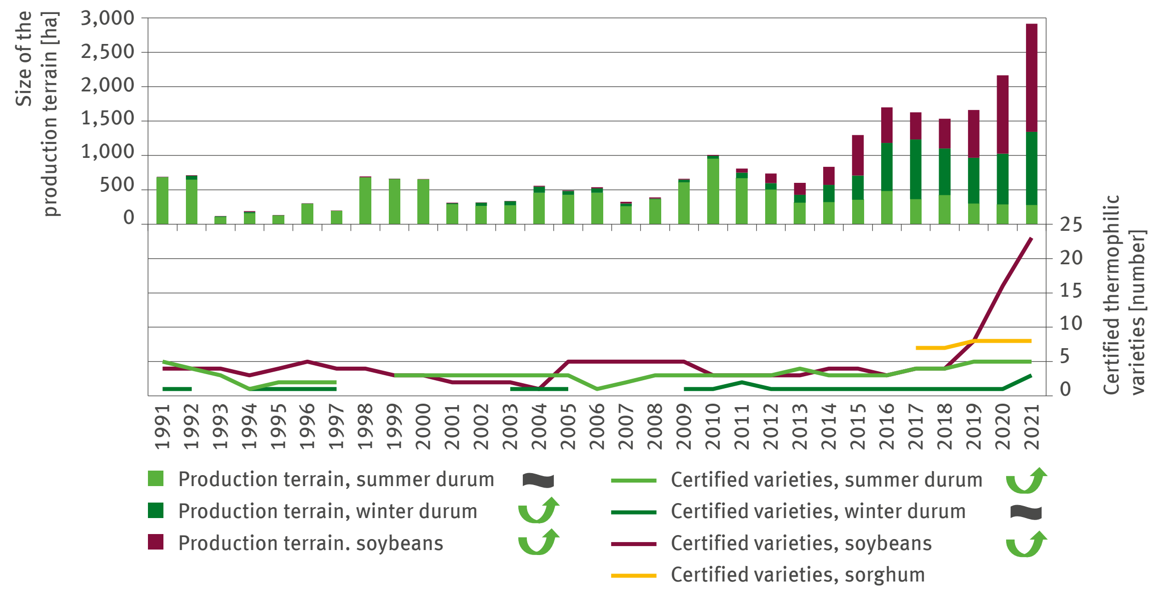
Changed climate – new crops and varieties

Climate change and milder weather patterns open up new options for agriculture regarding the choice of crop species. The cultivation of thermophilic crop species in Germany may benefit from expansion provided there is sufficient market demand and the prospect of cultivation appeals to agricultural businesses from a commercial point of view. Thermophilic crop species include grain maize, sorghum, soybean, sunflowers and durum wheat. The increasing interest in thermophilic crop species is reflected not only in the cultivation terrain (cf. Indicator LW-R-4, p. 162), but also in the activities undertaken in respect of the breeding of plant varieties and seed production. This has led to an increase in demand for varieties which – in the current and prospective change in circumstances – promise high-quality crops and secure yields. Weather patterns – to the same extent as any prospective marketing opportunities, individual experience and preferences prevailing in agricultural businesses, their willingness to experiment, as well as other factors – play an important role in selecting a crop species. Breeders organise the development of their varieties in line with the new requirements. Nevertheless, it typically takes several years to breed a new variety and to obtain certification from the Federal Plant Variety Office (BSA). This means that changed demands for certain varieties is not always reflected in the number of new certifications. An important indication of the rising demand for seed material and mounting interest in growing certain crops is also reflected in the development of the terrain used for the production of seed material.

Especially over the past seven years, a clear dynamic was observed in the certification and production of seed material in respect of durum wheat and soy. As far as durum wheat is concerned, there is a distinct preference for winter durum wheat, as outwintering offers many cultivation advantages over spring sowing. With regard to soy, the cultivation of this crop species was given a commercial fillip in 2013 in view of grants becoming available within the BMEL's protein plant strategy[111]. Furthermore, discussions around a vegetarian or less meat-based diet have contributed to driving the development of suitable varieties forward, so that indigenous soy (also non-genetically modified) can be grown in the prevailing climatic circumstances. The first sorghum varieties were certified in 2017.

LW-R-2: Cultivation and production of thermophilic arable crops

Durum wheat, soy and sorghum are thermophilic crops for which growing conditions have improved in Germany thanks to climate change. The interest in these crops is increasing to the same degree as breeders' efforts to develop suitable varieties, and the extent of terrain on which seed material is produced is increasing too. In respect of soy, the development is proceeding in a particularly dynamic way, as the demand for soy has been rising vigorously.



Data source: BSA (variety databases, database on seed production)

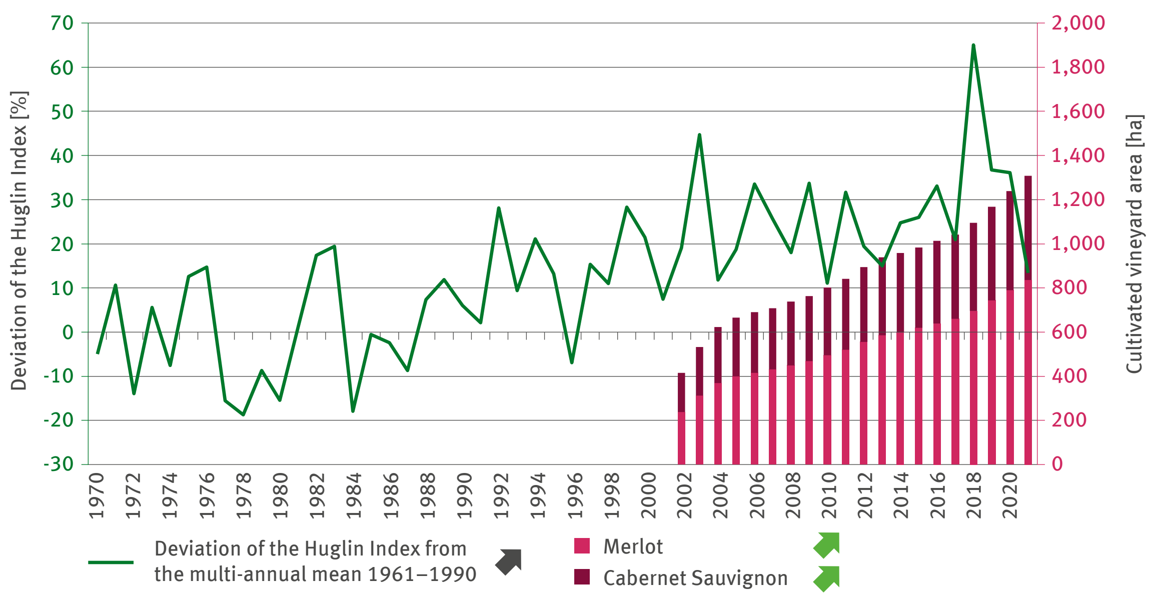
In deciding on annual crop varieties, agricultural businesses can be relatively flexible. However, with regard to perennial crops they have to make a long-term commitment when deciding on a specific variety. Especially in viticulture, the decision on new crop varieties to be planted requires careful deliberation, because vines have a long lifespan of up to 20 or 30 years. Besides, wine happens to be an agricultural product with extraordinarily high added value. The choice of variety is therefore particularly important.

For assessing the cultivation potential of specific grape varieties in certain wine-growing regions, the so-called Huglin Index is used. It sums up the days with temperatures of more than 10 °C for the period of 1st April to 30th September and indicates whether the amounts of warmth required by a grape variety for successful cultivation over an extended period can be achieved in a particular region. In the course of the past fifty years the Huglin Index has risen significantly throughout Germany. As a result, some highly thermophilic red grape varieties, hitherto limited to cultivation in southern regions, have now also become suitable for cultivation in German growing regions. Such varieties include Merlot, Cabernet Sauvignon and Syrah (also Shiraz). These grape varieties are highly acclaimed internationally which makes some viticulture businesses very keen on their cultivation subject to suitable climatic conditions. The areas where Merlot and Cabernet Sauvignon are cultivated, as recorded by wine statistics since 2002, are still comparatively small – in 2021 their proportion of viticultural terrain amounted to just short of 4 %. However, the recent increase in the terrain dedicated to growing these varieties indicates mounting interest. According to statistics, the grape variety Syrah quadrupled its growing terrain by 2021. It is to be expected that climate change will in future be reflected in the choice of grape varieties in Germany. However, it should be borne in mind that, especially in viticulture, consumer demand and fashion trends have a strong influence on decisions made by vintners on which grape varieties to cultivate.

Red grape varieties benefit greatly from climate change. As far as the cultivation of white grape varieties is concerned, climatic changes are seen more critically in respect of their impacts on wine quality and storage potential. Very high temperatures tend to produce rather disharmonious wines with high alcohol content and low acidity values. Nevertheless, this has so far not influenced the size of cultivation terrain used for white grape varieties in Germany.

LW-R-3: Adaptation of the variety spectrum in viticulture

Increasing amounts of warmth signify that even particularly thermophilic red grape varieties become suitable for cultivation in German cultivation areas. Although the cultivation terrain used for growing the internationally popular red grape varieties of Merlot and Cabernet Sauvignon is still limited, there are indications in wine statistics that it is in the process of expanding significantly.



Data source: DWD (German climate atlas – agriculture), StBA (Grunderhebung der Rebflächen und Rebflächenerhebung)

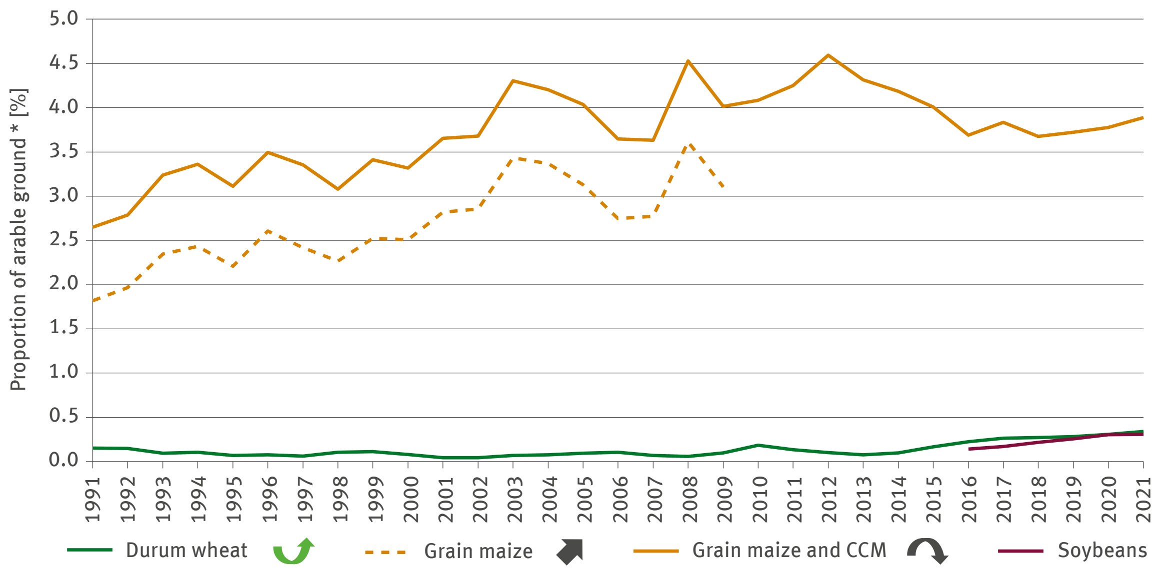
Cultivation terrain of thermophilic crops is expanding

Warmer weather conditions and an increasing choice of suitable varieties (cf. Indicator LW-R-2, p. 160) as well as increasing market demand have led to the cultivation of soy, durum wheat and also maize increasingly gaining in interest in Germany. As far as soybeans are concerned, the cultivation terrain has doubled since 2016 when the species began to be recorded statistically. In 2021 soybeans were grown on roughly 34,200 ha; by 2022 that extent had already increased to 51,500 ha. The cultivation hotspots are located in Bavaria and Baden-Württemberg where soybeans have by now overtaken peas, broad beans and lupins, thus becoming the leading grain legume in cultivation. Nevertheless, domestic production can only cover 3 % of annual demand. Within the framework of the BMEL's protein plant strategy, the cultivation of legumes receives extensive funding in Germany. Latterly, the funding allocated to the protein planting strategy for 2023 was increased by 3 million Euros to a total of 8.6 million Euros. The current Federal government pursues an objective of strengthening vegetable food alternatives. Thanks to the existence of attractive sales channels and high producer prices, there has been – currently and for the near future – mounting interest in the cultivation and in the seed material of soybeans, both in conventional and ecological agriculture. The favourable market-political conditions are of crucial importance for the expansion of soy cultivation terrain. At the same time, advantageous weather conditions help making the cultivation of this crop more attractive in Germany.

The European hotspots for cultivation of thermophilic and relatively drought-tolerant durum wheat are located, above all, in Spain, France and Italy. In Germany this species has been cultivated for many years as a niche crop. The largest cultivation areas are nowadays in Saxony-Anhalt and Thuringia. However, by now durum wheat is also cultivated in the warmer regions of Bavaria, Baden-Württemberg and Rhineland-Palatinate. As far as cultivation is concerned, durum is a challenging and risky crop as its usability strongly depends on its freedom from fungi and diseases. Durum is predominantly used and marketed as semolina for pasta production. Therefore any flaws in the harvested product – which manifest clearly as black spots – exclude the product from sale.

LW-R-4: Cultivation of thermophilic crops

The cultivation areas used for growing the thermophilic crops of soy and durum wheat are on the increase. The decisive factor for this are the agropolitical framework conditions. As a vegetarian protein alternative, the cultivation of soy, in particular, is strongly promoted. However, more favourable climate conditions are an important prerequisite for the expansion of this crop. The cultivation of grain maize is generally more economic where higher amounts of warmth are available.



*Cropland = cultivation area or terrain used for the production of grain, plants harvested green, root vegetables, pulses, industrial crops

Data source: StBA (Bodennutzungshaupterhebung, Erhebung über die Viehbestände)

Weather patterns– especially at harvest time – also play a very important role, and in many regions they have so far been too unpredictable to ensure successful cultivation. If summer droughts become more regular, the conditions for successful cultivation in this country might improve in the long term. In 2022 durum wheat was grown on a terrain of 40,800 ha – the equivalent of scarcely 0.37 % of the total cultivation terrain used for cereals, plants harvested green, pulses, root crops and industrial crops. Given the increased certification of crop varieties and the production of seed materials for winter durum, it is to be expected that there will be an expansion, given that winter durum provides distinctly higher yields than summer durum.

In view of the fact that durum grain is very firm, special rollers are required for grinding, and they are not readily available in every mill. However, having appropriate mills in the vicinity, is an important prerequisite for expanding the cultivation of durum wheat. To date, there are only six durum wheat mills in Germany capable of grinding durum wheat to produce semolina[112]. As shown above, climate change plays an important – albeit not the only crucial – role in furthering a further development of the terrain for durum wheat cultivation.

Maize is a crop that has been cultivated in Germany for a long time. Contrary to using the whole plant as silage maize for animal fodder and energy generation, grain maize – using only the cob for animal feed or human food production – depends on comparatively high amounts of warmth for the crop to ripen. The expansion of the cultivation terrain is therefore linked partly to more favourable weather patterns. Consequently, in respect of grain maize, the prospects of livestock breeding have to be taken into account, because the demand for fodder will shrink as livestock (especially pig) numbers decrease. However, this development is not influenced by the cultivation of energy plants. As soon as it has been harvested, grain maize has to be dried in order to lower its water content to roughly 14.5 %. Hence the costs of drying are the crucial profitability factor, especially in view of mounting energy prices. The more favourable the weather patterns and the drier the grain maize as it comes in from the field, the greater the commercial gain from its cultivation. Moreover, the temperature increase over recent years led to earlier ripening and harvesting of grain maize. The fact that fields were cleared earlier benefitted the subsequent cultivation of winter wheat, thus facilitating the scheduling of crop rotation. However, when conditions become very dry, grain maize will suffer too. Consequently, the grain maize harvest of 2018 was disastrous. In summer 2019, however, the harvest was unexpectedly good as a result of rainfall in late summer, thus increasing yields.

The cultivation of thermophilic crops such as soy and durum wheat is gaining in interest.
(Photo: © Johannes Wilke / stock.adobe.com)

There is some ambiguity in interpreting the relationships between the expansion of the cultivation area for grain maize and climate patterns. This is because grain maize can be processed into a moist silage feed known as corn-cob mix (CCM). In the production of CCM both the grains and the centre of the cob are utilised. For this type of use, favourable drying conditions are commercially less important than for the use of grain maize for ripening. From 2010 onwards statistics no longer differentiate between naturally ripened grain maize and CCM. Prior to this statistic amalgamation, the extent of the total terrain used for grain maize cultivation was constantly three to four times greater than that used for CCM, so the combined grain maize / CCM data also allow conclusions to be drawn. Basically, it is fair to say that – to explain the development of the cultivation terrain for grain maize in recent years in the light of prevailing weather conditions – has its limitations. For the future, it is to be expected that the current agropolitical framework will continue to play an important role. Given that grain maize responds relatively little to reducing the amount of nitrogen fertiliser, it might gain in attractiveness as a summer crop.

The cultivation terrain of sorghum, which is originating from the Sahel region, is not yet recorded separately in agricultural statistics. So far, temperatures in Germany have been too low for cultivation, so the areas under cultivation are still very small. However, given that by now there is also the development of indigenous varieties taking place (cf. Indicator LW-R-2, p. 160), the interest in cultivating this specific variety might increase.

Targeted application of pesticides

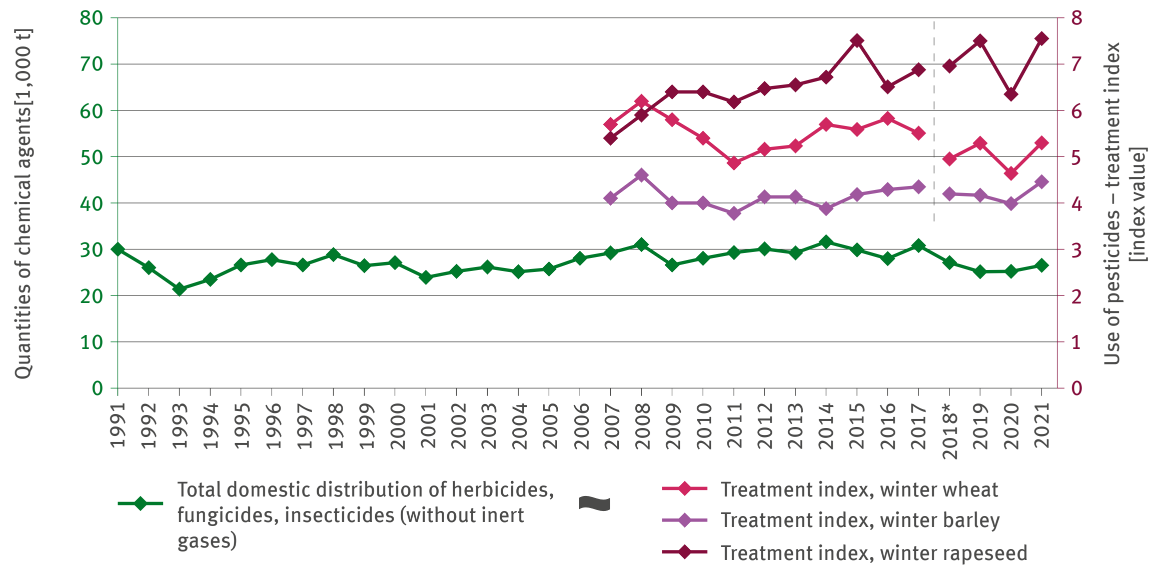
It is not yet possible to make any tangible forecasts regarding the impacts of climatic conditions and weather patterns on the infestation or infection with pest organisms of agricultural crops. It is undeniable, however, that pest organisms can respond very sensitively and spontaneously to changed weather conditions; this requires agricultural and horticultural businesses to respond flexibly and with the utmost speed in order to get plant protection problems under control.

Precautionary measures have become ever more important for agricultural businesses in order to ensure that crops are healthy and sufficiently resilient to buffer extreme weather events and latent infestation scenarios. This involves careful monitoring of crops within the framework of integrated plant protection and with due consideration of resistance management in the application of pesticides, while giving priority to the application of non-chemical plant protection agents. The National Action Plan for Sustainable use of Plant Protection Products (NAP) adopted by the Federal Government and the German Länder aims to further reduce the potential risks posed by the application of pesticides, and to limit the application of chemical pesticides to what is absolutely essential. It is intended that the NAP become an integral part of the new overall concept adopted by BMEL in order to reduce the use of pesticides. This concept is in line with the European Farm to Fork strategy which aims at reducing the application and the risk involved in the use of pesticides overall by 50 %[113].

Climate change can result in changing the first occurrence and development as well as the infection or infestation conditions of various pest organisms (cf. Indicator LW-I-4, p. 156). The appropriate response proposed is the targeted monitoring of crops as well as conformity with and – where necessary – adaptation of benchmark values as required for effective control. In practice this means that production systems will have to be adapted and that increased investments will be required in up-to-date and improved systems for forecasting and also regarding assistance in decision-making.

LW-R-5: Sales and application of pesticides

Climate change will lead to major fluctuations in the occurrence of pest organisms and in their control by means of pesticides. Suitable adaptation strategies should help curb the sale of pesticides and prevent an increase in the intensity of plant protection. So far, domestic sales of pesticides have not indicated any particular trend. Currently, it is not possible to make any statements on trends regarding the treatment index.



*As of 2018 different calculation of treatment index, hence trend analysis impossible

Data Source: BVL (reports according to § 19 Plant Protection Act), JKI, plant protection services of federal states (network reference farms plant protection)

When interpreting long-term data series on the sale of pesticides and the intensity of plant protection, it should be borne in mind that, apart from weather-related causes, developments are influenced by a considerable number of other factors. If, as a result of circumstances, measures – such as an increased specialisation – taken by agricultural businesses, lead to restricting their crop rotation practices, this could potentially entail an increase in pesticide problems. It is also important to remember that decisions to minimise tillage – in the interest of better soil protection and increased humus production – can result in increased weed growth competing with crop plants. In other words, management decisions can bring about an increased use of herbicides or pesticides if their use becomes inevitable as a last resort, in line with the principles of integrated plant protection.

The indicator illustrates the domestic sale of pesticides. This does not permit inferring any conclusions regarding the intensity of application or any associated risks. In the course of the past twenty years, the amounts sold have not changed to any relevant extent. If the spectrum of pest organisms changes as a result of climate change – for instance because individual groups of organisms benefit particularly from warmer weather patterns – it is conceivable that this development may be reflected also in the amounts of certain categories of pesticides (herbicides, fungicides, insecticides) sold, or in respect of the amounts of other agents / groups of agents sold. It is of interest to note that – at least among the categories of pesticides – no such shifts have been identified yet for the past twenty years. However, more targeted research would be required in order to identify the actual relationships with climate change underlying these developments.

While interpreting the data on sales volumes, it should be borne in mind that pesticides contain different amounts of active ingredients. However, there is no direct link between the ecotoxicological risks and the content of active ingredients. Therefore, any assessment of the risk potential is possible only with the aid of suitable risk indicators. Basically, regarding the development of pesticide sales, it has to be taken into account that the certification scenario can also be influenced by (global) political circumstances. For example, bottlenecks in supplies from China resulting from the country's zero-Covid policy, and recently the energy crisis owing to the war in Ukraine, have led to substantial price increases regarding pesticides, especially in respect of herbicides. Such developments can entail reduced sales figures.

The treatment index makes it possible to make statements on the intensity of the application of pesticides[114].

Crop monitoring is an essential prerequisite for targeted plant protection. (Photo: © Bits and Splits / stock.adobe.com)

It offsets the number of applications made per annum by the amounts used per spraying operation in relation to the highest permitted application quantity for the respective crop and indication. Any increase or decrease in the application intensity of pesticides is expressed in terms of rising or falling treatment indices.

In 2018 a methodological modification took place regarding the calculation of the treatment index. As a result of this modification, the indicator now calculates the intensity of the pesticide application in more detail. This adjustment caused a break in the time series which makes it currently impossible to provide a trend analysis. Besides, it is generally difficult to carry out trend interpretations in this context, as there are multiple factors of influence to be taken into account, alongside the weather patterns prevailing in any specific year. In this case too, targeted analyses would be required in order to facilitate a quantification of the influence of climate change.

Suitable adaptation strategies should help to prevent an increased intensity in the application of pesticides, despite any existing challenges associated with climate change.

Irrigated terrain on the increase

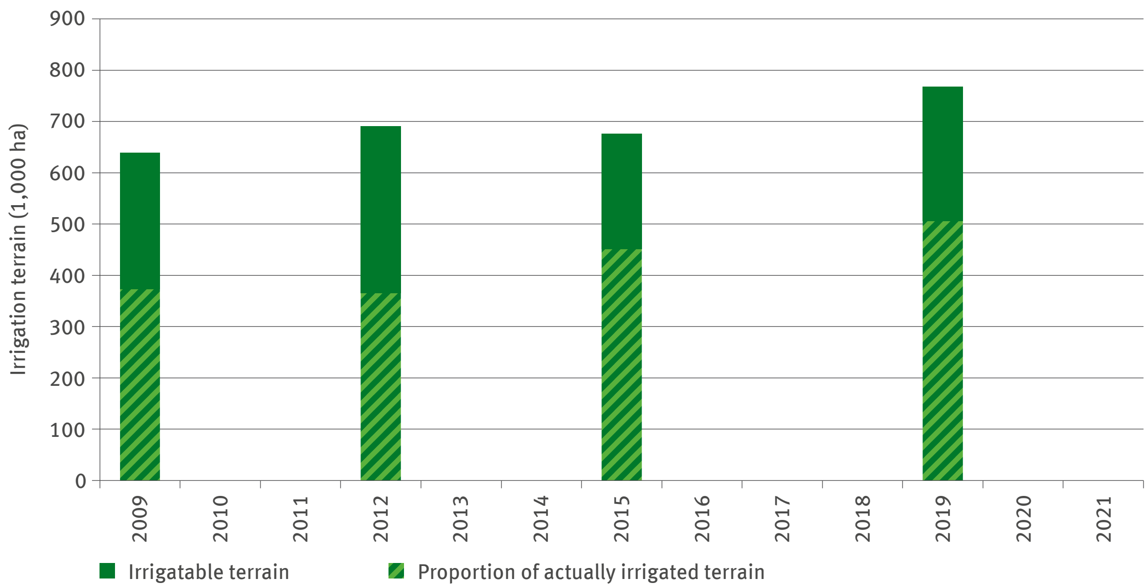
A fundamental requirement for high and stable agricultural yields is an adequate supply of water. The cultivation of potatoes and the production of vegetables, and also the cultivation of special crops are particularly worthy of irrigation. In many regions, marketable qualities and stable yields can only be achieved by using additional irrigation of fields in need of water. Two adverse climatic trends can already be observed today in respect of adequate water supply for agricultural crops during the main growth period, which are of crucial importance for the development of good yields: On one hand, at least regionally, (early) summer precipitation is in decline, while on the other, precipitation can fall increasingly as heavy downpours, thus making the availability of water for plants even worse (cf. Indicator BO-I-1, p. 134). Both developments have adverse effects on the water supply available for agricultural crops. The agricultural sector can, among other things, ensure an increase in soil moisture by cultivating more drought-tolerant varieties and by employing adapted processes of (conserving) soil cultivation and humus enrichment (cf. Indicator BO-R-1, p. 140). However, the impacts of such agronomic measures can be very limited depending on site conditions. Another option is to reduce water bottlenecks by making the irrigation of agricultural crops more efficient.

The need for irrigation of agricultural and horticultural crops usually arises as a result of extraordinarily long periods of dry weather or in regions where the meteorological conditions (for instance owing to low precipitation levels) and the soil conditions are generally unfavourable. Moreover, it also depends strongly on the relevant crop species grown whether additional irrigation is needed owing to crop-specific water requirements. Regions with high irrigation requirements are not necessarily drought areas. The (future) development of irrigation requirements and the irrigation actually carried out will also depend on the 'crop mix'.

In 2015 some 451,800 ha of outdoor cultivation terrain was irrigated in Germany. In 2019 this value had already risen to 506,480 ha. Compared to 2009 values, this is an increase by 36 %. These figures do not include any areas where frost protection irrigation was carried out; nor do

LW-R-6: Agricultural irrigation

Under climate change conditions, the need for irrigation is likely to increase and extend to additional crops. In Germany, both the terrain fitted with irrigation technology and the actually irrigated terrain have increased since 2009. In 2019, 506,480 ha of outdoor cultivation areas were irrigated. Frost protection irrigation is not included in these figures.



Data source: StBA (Landwirtschaftszählung, Agrarstrukturerhebung) they include any cultivation areas under high, walkable protective covers, such as greenhouses. With almost 55 %, Lower Saxony is the state with the highest proportion of land nationwide where irrigation plays the greatest role, followed by North Rhine-Westphalia with 10 %. In all the other Länder, this proportion is only up to 6.3 %.

By comparison, in 2015 and 2019, the areas – equipped with irrigation technology and where hence irrigation actually took place – increased further, amounting to 676,400 ha and 768,317 ha respectively. With 14 %, Lower Saxony was the state with the highest proportion of irrigatable terrain compared to the total of terrain in agricultural use, while the region of Lüneburg came top of the leader board with 25.6 %. Whether irrigation actually takes place in a particular year depends on the volumes of rain falling, but also on cost-benefit calculations carried out by the businesses concerned, and not least on the volumes of water available in the region concerned. In the drought year of 2019, 66 % of irrigatable terrain was irrigated, whereas in 2015, the proportion had been lower, amounting to 58 %. The fact that in the region of Lüneburg the cultivation of crops requires such intensive irrigation, is due to the following reasons: That particular area is one of Germany's areas most threatened and affected by drought, although the same might be said, if not even more so, of regions located in the more easterly parts of Germany; however the areas affected are distinctly smaller there. In fact, the region of Lüneburg is one of the main potato-growing areas in Germany. In the district of Uelzen more than 20 % of arable land is used for the cultivation of potatoes. The soils are sandy and therefore have very limited water retention capacity. Irrigation trials in Lower Saxony have demonstrated that both wheat, winter and summer barley as well as potatoes are particularly vulnerable to drought, which can cause distinct losses in yields. However, optimum irrigation of potatoes produces the highest profits. This crop, followed by 'Braugerste' (brewers' barley), is considered the crop most worthy of irrigation.

In order to mitigate any future conflicts of interests arising in the use of water among competing sectors, and also to ensure that limited water resources are used sustainably, the utilisation of water-saving irrigation technologies is indispensable. According to a statistical survey conducted in 2015, there were still 79 % of businesses which used sprinklers for irrigation, whereas only 32 % used (also) water-saving drip irrigation[115]. This is why funding for irrigation technology from sources such as agricultural investment funding programmes is nowadays granted typically only in those cases where such investments are linked to relevant water- (and energy-) saving purposes. In order to practise water-saving irrigation,

Drip irrigation is water-saving but not always suitable for application in annual crops. (Photo: © HotPhotoPie / stock.adobe.com)

it is furthermore crucial to ensure the optimum timing and to use the optimum amount of water: Irrigation in the mornings and evenings is distinctly more efficient in order to minimise water loss due to evaporation.

From an ecological point of view, irrigation cannot be judged to be of equal value in all regions or situations. Adverse effects of irrigation can manifest in terms of lowering the groundwater level and changing the soil's mineral balance. So far, the proportion of irrigated arable land is still low in Germany (amounting to 3 % in 2019). And also the proportion of agricultural use of water for irrigation purposes was low – in 2019 amounting to 2.3 % of total water abstraction, albeit already higher than in 2016[116]. Nevertheless, it is likely that the actual volume of abstracted water is underestimated. It must be said that sustained impacts on the water regime in regional irrigation 'hotspots' or conflicts of use cannot be ruled out. In north-eastern Lower Saxony, the limitations placed on businesses within the framework of water allocations – in accordance with permission required under water-related law – might be a limiting factor for any further expansion of irrigation. During the 2018 drought, it is estimated that some of these water allocations were indeed exceeded. It is therefore essential to increase water use efficiency. Opportunities include the increase in humus content, furthering deep root penetration, optimal tillage, creative crop rotation, choice of suitable species and varieties, adapting planting densities, irrigation control and adapting irrigation technology. Furthermore, there are options available for seasonal water storage


Photo: © matousekfoto / stock.adobe.com

Woodland and forestry

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

Germany's forest or woodland areas amount to approximately 11.4 million hectares which equates to roughly a third of the entire land surface. Owing to their multiple ecological, economic and social functions, woodland and forest ecosystems are of particular importance. The Federal Forest Act therefore requires that the forest (including woodlands) is to be conserved, and all its functions are to be maintained and, where necessary, enhanced and its proper management is to be safeguarded.

The heat and drought years of 2018 to 2020 as well as 2022 have demonstrated with unprecedented clarity to what extent climate change is a threat to the forest's existence. Quite suddenly, the issue is no longer 'just' to safeguard the forest's condition, growing capacity and good structure but its conservation in general. It has become a challenge to safeguard the actual forest area, while the reforestation of calamity areas has turned into a Herculean task making substantial demands on financial and staffing capacities. The objective must remain to maintain the forest functions for protecting water, soil, biodiversity, regional climate and as a source of recreation for human being; functions that are even more important in the face of climate change. Not least, forest conservation is indispensable also in terms of climate protection, as woodlands and forests are important carbon sinks. Whenever a vast expanse of forest dies or burns down, it becomes an additional source of greenhouse gas emissions – completely contrary to this goal.

DAS Monitoring –what is happening due to climate change

Climate change and the associated extreme weather patterns – such as heat and drought and possibly also storms – combine to confront forestry with one of its greatest challenges. The impacts on the nation's forests have to be taken very seriously as climate-related changes are progressing at unprecedented speeds, thus overwhelming the natural adaptability of long-lived forest ecosystems.

The impacts of climate change can be seen both in natural, unmanaged woodlands and in forests which are more or less subject to intensive silvicultural utilisation. It has now been 30 years during which the condition of the forest has been recorded in order to obtain an integral picture of the vitality of trees and forests (cf. Indicator FW-I-3, p. 178). Up until the end of the 1990s, data reflected the positive effects of a decrease in pollutant inputs. However, after the summer of 2003, it became evident for the first time that drought and heat were having serious detrimental effects on forest and woodland ecosystems, especially in areas with site-inappropriate growing stock. The drought years of 2018 to 2020 later demonstrated the momentous scope of the problem. There was increasing evidence of the canopy breaking up. From 2019 onwards, it became obvious that all tree species (including a proportion of dead trees still standing) were increasingly affected by dieback. As far as spruce and pine are concerned, the dieback rate peaked in 2020, while values for the deciduous beech and oak were continuing to rise in 2021 (cf. Indicator FW-I-4, p. 179). In those years, numerous trees died completely, thus having to be removed from forest stands. The proportion of unscheduled utilisation (in technical parlance: arbitrary use) of damaged timber, compared to the logging total, reached record values in 2019, amounting to 67 % and in 2020 reaching almost 75 % (cf. Indicator FW-I-5, p. 180). In 2021 this proportion – with just under 61 % – still amounted to almost the same percentage as in 1991 after hurricane Lothar. Up until 2018 the peak values of unscheduled or arbitrary use of damaged timber had been due to severe storm events. As of 2019, the 'insect timber' amounted to just under 70 % whereas by 2021 it distinctly accounted for the bulk of the proportion of damaged timber, with more than 81 %. The bark beetle, in particular, benefitted from recently deceased or weakened trees as a result of warm weather patterns and an abundant supply of breeding sites. This enabled a distinctly greater number of reproduction cycles and broods (regionally up to six cycles) annually (cf. Indicator FW-I-6, p. 182). This mass reproduction of beetles affected spruce trees in particular: The volumes of damaged timber owing to infestation with spruce bark beetle in some Länder in the years 2019 to 2021 was a hundred- to two hundred-fold higher than on average in the years of 1998 to 2017 (cf. Indicator FW-I-7, p. 183).

Heat and drought also made their mark on the forest fire statistics. During the period between 1991 and 2017 the expanse and number of forest fires was still decreasing despite – in meteorological terms – an increase in forest fire hazards. Forest fire prevention and rapid intervention as soon as a fire was breaking out, made it possible to prevent major damage. However, in 2018 and 2019 the extreme weather patterns were also clearly reflected in the forest fire scenario. There were considerably more and – in the north-eastern Länder – more large-scale forest fires. The most extensive forest fire occurred in Mecklenburg-Western Pomerania where an area of 944 ha was destroyed (cf. Indicator FW-I-8, p. 184).

The colossal forest damage and the high volume of calamity timber also impacted on the productive capacity of the forest. However, data illustrating growth rates are currently available only for the period of 2012 to 2017. This is reflected by distinctly falling growth rates for beech, oak and pine (cf. Indicator FW-I-2, p. 176). Nevertheless, apart from heat and drought, factors such as the generally increased age of stands may have played a role in this development. The growth rates of spruce trees in the period of 2012–2017 was again slightly higher than in the preceding period of 2008–2012. However, after 2017 there is evidence for much disruption in the growth rate of spruce trees. Changes have been observed also in natural woodland reserves free from direct managerial interventions, and these changes can be attributed to climate change. This is how tree species compositions change, especially in areas characterised by lack of water, bringing about a decline in the proportion of beech trees (cf. Indicator FW-I-1, p. 174). Site-inappropriate spruce trees do not play a role – or just a very minor one– in natural woodland reserves. The diminishing proportions of beech indicate that this species loses its competitive strength in these locations compared to other, more drought-tolerant tree species. Given that woodlands are very long-living ecosystems, many developments in such locations generally take place over long periods of time. However, the progress of climatic changes is much more dynamic, thus leading, in some places, to surprisingly rapid changes in the composition of woodlands.

Future climate risks – outcomes of KWRA

As already mentioned in the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7) major risks were identified for the middle of the century regarding heat and drought stress, stress from pests and diseases as well as detrimental effects on timber yields. A high risk of forest fires is expected to arise by the end of this century. Nevertheless – as for the other climate impacts – there is limited certainty regarding this projection. The experience of recent years has demonstrated – especially in the field of forestry – that it is necessary for any calculations to allow for surprising developments. As far as wind-throw damage is concerned, the risk for the present up to the end of this century was assessed as consistently medium (within an assessment grid of low – medium – high), because so far there are no development trends regarding storms discernible. Likewise, there is limited certainty regarding this assessment. The risk of limitations to the recreational function of woodlands is assessed as medium – albeit with low certainty – as of the middle of this century. Large-scale forest damage can impose major restrictions on the recreational quality and attractiveness of woodlands and forests. If, at the same time, the recreational function were to gain in importance, the utilisation pressure on healthy woodlands and forests might increase.

Where do we have gaps in data and knowledge?

Any changes in the composition of tree species and in terms of growth are recorded within the framework of the National Forest Inventory (BWI); however, this survey is conducted every 10 years only. This is also the reason why it is not possible to include a statement in this Monitoring Report on the prevailing tree species mix or the proportion of mixed forest stands. Already in 2019, it was not possible to provide new data for this important indicator (then entitled FW-R-1 Mixed forests) compared to the 2015 Monitoring Report. For an update, data are required from the 2022 BWI which will only be available in 2024 after the submission of this report. The indicator on mixed forests is therefore based temporarily on the 2023 Monitoring Report. Interim inventories identify the condition of the German forest estate on the basis of a restricted range of characteristics for a quarter of the BWI inventory focal points; the data provided refer primarily to the greenhouse gas reporting submitted at Federal level. The interim inventory data from 2017 in respect of carbon reserves made it possible to update and re-issue the indicator for humus reserves in the forest (cf. Indicator FW-R-3, p. 190). Furthermore, it was possible to make use of the inventory data in respect of the timber increment (cf. Indicator FW-I-2, p. 176).

Research projects are underway exploring issues such as the utilisation of satellite image data in order to obtain information on any changes in the composition of tree species in a higher temporal resolution than the BWI. For example, the TI for Woodland Ecosystems – in the joint project 'WaldSpektrum' financed from the Waldklimafonds (woodland climate fund) – identifies remotely-sensed data on the prevailing spruce stocks in order to provide forestry employees and forest / woodland owners with an improved planning tool. With a view to the rapid progression of changing forest scenarios as a result of drought years and the intensive efforts in respect of forest transformation, the BWI conducted every ten years will no longer suffice to illustrate actual changes in a timely manner.

There are also still gaps in terms of data and information regarding the identification of calamity areas and the volume of damaged timber. The diagnosis of wind-throw areas or large areas with tree death symptoms as a result of pest organisms is possible – both operationally and in terms of real-time observation – by means of remotely-sensed satellite data; the methods for identifying the volume of damaged timber have not yet been properly established. This gap is to be closed at least partly, as of 2023 by the woodland climate fund project entitled 'Fernerkundungsbasiertes Nationales Erfassungssystem für Waldschäden' (FNEWs / Remote-Sensing based national detection system for forest damage) operated by the TI. This system is to provide information regarding areas affected by tree death, the volume of damaged timber and other adverse effects on the economy.

Data from the intensive Environment Monitoring in Forestry (LEVEL II) have so far not been used in terms of indicators for the DAS woodland and forestry action field.

For the 'soil' action field, an indicator was developed in respect of soil water in forest soils (cf. Indicator BO-I-2, p. 135) on the basis of a case study for Bavaria. As before, explorations at LEVEL II regarding nationwide assessments continue to be restricted despite harmonisation efforts. As far as soil water is concerned, the TI is currently involved in work aimed at generating homogeneous and gap-free time series with the aid of water-balance models.

While it is already possible to illustrate a wide range of themes in respect of impact indicators for the woodland and forestry action field as part of DAS-Monitoring, there are still gaps at the level of responses in relevant fields of activities. For example, as yet it has not been possible to develop a suitable indicator regarding the theme of woodland conservation measures (controlling deer damage, deer management monitoring, monitoring and curbing forest pests). Neither has it been possible yet to illustrate forest fire prevention and control by means of data.

What's being done – some examples

Given that forests are very long-lived ecosystems, forestry managers need to plan far ahead to take account of changing growth conditions. The aftermath of the drought years has shown that forestry managers are required to be highly responsive. Scheduled management tasks will always have to yield to priority challenges in order to ensure that there is sufficient capacity available to cope with extreme events.

There is policital and operational support available at many levels for the conversion of forests towards more climate-stable stands. Apart from the funding provided for research within the framework of the woodland climate fund, the financing of forest transformation in state-owned forests as well as the funding available for privately-owned forests , especially within the framework of GAK have been expanded considerably (cf. Indicator FW-R-1, p. 186). At the end of 2018 GAK introduced a new eligibility status 'Funding for remedying impacts on woodlands caused by extreme weather events' in order to expedite the clearing and reforesting of calamity areas. Furthermore, in 2022 the funding programme entitled 'Climate-adapted forest management' was established by BMEL for the benefit of private and municipal forest owners; this fund is endowed with funding from the Climate and Transformation Fund (KTF) for the purpose of accelerating the development of stable and climate-resilient forests. Among the eligibility criteria for funding are, for instance, the requirement that measures are implemented for water retention as well as the conservation and maintenance of humus (cf. Indicator FW-R-3, p. 190). The BMBF also provides funding for innovative climate-protection solutions for forest and timber management by means of the 'REGULUS' funding measure.

In order to ensure a site-appropriate and future-resilient selection of tree species in the process of rejuvenation and reforestation, the federal states' forestry departments and institutions revised and re-issued their planning advice, for example by including recommendations on the selection of tree species. In addition, advice to private forest owners has been given more impetus (cf. Indicator FW-R-6, p. 194), in view of the great need for action also in this field.

The Forest Protection Institute (Institut für Waldschutz) launched in 2021 at the JKI is tasked with conducting research into issues of biology, avoidance and integrated control of pests and diseases in forests, and of strengthening any natural control and defense mechanisms prevailing in forests. It is intended that this should lead to the formation of concepts that are suitable for practical forest protection, with due consideration of climate change.

In the process of forest conversion and the associated changes in tree species composition, it is also important to advance the timber market. The challenge is to open up new opportunities for the increased use of timber from deciduous forests for the production of material objects (cf. Indicator FW-R-4, p. 192), to support and expand the range of practical applications in timber-based construction, and not least to gain experience in practical applications (cf. Indicator FW-R-5, p. 193).

Climate changes relevant to the action field

Heat and Drought

In Germany, the annual mean precipitation has increased since 1881 in respect of the total surface area mean measured for the country. There are, however, distinct regional and seasonal differences. Overall, the rainfall mean has remained largely unchanged in summer, whereas particularly in winter, conditions have become significantly more humid. However, these minor changes in mean precipitation values should not be misunderstood as signifying that there are no phases where extreme water shortages occur regionally. Soils can dry out whenever the evaporation in summer increases as a result of high temperatures. Since the 'summer of the century' in 2003, such dry phases in summer have occurred frequently, resulting in soils drying out severely and to considerable depths (cf. page 26).

Impacts of climate change

FW-I-6 Endangered spruce stands

Many trees suffer from diminished vitality caused by climate-related changes, especially during the increasing summer droughts, while thermophilic insects can benefit from such conditions. Bark beetles such as the European spruce bark beetle (Ips typographus) and the six-dentated bark beetle (Pityogenes chalographus) breed – for instance after windthrow – in newly dead timber or by penetrating the bark of trees weakened by heat and drought. In warm years, they can produce up to six generations thus leading to major infestation pressures.

FW-I-5 Damaged timber – extent of random use

After periods of storm, heat, drought and infestation with insect pests, it is essential to remove – at least partially – newly dead trees from any affected areas in order to facilitate reforestation as soon as possible and to reduce the breeding spaces available to insect pests. During and after recent drought years, arbitrary use accounted for almost three quarters of the annual logging total in Germany's forests. The work involved tied up considerable capacities in the forestry sector, which would in fact have been required for implementing forest transformation measures.

Adaptations – activities and results

FW-R-1 Financial support for forest transformation

The transformation of forests by creating climate-resilient stands has become the most important forestry strategy. The transformation objective targets the composition of tree species which are able to cope better with changing site conditions and climatic conditions as well as maintaining well-structured stands. State forest entities have for years made massive investments in forest transformation. In the field of privately-owned forests, and forests owned by corporate entities, the funding opportunities available have been expanded too, the purpose being to catch up on the rehabilitation of vast areas of calamity forest.

Adaptability of natural tree species

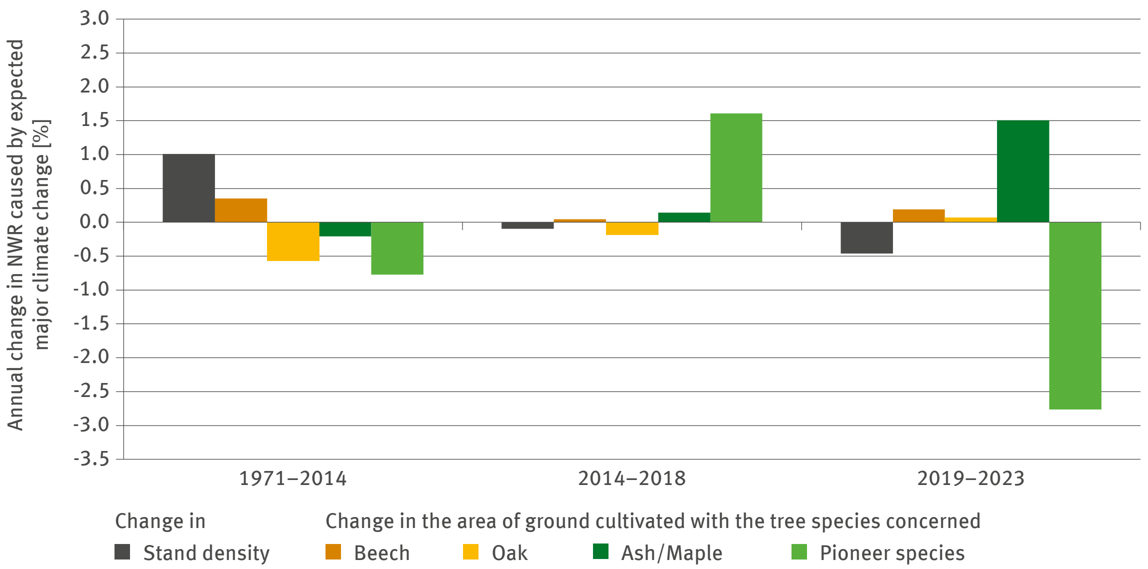
Woodland and forest ecosystems have great longevity. Accordingly, forestry management has to deal with extended production cycles. Planning must be for the long term and has to take future changes in growth conditions into account. Tree species which hitherto coped well with the climatic conditions prevailing at their location may, in coming decades, become more vulnerable to incremental losses. In commercial forests the species composition is informed by silvicultural principles of utilisation and cultivation. These are forests marked by interactions of natural succession and the effects of forest management.

In natural forest reserves woodlands evolve free from direct human intervention. In 2023 Germany had 746 natural forest reserves covering a total of 36,000 ha. In most of these reserves, the autochthonous (locally indigenous) tree species predominate. Whether the limits of their adaptability are exceeded as a result of climate-related changes is an issue that is being examined by means of ongoing observation of natural woodland dynamics in natural forest reserves. The findings resulting from these observations will make it easier for woodland and forest managers to make decisions on the extent to which warmth- and drought-tolerant tree species in stands used for forestry purposes should be incorporated in future, in order to safeguard the existence of our forests with their varied ecosystems alongside the continued use of timber.

Regional projections of future climate change make it possible to differentiate between natural forest reserves on one hand where future changes in water supply are expected to be rather negligible, and on the other, forests where the water regime will presumably be affected quite badly, thus threatening the exposure of stands to drought stress. By categorising the prevailing tree species in groups characterised by specific adaptability properties and by monitoring their long-term development, it is possible to infer statements on the development of adaptation processes in forest ecosystems. Adaptability to drought is regarded as comparatively high in respect of sessile and pedunculate oak, ash, sycamore, Norway maple and so-called pioneer species such as sallow, aspen and rowan. However, it is assumed that the European beech will be rather vulnerable to drought stress.

FW-I-1: Tree species composition in forest nature reserves – case study

In natural forest reserves where stronger climate-related changes with higher temperatures and drier conditions as well as more frequent and more pronounced weather extremes are expected, the stand density has declined, especially in the most recent monitoring period from 2019 to 2023; this is due to increased tree mortality. The proportion of beech trees has continued to rise. The development of pioneer species, in particular, has been subject to major fluctuations.



Data source: Nordwestdeutsche Forstliche Versuchsanstalt / Projektgruppe Naturwälder (federal state data from research and monitoring in natural forest reserves)

Besides, it should be remembered that also other factors such as pest infestation, wind throw or competition for light, water and nutrients will influence the development of individual categories of tree species.

In the natural forest reserves owned by Länder such as Baden-Württemberg, Bavaria, Brandenburg, Hesse, Lower Saxony, North-Rhine Westphalia, Rhineland-Palatinate, Saxony-Anhalt and Schleswig-Holstein, there have been indications of shifts in tree species compositions up to 2014, which cannot be attributed to climate-related changes. The majority of stands are characterised by increasing density, which points to the continued predominance of vigorous trees. While beech trees were able to increase their share, the proportions of oak species and the ash / maple group had declined. This development can be explained on one hand by the competitiveness of beech trees, and on the other, by disease-related dieback affecting oak and ash trees. The group of pioneer tree species showed only negligible change. Overall, events did not indicate that developments were strongly influenced by climate change.

As far as the second and third observation periods from 2014 to 2018 and from 2019 to 2023 respectively are concerned, the direction of development has changed in those natural forest reserves where more distinct climate-related changes with higher temperatures and drier conditions as well as more frequent and more pronounced weather extremes are expected. In this context, the density of stands has decreased, especially during the period from 2019 to 2023. Obviously, this development can be attributed to greater tree mortality owing to drought years occurring more frequently since 2018. Whilst major fluctuations were observed regarding the proportions of pioneer tree species and the group of maple / ash trees, the proportion of European beech (Fagus sylvatica) has continued to increase – albeit to a much lesser extent than prior to 2014. As far as oak species are concerned, a minor decrease, and from 2019 to 2023, a minor increase were observed.

Likewise, in natural forest reserves which are expected to benefit from more favourable conditions in terms of water supply, the period from 2019 to 2023 shows a decrease in the density of stands and a continued increase in the proportion of beech trees. In these areas, the stand density had still increased distinctly in the period of 2014 to 2018.

Natural forest reserves are free from forestry management interventions. These areas demonstrate which species are strongest in terms of competitive success under conditions of climate change. (Photo: © Peter Meyer)

Changes in incremental growth

How quickly trees grow and how much timber volume per time unit develops, is essentially dependent on the nutrient and water supply at their location and also on the prevailing temperatures. In montane topography or in cold hollows which have so far had limited warmth, temperature increases can indeed have positive impacts on incremental growth in stands with stagnating growth. However, in areas such as the Upper Rhine plateau where growth is already limited now in many places owing to heat or drought, further increases in temperature and increasing drought caused by climate change will have detrimental impacts on timber growth. In general it is expected that changes in the weather associated with climate change will have different impacts on timber growth in respect of specific locations and stand compositions.

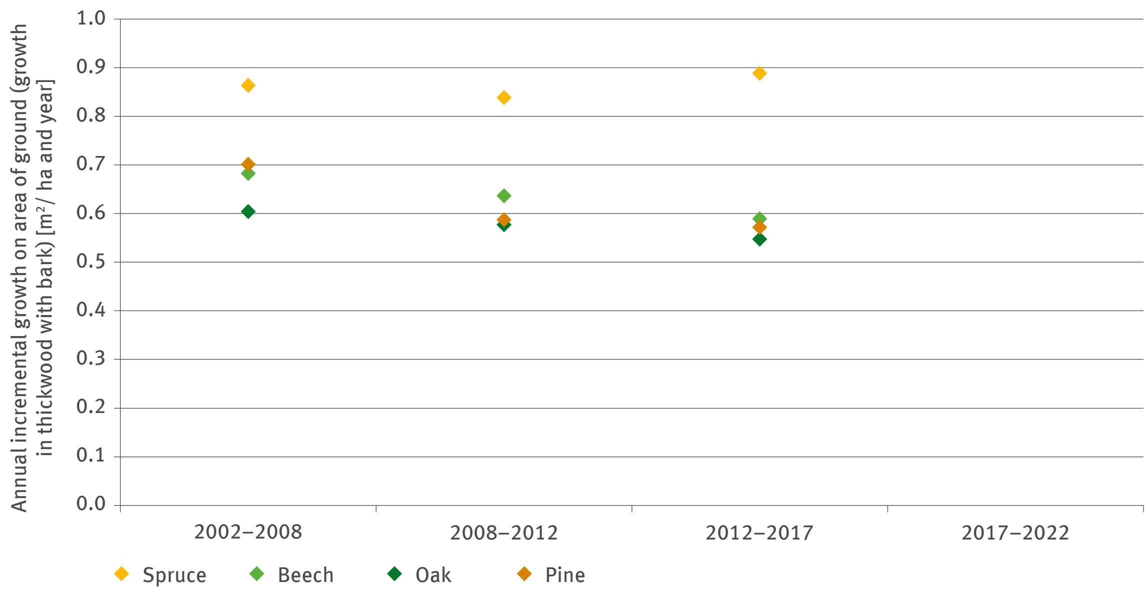
Apart from weather-related effects, there is also a lot of discussion regarding the fertilising effect of increased CO_2 concentrations in the atmosphere. This increase can, in principle, benefit productivity unless there are other factors restricting carbon absorption. Another important influential factor is the age structure of forest stands.

In young trees less than 20 years old, volume growth is low. In subsequent years of the life of these trees, volume growth will increase considerably while in old trees it will decline according to the species concerned. Any analysis of growth data will therefore have to take the age factor into account. The values of the indicator illustrated have therefore been adjusted according to relevant age categories.

The interaction of all influencing factors combined is complex, which is why the resulting impacts on future growth are hard to predict. It is abundantly clear, however, even now that there will be winners and losers regarding the effects of climate change depending on the specific site conditions in a forest. In principle, productive timber growth, apart from the quality of the timber, is a relevant variable in forestry, as it ultimately determines the level of achievable timber yields. If growth increments in commercial forests decline continuously to a considerable extent – for instance owing to unfavourable weather conditions – it may be possible to use targeted silvicultural management measures to actively

FW-I-2: Incremental growth in timber

The incremental growth rates for beech, oak and pine trees have declined distinctly since 2002. It is assumed that dry years and their aftereffects on forest ecosystems have a detrimental influence on growth rates. The higher growth rate in respect of spruce stands in the period of 2012 to 2017 can probably be attributed to the fact that there were no supraregional damage events during that period and that precipitation was of average extent.



Data source: TI für Waldökosysteme (analyses based on the national forest inventory and carbon inventory) reduce stand density and competition within stands, thus counteracting a decrease in the incremental growth of trees in a forest. Besides, incremental timber growth is also important insofar as it is a prerequisite for a forest's ability to function as a carbon sink. The more timber accrues in a forest, the more carbon dioxide can be extracted from the atmosphere for storage as carbon in the timber (cf. Indicator FW-R-4, p. 192). It is assumed that every cubic metre of timber stores approximately 250 kg of carbon. This means that forests with a positive carbon regime make a valuable contribution to protection from climate change.

The outcomes of National Forest Inventories available so far are starting points for the establishment of a long-term time series pertaining to timber growth increments. From 2002 onwards, there are nationwide inventory data available. The data provide opportunities to draw inferences regarding the effects of extreme weather situations in a specific observation period. For example, it was no longer possible to find evidence, especially for spruce forests, in the old-established Länder for the period from 2002 until 2008 in the same volumes as the high average timber increments which were found in those areas until the end of the 20th century. It is assumed that, especially during the hot and dry years of 2003 and 2006, productivity losses will have occurred. However, it must be said that also in the subsequent period of 2008 to 2012 in which there were no drought years, the nationwide mean of timber increments for the four main tree species declined further, with pine trees most badly affected, followed by beech trees. One reason for this may be the increasing average age of all main tree species which would lead to decreasing timber increments.

During the observation period of 2012 to 2017 the incremental growth rates for beech, oak and pine trees declined further. By contrast, timber increments for spruce forests have shown a surprising increase – higher in that period than in the two preceding periods. More than the other main tree species, the spruce tree benefitted from the absence of supraregional damage events (such as storm, drought and infestation with insects), while also benefitting from average precipitation during the period in question. However, it must be taken into account that the surveys were completed prior to the heat and drought years of 2018 to 2020. The current situation would present a distinctly different picture.

A longer time series will make it possible in future to illustrate the long-term impacts of climate change on timber growth increments.

When the timber increment decreases, the volume of timber harvested decreases too, if sustainability principles are adhered to. (Photo: © Ansario / stock.adobe.com)

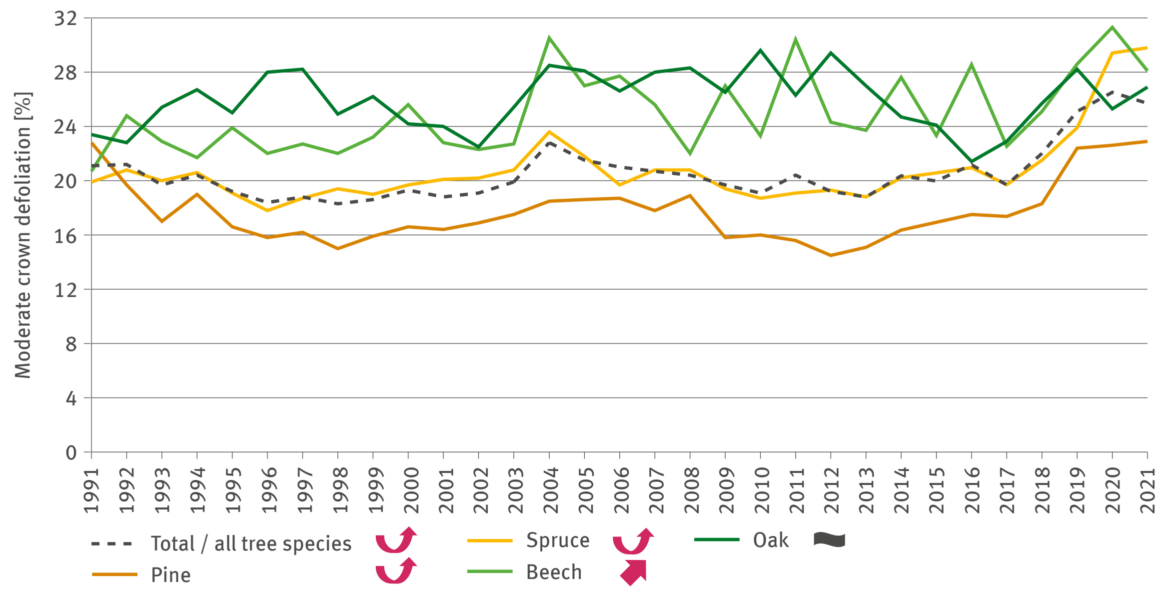
Forest in poor condition with trees dying

For many years, the condition of crowns was considered a suitable indicator for illustrating the impacts of pollutants on the vitality of forest trees. Nowadays the focus of interpreting data on forest condition has shifted to weather patterns and infestation with pests. The connections between the temporal progress of needle or leaf loss and summer heat or drought have become evident. The following points should be taken into account when interpreting data regarding the condition of tree crowns: However, trees losing their leaves or 'needles' does not necessarily mean that they are damaged. In the case of deciduous trees, the spontaneous shedding of leaf mass under unfavourable conditions is frequently an appropriate adaptation response. This response helps trees to take precautions against losing too much water. The situation becomes only critical when an accumulation of drought-stress years causes crown defoliation to become a permanent feature in the affected trees. This kind of development is bound to lead to vitality losses or even to trees dying. However, the situation is slightly different in respect of coniferous trees, because they respond less spontaneously to needle loss owing to their greater investment into making permanent leaves ('needles'). In these cases it seems more reasonable to assume that crown defoliation suggests some kind of damage affecting the trees. The connections with fruiting should also be taken into account, as this too, has a major influence on crown condition. In so-called mast years with particularly heavy fruiting, trees reduce their investment in leaf and needle mass. In those circumstances, a tree's crown appears more transparent. 2016, for instance, stood out as a year of an abundant production of beechnuts – a mast year. So far, there is only scant information available on fruiting regularities. This issue, too, is seen as connected with climate change. For example, in former times beech and oak trees would have had mast years approximately every six or seven years, whereas these days the frequency is every two or three years.

Up until 2017 there had been no indications that the condition of forests was deteriorating continuously owing to climate-related changes. This has changed since the time of the heat and drought years of 2018 to 2020. Apart from oak trees, all main tree species nowadays indicate significantly rising trends in terms of deteriorating

FW-I-3: Forest condition

Until 2017 there were no signs that the condition of forests was deteriorating continuously owing to climate-related changes. This has changed since the heat and drought years of 2018 to 2020. With the exception of oak the mean crown defoliation shows a rising trend until 2021. In respect of beech, spruce and pine trees, crown defoliation was higher than after the extreme year of 2003. As far as deciduous trees are concerned, the values fluctuated strongly from year to year.



Data source: BMEL (nationwide forest condition survey) condition. As early as 2019 – the first year that succeeded the drought year of 2018 – the forest condition in respect of beech, spruce and pine trees was worse than after 2003, the 'summer of the century'. As far as oak trees are concerned, there has been less evidence of crown defoliation caused by impacts of weather patterns. This species is therefore considered to be the tree of the future in climate-resilient forests.

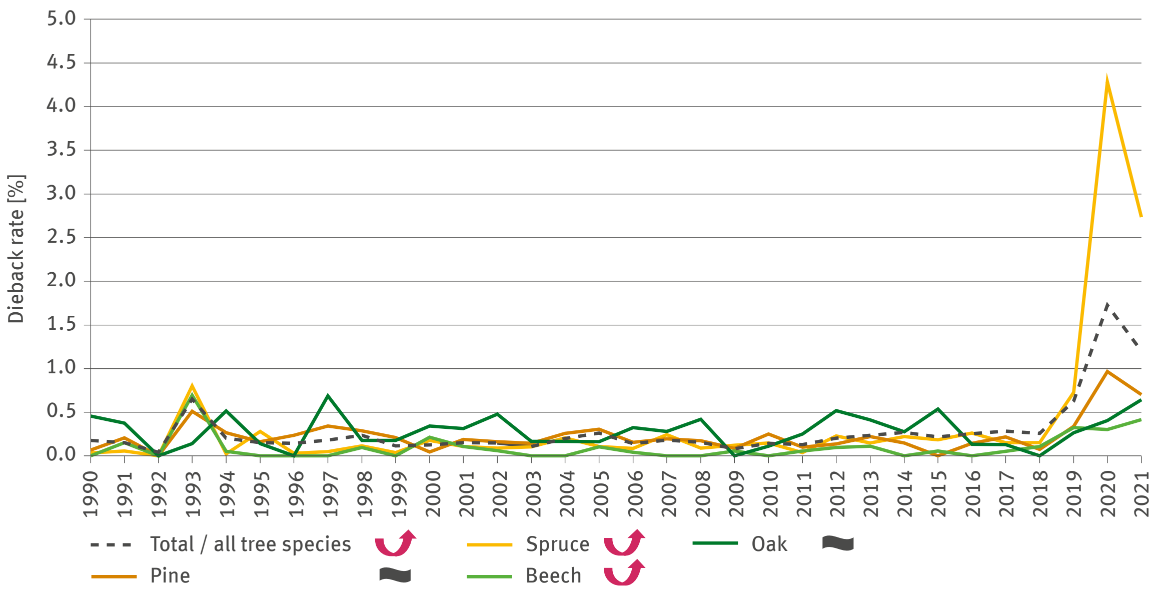
The impacts caused by heat and drought are reflected even more conspicuously in the dieback rate than the crown defoliation mean. Trees are considered dead once they no longer have any living 'needles' or leaves or conductive tissue in the trunk but are still upright in the stand, thus being included in the trees sampled as part of a forest condition survey. First, recumbent trees and any trees removed from the forest (cf. Indicator FW-I-5, p. 180) are substituted by sample trees. The annual dieback rate is typically not influenced by individual damaging events in the short term. Instead, problems can emerge years later as consequential damage at a much higher dieback rate, when damaged trees are no longer able to compensate for high leaf und needle losses or when – owing to their weakened state – these trees fall prey to pest organisms.

However, as a result of recent drought years, the incidents of damage were so enormous that already in 2020, the subsequent year, the dieback rate skyrocketed. As far as spruce trees are concerned, the mean of the preceding 10 years (2010–2019) had increased 20-fold. Dieback affected spruce trees – and to a lesser extent – also pine trees and this entailed not just individual trees but entire forest stands dying. Beech and oak were also affected by the consequences of increased dieback rates, although in these cases, it was predominantly individual trees and smallish stands of trees which died.

Wide areas of dead stands present reforestation with particularly demanding challenges. For natural regeneration of forests to occur, there is often a lack of suitable seed trees for future-resilient tree species in the local environment or the potential for natural regeneration is low. Natural regeneration by means of active planting or seeding can be inhibited by large quantities of calamity timber. Moreover, without the shading or sheltering effect of mature trees, potential regeneration areas are unprotected from wind or irradiation from the sun; this makes it harder for trees to grow whilst favouring the development of high grass and regeneration damage by mice.

FW-I-4: Dieback rate

Owing to the drought years of 2018 to 2020, the dieback rates for all main tree species índicate a spontaneous, distinct increase. In the case of spruce stands, extensive areas fell victim to dieback. The dieback rate in 2020 was more than 20 times higher than in the previous years of 2010 to 2019. In locations where extensive areas of trees have been decimated by dieback, it is notoriously difficult to achieve (natural) reforestation.



Data source: BMEL (nationwide forest condition survey)

High volume of damaged timber hinders planned management

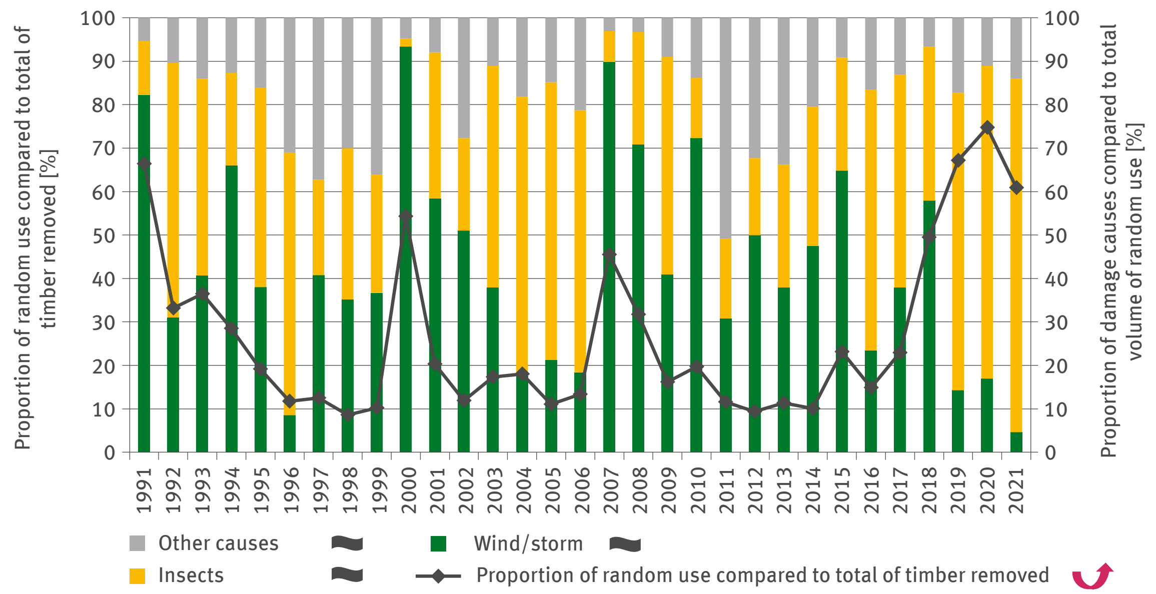
Poor forest condition and high dieback rates (cf. Indicators FW-I-2, p. 176, and FW-I-4, p. 179) lead to an increase in damaged timber in woodlands and forests. Wind-blown and wind-broken timber after storms as well as beetle-infested timber lead to unscheduled or so-called random use. Damaged timber can have negative effects on the safety of other production operations. If – especially in spruce stands – newly dead trees still covered in bark are left in the forest, they can provide perfect breeding sites for pest organisms, thus strongly favouring their reproduction, unless appropriate action is taken. In cases where there are extensive areas of damaged timber, this will put extra pressure on other production operations in forests and woodlands, thus giving rise to safety risks for recreational woodland users or for people who work in these areas. This is why forestry organisations – at least regionally – endeavour to remove damaged timber from forest stands as rapidly as possible. Taking prompt action is also important regarding beetle-infested timber – left standing or lying, thus losing its bark – as it is usually of limited practical use. On the other hand, leaving some dead timber in the forest is desirable with a view to enhancing biodiversity and increasing soil humidity in the forest. Deadwood provides essential habitats for fungi, insects and birds and can have beneficial effects on the interior climate of a forest or woodland.

Random use – especially after major damage events on a regional scale – is apt to tie up considerable capacity in forestry management. In such cases, the diverted capacity is consequently not available for implementing targeted cultivation measures which are, after all, of vital importance in achieving the required adaptation of forests to climate change. As a rule it takes several years until the consequences of calamities have all been dealt with enabling forestry organisations to return to planning and managing 'normal' utilisation and cultivation activities.

For the forest proprietor – no matter whether it is the state, the local municipality or a private forest proprietor – major volumes of damaged timber are associated with considerable revenue shortfalls. In fact, the restoration costs in damaged stands are distinctly higher and the timber qualities often inferior. At the same time – especially in the

FW-I-5: Damaged timber – extent of random use

Random use owing to wind-blown, wind-broken and infested timber is detrimental to forestry in many ways. The proportion of random use compared to the logging total has been rising significantly in the run-up to 2021. The causes of this development vary from year to year. Major winter storms which occurred in 1990, 1999, 2007, 2010 and 2015 resulted in considerable volumes of damaged timber. However, in the years of 2019 to 2021 insect-related damage predominated.



Data source: BMEL and StBA (timber logging statistics) aftermath of major damage events – timber prices decline distinctly. Besides, timber will have to be stored longer and this causes added expense. Furthermore, the legal obligation to achieve reforestation of damaged forest areas can entail financial burdens faced by forestry enterprises, owing to various extra cost factors in terms of timely planting and conservation operations on ground where normally natural forest regeneration might have been a cost-effective, near-natural option. Where reforestation is delayed, this would also result in delayed harvest operations thus entailing commercial losses.

The proportion of random use resulting from damaged timber in terms of the logging total in German commercial forests has increased significantly over the past 30 years. The average proportion during this period amounted to roughly 26 % compared to the average for the period of 2019 to 2021 amounting to 67.6 % which is more than double. The record value reached in 2020 amounting to just under 75 %, exceeded the value of 66.4 % after hurricanes Vivian and Wiebke in the late winter of 1990. The volume of calamity timber recorded for the period of 2018 to September 2022 amounted to 245 million cubic metres solid. In recent years professionals in forestry circles have gained the impression that phases free from relevant impacts caused by random use are becoming ever shorter.

Up until 2018, the extremely high proportions of random use compared to the logging total were essentially caused by wind-blown and wind-broken timber in the aftermath of storms. As mentioned above, in the late winter of 1990 for example, hurricanes Vivian and Wiebke resulted in extensive restoration work required in the subsequent year of 1991, and this applied to major parts of Germany. In December 1999 'Lothar' devastated extensive parts of south-west Germany. In January 2007 cyclone Cyril destroyed forests particularly in North-Rhine Westphalia with a focus on Sauerland. In late March 2015 hurricane Niklas wrought havoc in Bavaria but left behind smaller amounts of damaged timber than comparable hurricanes. The autumn tempest Xavier in October 2017 caused damage in deciduous woodlands in Brandenburg, as trees were still in full leaf, whilst the low-pressure related storm Burglind, right on the cusp between 2017 and 2018, as well as Friederike in mid-January, broke trees in the western and southern woodlands of Germany. These events led to an increase in the damaged timber statistics for 2018.

As of 2019, the situation changed insofar, as pest insects accounted for the major part of the enforced use of damaged timber. Subsequently to the extreme year of 2003 (based on the mean value for the period of 2004 to 2006), insects caused 63 % of all random use; after 2018 this

If there is a lot of damaged timber in a forest, extensive capacities required for other forestry operations are tied up, thus inhibiting scheduled utilisation. (Photo: © Alexander / stock.adobe.com)

value amounted to 74 % (based on the mean of the period from 2019 to 2021). It is therefore necessary to assess the importance of biotic pest organisms differently in the overall damage scenario nowadays (cf. Indicators FW-I-6, p. 182, and FW-I-7, p. 183).

When interpreting the data on wind-blown, wind-broken and infested timber, it is important to remember that, as a rule, these data do not provide a comprehensive overview of the actual damage caused to timber. Not all Federal Länder record and provide data on private and corporate forests in addition to data on state-owned forests. Besides, the focus of data collection has so far been on winter storms. Apart from impacts caused by climate change, there can also be other trends exerting strong influences on the time series. As far as the age structure of German forests is concerned, stands tend to contain a lot of the older range of the age spectrum. It is important to note that older and thus taller trees are more vulnerable to wind-blow than younger ones, and the greater the timber reserve, the greater the volume of damaged timber. The latter can also mean that depending on where the calamity is located, the damage caused can vary in terms of volumes. For example, storms in regions with fairly open stands of pine forest – which are widespread on the sandy soils of Brandenburg or Mecklenburg-Western Pomerania – will cause smaller volumes of damaged timber than storms or pest infestations in the timber-rich forests of the uplands, or the foothills of the Alps.

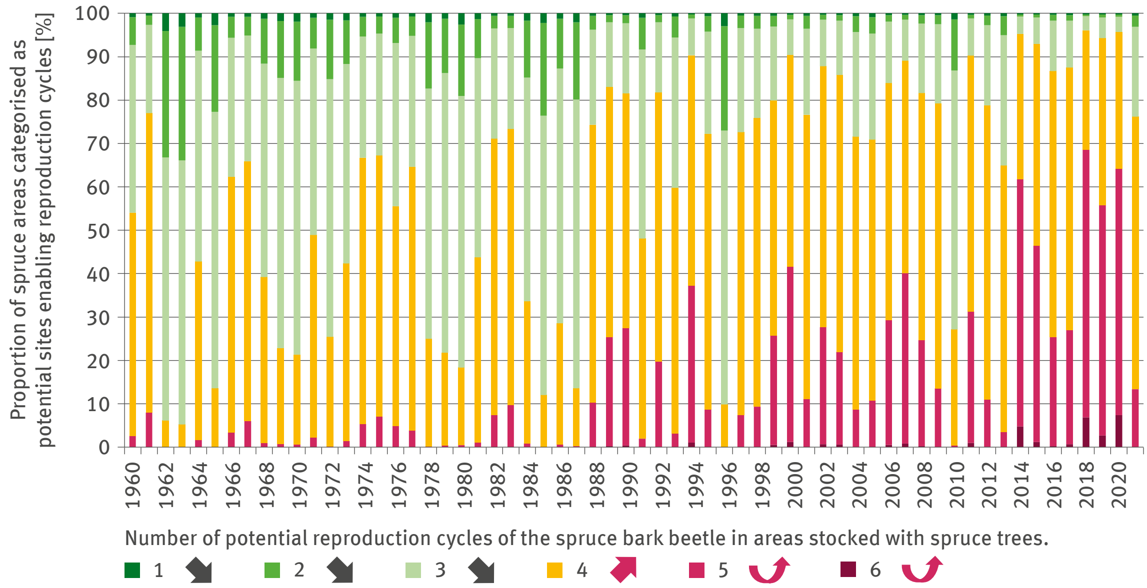
Prolific bark beetle reproduction

Many trees suffer from diminished vitality caused – as projected – by climate-related changes, especially during the increasing summer droughts. Thermophilic insects and pathogens can benefit from such conditions. As far as spruce trees are concerned, bark beetles – such as the European spruce bark beetle and the six-dentated bark beetle which breed in their bark – cause particular problems to this tree species. However, there are other pest organisms whose development also benefits from climate change: Coniferous trees are particularly affected by silver fir adelges and by fungi. As far as deciduous trees are concerned, pests include the common European cockchafer, the oak processionary moth, gipsy moth, the oak-boring beetle, the leaf-mining moth on horse chestnuts, the small beech bark beetle and the beech jewel beetle on beech trees. The increasing incidence of these species is thought to be associated with warm and dry summer weather.

In the case of spruce trees, damage from bark beetles has reached devastating proportions as this tree species is now extensively planted in locations which – owing to climatic changes – no longer provide the cool and moist conditions preferred by it. These issues originated some 200 years ago – the beginning of a deliberate expansion of spruce cultivation in German forests. In those days many forests were badly fragmented and thinned due to forest pasture and intensive use of timber. Owing to their undemanding nature, sturdiness, and easy propagation, spruce trees were considered the ideal tree species for rapid reforestation of large areas. The useful and versatile timber was regarded as suitable for overcoming an impending timber shortage. It is true to say, however, that spruce trees – owing to their mostly shallow root system – are vulnerable to storms and droughts. Hence, there were early indications that pure stands of spruce trees were fraught with high cultivation risks. From the late 19th century onwards, there were already repeated incidents of pest infestation or storm events which destroyed localised stands. Eventually, the extensive storm events of recent decades and latterly, the severe impacts of heat and drought became unmistakably obvious (cf. Indicator FW-I-4, p. 179).

FW-I-6: Endangered spruce stands

The risk from bark beetles breeding in the bark of spruce trees – thus endangering the trees – is very serious, especially during and after hot and dry years; it can bring about the collapse of entire spruce stands. Bark beetles thrive in warmer weather, and provided there are adequate amounts of wood to breed in, they can produce up to six generations annually in those conditions. Extremely high pressure from pest infestation can kill even healthy, vigorous trees.



Data source: TI für Waldökosysteme (modelling with PHENIPS, national forest inventory 2012)

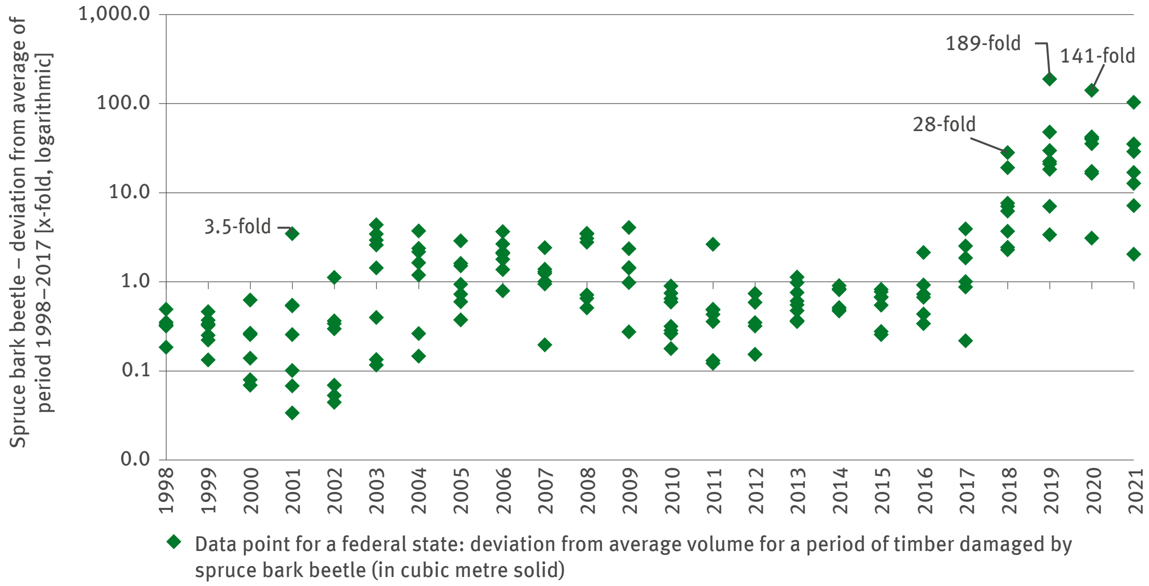
Even if climate change is not the only cause of increased pest infestation, it is assumed – for instance with regard to the spruce bark beetle – that higher temperatures cause this species to swarm earlier in the year thus enabling the development of additional generations. It is possible to calculate the potential number of reproduction cycles of the spruce bark beetle on the basis of data on temperature developments within the course of a year. Normally, the spruce bark beetle raises two generations per summer, with one female able to lay up to 80 eggs. Given optimum conditions, however, several broods are feasible, producing several generations, as well as sibling broods. Every new brood increases the number of individuals – and thus the damage potential – exponentially. In years such as 2018, a female beetle can raise a six-figure number of offspring[117]. The area of spruce forests available to bark beetles for four and more reproduction cycles annually has – owing to changed weather patterns – increased significantly. As a result, the risks faced by forestry organisations in terms of pest infestations have risen noticeably. This increased risk is reflected also in the data collected by eight Länder in respect of damaged timber caused by infestation with bark beetles.

These data clearly show that beetle infestations caused as a result of the heat and drought year 2003 increased rapidly in nearly all the Federal Länder examined. The after-effects continued for some subsequent years, reinforced by another very warm and dry summer in 2006. In 2007 – owing to the rather rainy month of May and a cold September – the bark beetle population was not able to reproduce quite as successfully. This species was not able to regain that opportunity until 2010 when the volume of damaged timber again reached roughly the level experienced in the hot summer of 2003. After the warm summer of 2015, the volume of damaged timber first increased moderately but 'exploded' eventually owing to the drought years of 2018 to 2020. Compared to the average for the period of 1998 to 2017, a 189-fold deviation from the volume of damaged wood occurred. In all eight of the Länder which filed reports, the volume of damaged timber increased by several multiples.

It is also possible to infer – from the time series – the impacts of extreme storm years (such as Lothar in 1999 and Cyril in 2007) incurred as a result of the typically increased beetle infestations of damaged or thrown trees. However, recent developments have eclipsed these events.

FW-I-7: Volume of damaged timber due to spruce bark beetle – case study

The spruce bark beetle benefits from dry hot weather and prefers to infest trees that are already damaged or weakened in some way. Infestation data from eight Federal Länder demonstrate that hot and dry years and also storm events lead to increased volumes of damaged timber. After the drought years of 2018 to 2020, the volume of beetle-damaged timber was 189 times as high as the multi-annual average recorded for the period of 1998 to 2017.



Data source: Zeitschrift AFZ – DerWald (overview chapters of federal states on forest protection)

Forest fire hazards rising, forest fires again on the increase

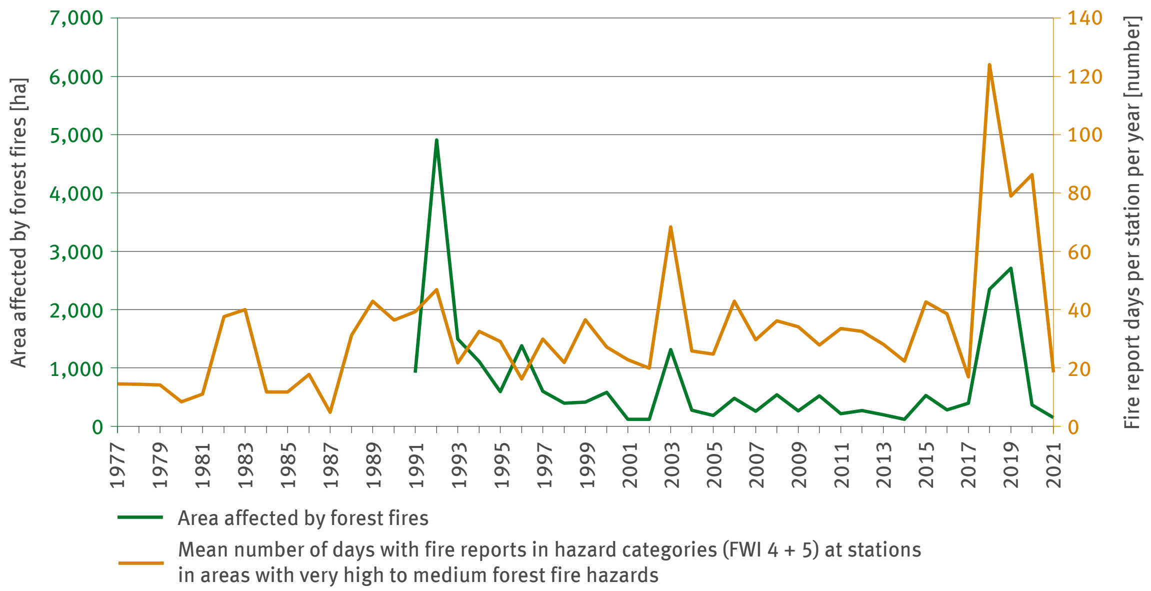
Compared to damage in terms of windblown, wind-broken or pest-infested timber, damage caused by forest fires has so far played a secondary role in most regions of Germany. Brandenburg and regions such as Mecklenburg-Western Pomerania, Saxony, Saxony-Anhalt and Lower Saxony are characterised by a more continental climate. These regions are among the traditional areas of pine cultivation. In summer they are often exposed to extended dry periods, thus putting them at greater risk of forest fires which is therefore a very serious hazard in those regions. In view of the increase in forest fires in the particularly dry and hot years of 2018 and 2019, forest fire risks have again become the focus of greater attention.

Forest fires can be caused by numerous different factors. Major triggers are primarily negligent actions and arson. Whether the first ignition leads to a forest fire depends essentially on the amount of dry, flammable material available on site and thus on the weather pattern and stand structure. However, whether the fire is able to spread depends on wind speeds, fire monitoring and fire fighting capacities – in other words, the time it takes until a fire is tackled as well as the intensity of that fire. Apart from the weather, all the other causal factors usually change more gradually. However, when there are years with abrupt changes – as for instance in 2003 and latterly in the years of 2018 and 2019 – which witnessed frequent and some extensive forest fires – these can often be attributed especially to extreme weather conditions with intensive drought in the spring, summer and autumn months as well as great heat. In cases where these conditions are combined with strong dry wind, such extensive fires spread with particular rapidity.

Up until 2017, according to Federal forest fire statistics, both the number of forest fires and the size of forests affected in Germany declined significantly. The fact that the size of the burn area declined to a greater extent than the number of fires, indicated that there have been improvements in recognising incipient forest fires at an early stage and in containing them successfully. It is true to say that, with financial assistance from the EU, the Federal Länder have in recent years indeed invested considerably in forest fire prevention and in improving

FW-I-8: Forest fire hazards and forest fires

Between 1991 and 2017 the areas affected by forest fires declined significantly. Weather-related forest fire hazards remained mostly the same during that period although in some areas they have been increasing. However, in 2018 and 2019 the extreme hot-dry weather pattern was also clearly reflected in the forest fire scenario. There were considerably more and – in the north-eastern Länder – also more large-scale forest fires.



Data source: BLE (forest fire statistics Germany), DWD (regionalised Canadian FWI) the infrastructure required for recognising and tackling forest fires at an early stage. For example, in the eastern Länder which are particularly at risk from forest fires and in the east of Lower Saxony, which is also at risk of forest fires, the old fire watch towers were replaced by digital and remote-controlled optical sensors which facilitate the immediate communication of alerts to forest fire alert centres. Furthermore, traditional precautionary measures such as the installation of firebreaks and water abstraction points were driven forward, and improvements were made regarding public information. While the latter is of importance in respect of negligent actions, it also furthers the willingness of recreation-seeking forest visitors to alert the fire brigade as soon as they spot a fire (typically by using their own mobiles) thus facilitating rapid intervention.

As global warming increases, the forest fire risk is rising too, given that it gets warmer and drier during the critical months. In Germany, the weather-related forest fire hazard is expressed by means of an index value. The higher this value is on the 5-level scale, the higher the forest fire hazard. Over recent years, the time series for the number of days on which high index values were reported at levels 4 and 5 is showing values that are rising significantly. During the particularly hot and dry year of 2018, there were on average 124 days on which the risk levels 4 and 5 were declared in areas which are in general much at risk from forest fires.

In the 1990s, forest fire prevention and fire fighting in the eastern Federal Länder underwent reorganisation which led to the creation of advanced and well-functioning structures. As a result, there was a distinct decline in damage from forest fires recorded during the examined time period up until 2017. However, in the dry years of 2003, 2006, 2015 and 2016 it is possible to see that there were higher risks of forest fires as well as more extensive areas affected by forest fires compared to other, less dry years. In the extremely dry year of 2018 a total of 2,349 ha of forest were either destroyed or severely damaged by 1,708 forest fires nationwide. In Brandenburg the forest fire season was particularly disastrous, with 512 forest fires affecting a terrain of 1,674 ha. The most extensive area affected by fire occurred in the environs of the town of Jüterborg, amounting to 573.72 ha, with privately-owned forest affected particularly badly. The greatest media attention was generated by a forest fire near Treuenbrietzen in August, which was exacerbated by gusts of wind and extinction problems – owing to world war munitions that were still in the ground – thus spreading rapidly to engulf 300 ha. Several villages had to be evacuated. The number of forest fires and affected areas of forest owned by the Federal government doubled in 2018 compared to a rather hot previous summer in 2016.


The dry-hot weather pattern in 2018 and 2019 gave rise to several forest fires. (Photo: © Rico Löb / stock.adobe.com)

In 2019 the number of fires was slightly lower – amounting to 1,523 – than in the preceding year – but the area affected by these fires amounted to 2.711 ha. In this year too, the state-owned forest of Brandenburg topped the leaderboard with a total of 1,353 ha. The most extensive fire of that year occurred at the end of June, on the former military exercise terrain of Lübtheen in Mecklenburg-Western Pomerania. The fire extended to a total of 944 ha. The administrative district of Ludwigslust-Parchim declared this disaster. Temporarily, there were more than 3,000 emergency relief respondents involved who came from several Federal Länder. Several adjacent villages with a total of 700 inhabitants had to be evacuated. In the case of the Truppenübungsplatz Lübtheen (military exercise terrain) too, remnant munitions made the fire-fighting efforts more difficult.

As weather patterns give rise to more hazardous conditions, the challenges facing forest fire prevention and control are likely to increase rather than diminish. The continuous improvement of systems as well as the training and organisation of fire fighters have thus become a persistent challenge. Besides, the experience gained in disaster spots such as Treuenbrietzen, Lieberose and Lübtheen makes it ever-more urgent to carry out the clearance of remnant ordinance, thus facilitating any fire extinguishing efforts as required by the extent of a fire.

Active forest transformation and reforestation are required

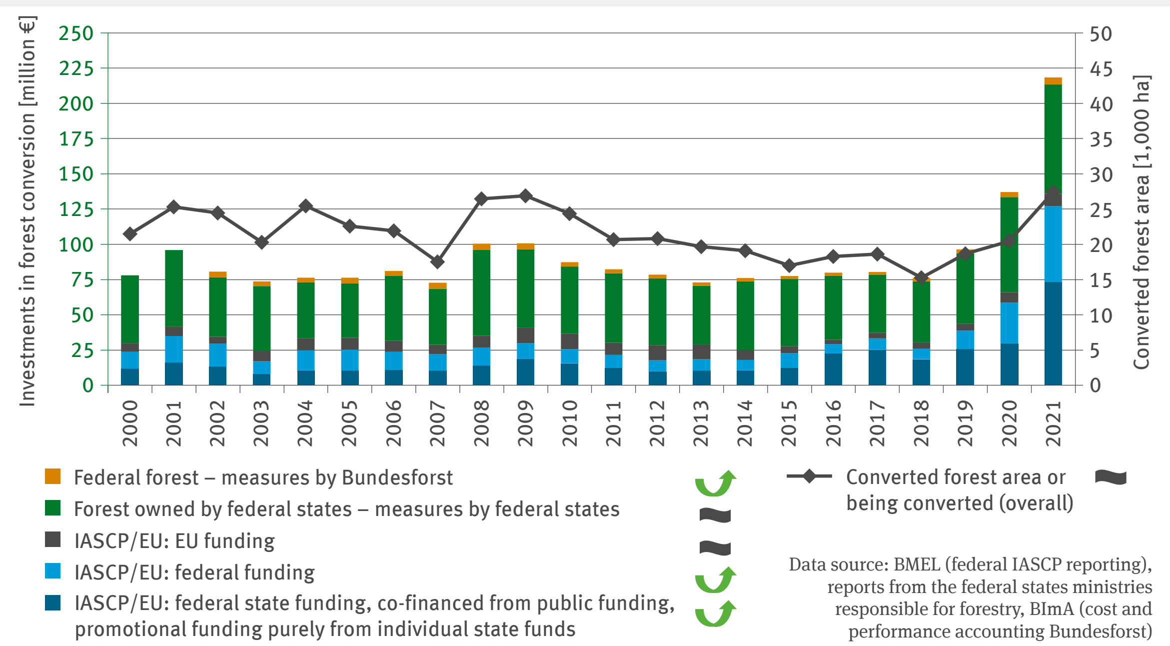
Natural regeneration is usually considered a favourable and natural form of forest regeneration. This process involves focusing forestry operations on the removal of individual mature trees and groups of trees from a stand. This results in gaps of sufficient size to provide enough light for seedlings to grow which emanate from neighbouring trees. The traditional near-natural method of structuring forests used to consist exclusively in letting natural regeneration take its course.

However, the adaptation of forests to changed climatic conditions often requires a targeted restructuring of existing stands. Natural succession does not always lead to a change in tree species, especially when there are no suitable seed-bearing tree species nearby or in places where game and deer browsing is excessive. The occasional exception are trees that emanate from natural wind dispersal of lightweight seeds, for example pine, birch or poplar trees, which can drift into a stand even from considerable distances, and they can also emanate from being dropped or buried by jays and squirrels thus giving rise to oak and beech trees. Where it is the aim to convert site-inappropriate conifer stands to mixed forests or to incorporate more thermophilic species or trees with thermophilic provenance into stands, it is imperative to adopt methods of artificial regeneration. This involves incorporating the desired tree species into stands either by sowing or planting, and in cases where browsing by deer and game is a problem, by taking appropriate protective measures to get such tree species established. In this approach, it is also possible to carry out targeted supplementation of otherwise spontaneous natural regeneration.

Following the devastating drought of 2018 until 2020 it was necessary to reforest an area of roughly 285,000 ha[118]; by 2023, an even larger terrain of up to 540,000 ha is to be expected due to consequential losses. Natural succession in all areas is not very likely. As a result, new stands have to be created with the aid of seeding and planting. On calamity sites it is often necessary to carry out additional removal of vegetation in order to prepare the ground appropriately for new plantings. It will be necessary to decide whether it is advisable to remove any natural regeneration (for example of previous tree species that were inappropriate for the site). However, natural regeneration has better initial growing

FW-R-1: Financial support for forest transformation

The transformation of state, corporate and private forests is promoted by funding from EU, Federal and Länder sources, as well as from individual budgetary sources. In the aftermath of the devastating drought years of 2018 to 2020, in particular the Federal government and the Länder have made available considerable amounts of additional funding in order to drive forest transformation forward and to facilitate the reforestation of calamity areas.



Data source: BMEL (federal IASCP reporting), reports from the federal states ministries responsible for forestry, BImA (cost and performance accounting Bundesforst) conditions compared to planting due to uninterrupted root development and potential epigenetic adaptation

Forest transformation is an objective that has meanwhile been embedded in silvicultural strategies and programmes at Federal and at Länder level. Appropriate funding is being provided at EU level and by Federal and Länder governments for the transformation of private, corporate and state-owned forests. In addition, there is now also extensive funding available for the reforestation of calamity areas. Funding mechanisms vary among individual Länder. As far as private and corporate forests are concerned, the majority of funding activities have so far come from the GAK and EAFRD programmes. EU, federal and state funds are combined differently by the individual Länder. In addition, some Länder support forest conversion measures under specific programmes with state funds only. At the end of 2018 GAK agreed a new funding eligibility status entitled 'Funding for remedying impacts on forests / woodlands caused by extreme weather events' which was augmented by funding provided by Federal government. This is why – especially from 2020 onwards – extensive additional finance was invested in private and corporate forests in several Länder. Furthermore, in 2022 the funding programme entitled 'Climate-adapted forest management' was established by BMEL for the benefit of private and municipal forest owners; this fund is endowed with funding from the KTF for the purpose of accelerating the development of stable and climate-resilient forests / woodlands. The funding is bound up with stipulations. For instance, preparatory regeneration is one of the obligatory requirements. Natural regeneration takes priority over planting. The objective is to use or promote predominantly autochthonous tree species. The diversity of tree species is to be increased, and more deadwood and habitat trees are to be left in-situ. Furthermore, measures to conserve soil quality and water retention are obligatory. Up until the end of 2022 an amount of 200 million Euros was available. This amount has not yet been taken into account for the indicator ending in 2021. As far as private forests are concerned, it has to be taken into consideration that many woodland or forest owners carry out transformation measures for which they have not requested funding. The extent of transformed areas is therefore likely to be greater than might be thought judging by the terrain transformed with the aid of funding.

As far as forests are concerned that are owned by individual Länder, forest transformation is pursued almost exclusively as part of 'normal' forestry management which receives the bulk of its funding from budgetary sources. Proactive transformation measures – as taken into account for the indicator – usually serve the objective to establish autochthonous tree species and to increase the mix of tree species. This includes, apart from reforestation, actions to supplement natural regeneration in young stands as well as advance planting and underplanting. Advance planting involves the planting or sowing of new target tree species in a typically single-layer main stand, to be incorporated into the main stand once the existing stand has been harvested. In some of the Federal Länder additional funding was made available for the Länder-owned forest areas, in response to the great demand prevailing for major reforestation.

As far as forest transformation and reforestation are concerned, there is enormous pressure to act.
(Photo: © mitifoto / stock.adobe.com)

The proportion of federally owned forests amounts to just 4 % of Germany's overall forest terrain. Essentially, this is forest on (former) military exercise sites and along Federal waterways and motorways which come under the remit of Institute for Federal Real Estate (BImA), Department 'Bundesforst'. In the federal forest, too, site-inappropriate stands are being converted into stable and more natural forests. In 2021, funding for these tasks was more than doubled compared to the previous three years, but was in the same order of magnitude as in 2017. Compared to the share of Länder-owned forest amounting to 29 % of Germany's overall forest area, the proportion of funding allocated to the conversion of these forests from 2011 to 2020 was disproportionately high, at just under 57 % of the total national funding. By comparison, the proportion of funding for the conversion of private and corporate forests, which cover around 67 % of the total forest area, was lower at an average of 40 %. Given the additional GAK funding eligibility status, this relationship has been reversed as of 2020. In 2020, private and corporate forests received 62 % of the funding.

Genetic diversity increases the adaptation capacity

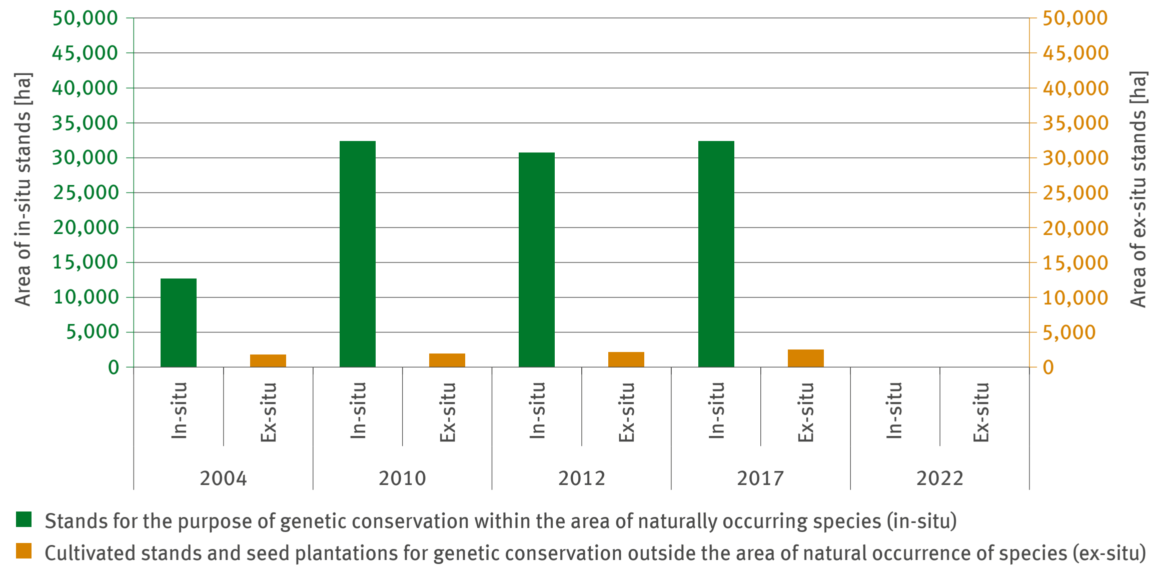
Forest transformation is intended to build up mixed and climate-resilient stands. The objective is to promote above all resilient autochthonous tree species and to ensure that forest transformation takes care to ensure as far as possible, that new trees originate from local, site-adapted stock. An essential element for the adaptation to present and future site condition is intra-species genetic variation. This is true, above all, for site-bound, long-lived organisms such as trees. Genetic variation results from processes of molecular-biological and population-genetic processes. Processes of adaptation to local environmental conditions produce populations with a characteristic genetic composition which differentiates from other populations of the same species. The loss of genetic diversity is an important indicator for the loss of adaptability of populations.

Progressive climate change with ever-more extreme weather events and associated impacts increase the selection pressure on forest stands. It is only the genetically adaptable individuals – in other words, individual trees – which can survive, grow and reproduce within greater populations. In view of the multitude of interactions and the dynamics of individual factors it is not possible to predict to which individuals or populations this will apply. This dilemma can only be resolved by maintaining a sufficiently large number and diversity of potentially adaptable individuals. Hence, the monitoring and maintenance of genetic diversity and the genetic system continue to be the focus of measures aimed at conserving genetic resources. Of particular importance is the ongoing recording of various spatial occurrences of a multitude of species in vigorous, adapted and potentially adaptable tree and shrub populations in Germany.

The measures taken to conserve genetic resources for silvicultural purposes can be differentiated as in-situ and ex-situ respectively. The objective of in-situ measures is to conserve – as dynamically as possible – the relevant genetic resources as so-called 'gene conservation objects' on the sites where they occur and in the environmental conditions prevailing at that site. Both natural and artificial regeneration safeguard and transmit genetic information to the next tree generation. Particularly endangered species or varieties are kept ex-situ in specially established archives and, where

FW-R-2: Conservation of forest-genetic resources

Up until 2017, it was possible to expand the in-situ and ex-situ conservation resources. The data of the most recent survey, however, are not yet available. The conservation stands ensure that the genetic diversity is retained in respect of both frequent and scarce / rare tree species. This serves the purpose of establishing the basic prerequisites for conserving the adaptability of forests.



Data source: BLE (gene conservation objects: GENRES (information system on genetic ressources), FGRDEU-Online (national inventory of forest genetic ressources)) necessary, in ex-situ seed plantations. The ex-situ measures are static measures with the objective to safeguard the current character of genetic diversity. This includes taking measures for the long-term storage – under controlled conditions – of seed material, pollen, plants or plant components as carriers of genetic information. Such conservation strategies are characterised by requiring differing amounts of surface area, investment costs, utilisation and monitoring. This is why expensive ex-situ conservation is less frequently used than in-situ conservation. Seed plantations serve dual purposes: the production of genetically diverse seed materials and as the foundation required to strengthen and transform forests adapted to climate change.

In Germany the individual Länder have the remit for gene conservation measures. It is the Länder's individual concepts which create the framework for the conservation of genetic resources for the silvicultural measures to be taken. At Federal level the genetic information on the indication of all genetic conservation objects is collated in the National Inventory of Forest Genetic Resources (FGRDEU). The data are updated and supplemented every few years.

Seed plantations serve the purpose of genetic conservation. They are the essential foundation of forest transformation. (Photo: © Andreas Meier-Dinkel)

A straight-forward interpretation of changes in number and surface area of genetic conservation objects in Germany is not possible. This is because there are numerous crucial factors which determine genetic adaptability to climate change. The number of genetic conservation objects per tree species and the size of conservation areas can only convey a rough idea. In principle, the interpretation of these data requires detailed silvicultural knowledge and the application of specific indicators (such as conservability and ecological conservation index). On the other hand, the number of overall genetic conservation objects does not provide any clues regarding the size of a population. For example stating the number of 'in-situ conservation stands' for rare and secondary tree species would exaggerate the conservation status of small population numbers or low numbers of individuals. Besides, genetic inventories which would meet the principles of silvicultural monitoring are still in their infancy. It would therefore be unreasonable to apply a one-dimensional principle such as 'the more genetic conservation objects, the better', because for every tree species there is a meaningful extent of genetic conservation stands beyond which any increase in surface area or amount of stored genetic conservation objects would not result in improving the safeguarding conditions.

In general, it can be stated that distinct progress has been made regarding the conservation of forest-genetic resources: The designation criteria for genetic conservation objects are homogeneous nationwide; increasingly genetic markers are applied in the characterisation of forest-genetic resources, and nationwide pilot monitoring programmes have been established in respect of population-genetic issues. These developments provide an additional basis for assessing the genetic adaptability of trees in climate change conditions.

In Germany the area used for in-situ and ex-situ genetic conservation objects increased up until 2017. Only the terrain of in-situ stands decreased slightly between 2010 and 2012. As far as the more frequently occurring forest tree species are concerned, for which the Forest Reproductive Material Act (FoVG) governs production, trading, as well as import and export of forest reproductive material, the area of in-situ stands increased from 12,681 to 32,405 ha between 2004 and 2017. The data captured in the latest data collection with declaration date 31-12-2022 did not come to hand in time for the due date of this Monitoring Report. It was therefore not possible to update the time series. Rare or endangered tree species are not governed by the FoVG. They will play a more important role as alternative tree species in climate change. For pubescent oak, wild service tree, true service tree, crab apple, wild pear, yew, field maple, green alder, grey alder and bird cherry, data were collected in a systematic and homogeneous manner. The factors examined were topographic aspect, population size, vitality status and age structure of the occurrences. By 2017, the in-situ stands reported had been expanded to roughly 4,560 ha. The area of cultivated stands and seed plantations established for genetic conservation (ex-situ)also increased – from 1,777 ha in 2004 to 2,470 ha in 2017. In this case too, the next Monitoring Report will present current data.

Humus – essential for storing water and nutrients

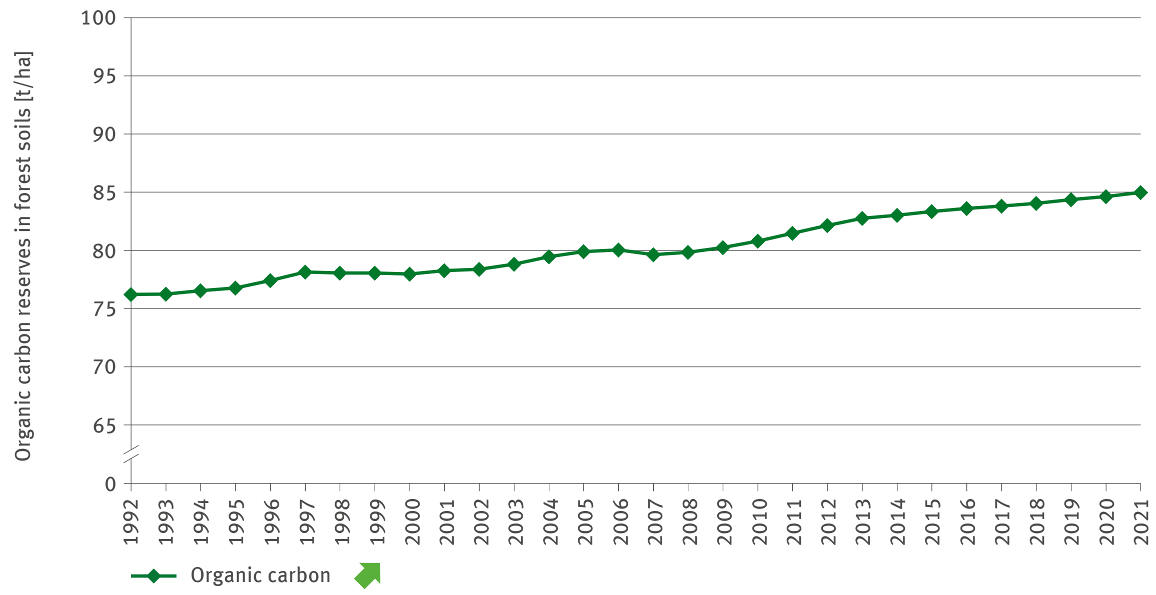
Apart from controlling the composition of tree species (cf. Indicator FW-R-1, p. 186) and the selection of appropriate provenance (cf. Indicator FW-R-2, p. 188), forestry professionals have additional ways of furthering the adaptability of forests to changing climatic conditions. Hence, humus conservation is an important key to the creation of favourable growing conditions and greater stability. This is because humus or rather organic carbon – its vital component – creates a favourable soil structure thus making it hugely important for the supply of nutrients and water to forest trees. Especially on nutrient-poor and rather dry sites, the conditions for forest trees can be enhanced by ample supply of humus. Nevertheless, weather patterns also influence the activity of micro-organisms in the soil. If temperatures rise at the same time as the water supply is plentiful, the process of humus decomposition is apt to accelerate.

Apart from their favourable influence on the adaptability of forests, sufficient humus reserves are also worth striving for as a means of climate protection. This is due to the fact that soil is the most important terrestrial organic carbon sink, at the same time as being one of the most important natural sources of CO_2 in the atmosphere. Carbon sequestered in the soil is the only form of carbon not contributing to climate change by way of CO_2 in the atmosphere. Humus conservation therefore is both an adaptation measure and a method of protecting the climate (cf. Indicator BO-R-1, p. 140).

In virgin forests, the organic matter – available for the formation of humus – is particularly plentiful, as all trees are decomposed when they die, thus ultimately adding to the formation of humus reserves. The situation is different in commercial forests, because harvesting the timber means that there is carbon loss involved in the forest. On one hand, the forest floor is disturbed by such interventions thus potentially leading to increased decomposition of humus. On the other hand, considerable amounts of carbon are removed from the forest by way of timber, the extent of which depends – to a considerable extent – on the amount of debris remaining in the forest after harvesting. The more leaves, needles or branches remain on the logging site in the forest, the more organic

FW-R-3: Humus reserves in forest soils

High contents of organic carbon in forest soils further the water storage capacity and improve the supply of nutrients. They also improve the trees' chances of surviving hot periods with poor precipitation levels. Between 1992 and 2021 the humus reserves in Germany's forest soils increased. However, this does not exclude the possibility of regional humus depletion.



Data source: TI für Waldökosysteme (analyses based on data from BZE Wald) matter is available for replenishing the humus reserves. In that context, it also matters how well the harvesting remnants are distributed in the areas where logging has taken place. As the demand for energy from timber rises, increasing incentives have emerged for making use also of inferior material including crown material. This development is driven even more strongly owing to the circumstances arising from the war in the Ukraine and the resulting energy crisis which, as of 2022, caused firewood prices to rise even more. In contrast with agriculture, the technical opportunities of compensation for the removal of carbon and nutrients from the forest are quite limited. It is therefore ultimately crucial to achieve the best possible adaptation of use intensity to site requirements. That is the only way to ensure that sufficient humus is formed.

As part of forest soil condition surveys (BZE-Wald), research has been carried out nationwide to assess carbon reserves in forest soils. However, BZE-Wald surveys are conducted at major intervals only. The first BZE-Wald survey was carried out in the period of 1987 to 1993, the second between 2006 and 2008. The third BZE-Wald survey began in 2022. Process-based modelling – developed on the basis of BZE-Wald data for greenhouse gas reporting at Federal level – facilitates the derivation of annual mean values for organic carbon reserves in Germany's forest soils.

The time series shows a significantly rising trend prevailing over the past 40 years. However, it is questionable whether the changes observed can be attributed to the targeted promotion of humus management because the trend is liable to be masked by forest transformation measures or liming activities. Furthermore, air pollutant inputs as well as unremittingly high nitrogen deposits are apt to affect the development in respect of reserves of soil carbon in the forest.

The organic carbon contained in the humus cover is subject to comparatively rapid formation and decomposition processes thus exposing it greatly to external impacts. Furthermore the humus levels have been fluctuating quite strongly from site to site which makes the interpretation of rates of change difficult. The indicator illustrated in this report shows changes in organic carbon reserves in the humus layer and in the upper 30 cm of mineral soil.

Humus reserves – regarding their deviation from the nationwide mean – can develop quite differently from region to region. In the Northeast-German lowlands, soil carbon reserves increased comparatively strongly in stands of pine trees. Those areas were reforested massively from the middle of the past century onwards, thus enabling them to build up both biomass and humus reserves. Research projects undertaken in the region of the Bavarian Alps have indicated, however, that distinct humus losses occurred there, most strongly in soil on limestone or dolomite rock and most distinctly in areas particularly affected by warming. The losses arisen might be attributable to increased biological activity which would presumably lead to accelerated decomposition of humus. The management of montane forests has not been adapted to changing site conditions over the past 50 years. It is conceivable that, in this region too, forest management will have to include the promotion of humus generation in order to curb its depletion.[119]

Humus is essential for storing water and nutrients. Extensive humus reserves increase the forests' resilience.
(Photo: © SoilPaparazzi / stock.adobe.com)

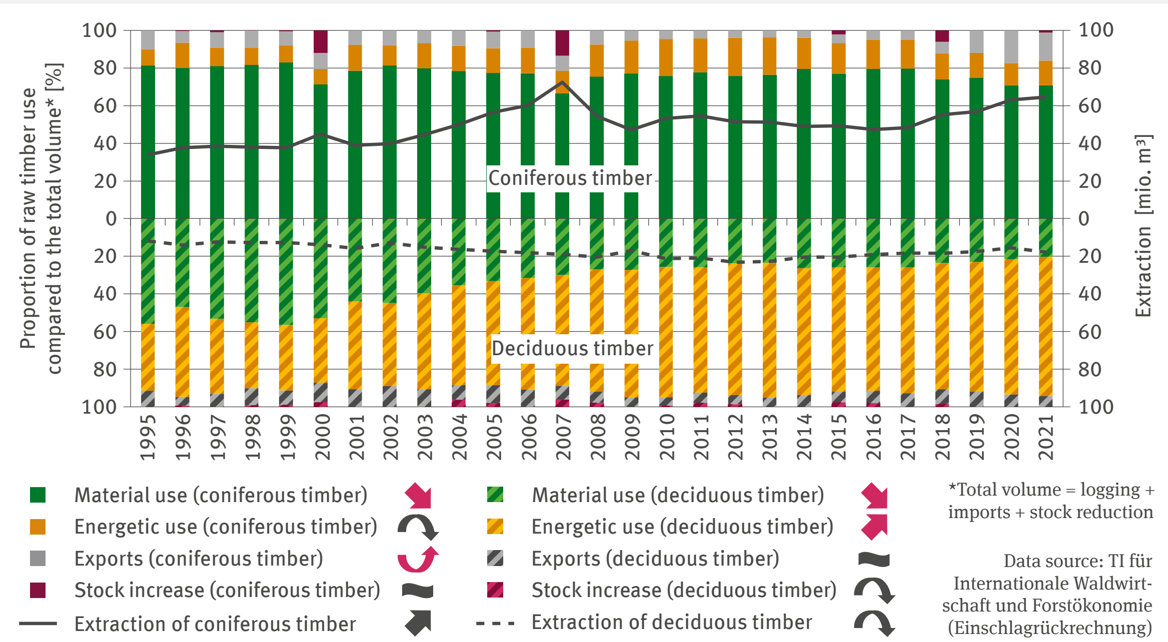
More hardwood for material use!

Both the forest transformation in favour of more vigorous and climate-resilient forests and the calamities of recent years (cf. Indicator FW-I-5, p. 180) have made substantial impacts on the timber market. Overall, timber extraction from German forests has increased since 1994, latterly especially in respect of coniferous timber. This demonstrates the extensive efforts to bring timber from site-inappropriate coniferous stands and from calamity areas into 'controlled use'. This can be done only as long as the capacities in the wood-processing industry are not overstretched by the amounts of raw timber to be processed. Such capacity overloads are reflected in mounting stock levels and / or exports, and they usually lead to the collapse of prices paid for raw timber. The distinctly higher exports of coniferous timber from 2019 to 2021 indicate that Germany's wood-processing industry was unable to cope with the high volumes of calamity timber on offer. Against this background, the question arose to what extent it might be possible to treat calamity areas increasingly as a source of passive deadwood enrichment; in other words to waive its removal, insofar as there is no risk of direct hazards arising in terms of forest and health protection or in terms of road safety.

Forest transformation aims at a more mixed composition of stands where in particular site-adapted deciduous tree species play an important role. This would mean for the future timber market – albeit with some considerable delay – that a higher yield of deciduous timber could be expected. It would be essential to increase sales opportunities for this deciduous timber, above all and as far as possible in the domestic market. To this end, new utilisation potentials for deciduous timber would have to be opened up or developed; it would therefore be necessary to expedite research; and timber processing in sawmills would have to be developed to a higher level. As far as climate protection is concerned, the utilisation of deciduous timber will have to be more focused on its use for making material objects, in order to maintain the timber's long-term function as a carbon sink. Currently, however, 70 % of deciduous timber is used as a source of energy. By now, firewood, woodchips and pellets for the generation of heat and power have become mass products. The intention is to replace fossil fuels and to reduce greenhouse gas emissions. However, this means that the CO_2 previously stored in wood is released to the atmosphere. For long-term carbon sequestration it

FW-R-4: Utilisation of raw timber

Forest transformation and the large amounts of calamity timber, especially in recent years, pose new challenges for the timber market. For climate protection reasons, it is important to find ways for the material utilisation of timber wherever possible, and preferably domestically. Given that deciduous timber is still clearly used predominantly for energy generation, the challenge is to open up new potentials for the use of this type of timber in producing material objects.



*Total volume = logging + imports + stock reduction

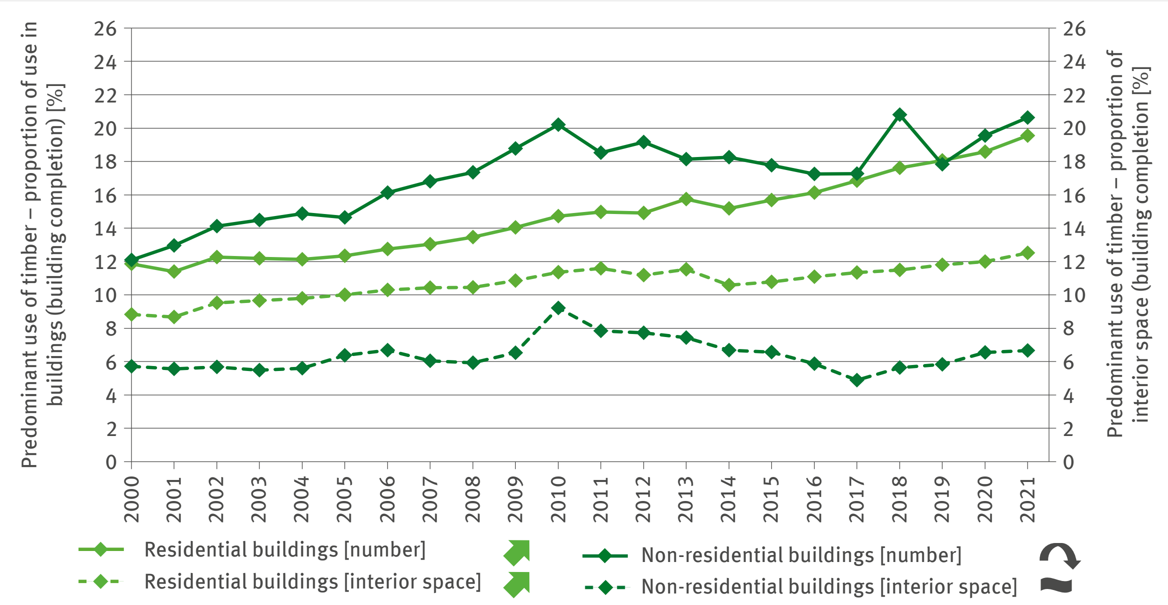
Data source: TI für Internationale Waldwirtschaft und Forstökonomie (Einschlagrückrechnung) is therefore preferable to use deciduous timber for the production of material products that have some longevity. In sum, there are close connections between climate protection, climate adaptation and opening up further potentials in the timber market. The increased use of deciduous timber for the production of material objects continues to present challenges. Construction products made of deciduous timber are being developed, but so far official approval granted for such products has been limited. Overall it is true to say that the market for construction material made from deciduous timber is still in its infancy. As far as the wider use of deciduous wood is concerned, there is a need of further research and development, and it will also be necessary to gain more experience in this field. Also with regard to interior fittings, the situation is challenging, as currently trends lean towards perfect wood-imitation flooring and voluminous but lightweight furniture.

Overall, the timber construction quota is on the increase. However, statistics on building products so far do not differentiate between the proportions of deciduous versus coniferous timber. In 2021, a fifth of all residential buildings, measured by the number of building permits, were predominantly made of timber. In this context, the focus is on the field of one- and two-family houses. As far as multi-family houses are concerned, the use of timber is also on the increase, but this is still limited to a distinctly lower level. With regard to non-residential buildings, the timber construction quota is strongly characterised by extensions to individual buildings (complexes). For example, the completion of two large-scale projects (holiday resort) in 2018, comprising a total of 680 buildings in timber construction increased the timber construction quota to over 20%[120].

In order to achieve a trend reversal towards more material utilisation of deciduous wood, it will be essential to open up additional potentials for material utilisation – way beyond the building sector – in line with the objectives of the National Bioeconomy Strategy[121]. For example, one relevant substitution potential is envisaged for using deciduous timber in lieu of synthetics based on mineral oil or in lieu of metals, thus achieving a trend reversal towards biogeneous raw materials. The range of potential applications also includes clothing and textiles for home furnishings made of timber-based cellulosic fibres. Such potentials are of increasing interest, given that climate change has made the cultivation of cotton more difficult, thus basically making wood fibre production more competitive.

FW-R-5: Timber construction quota

The building sector plays a major role in the material utilisation of timber. Especially in the residential building sector, the use of wood is increasing. However, there are many other potentials remaining to be opened up, especially in respect of non-residential buildings. Owing to its more favourable properties, it is predominantly coniferous timber that is used in the building sector. By contrast, the use of deciduous wood in the building sector is still in its infancy.



Data source: StBA (Baufertigstellungen)

Silvicultural information on the subject of adaptation

In view of climate change, forestry will be confronted with immense challenges in the next few decades. Numerous practical development and management issues will arise in connection with the adaptation of forests including the choice of tree species, the technical implementation of forest transformation and the adoption of suitable measures for a targeted approach to tending forests. Action is required not only in state and corporation forests but also in private forests as the latter comprises roughly 48 % of Germany's entire forest terrain[122].

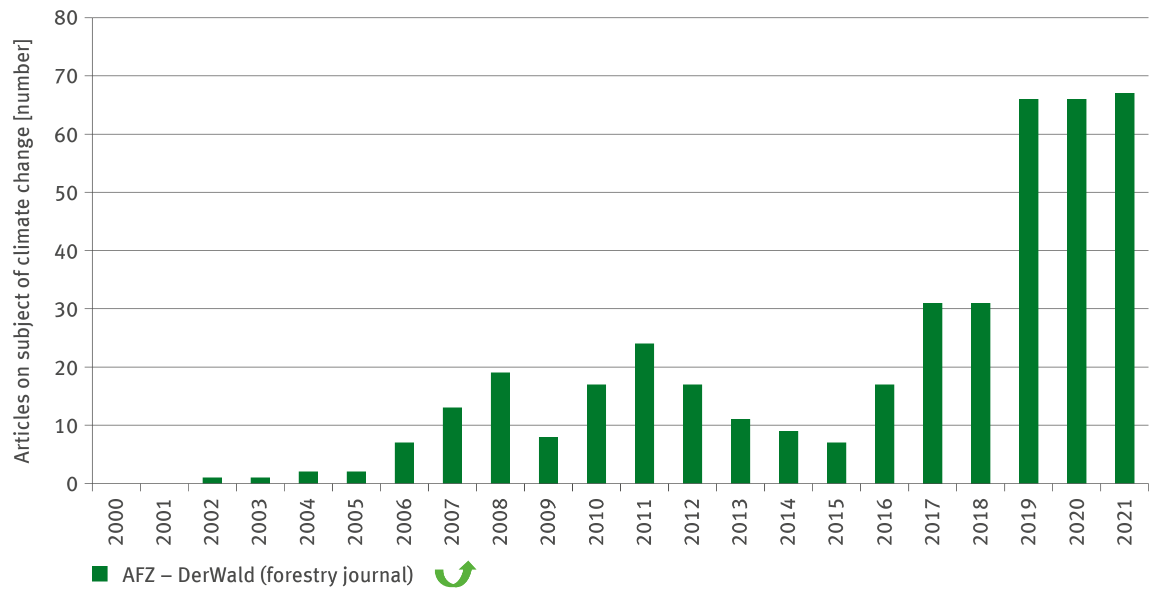
In many cases, proprietors of private forests own comparatively small areas, on average comprising less than 10 ha. These proprietors have their focus mostly on matters not pertaining to forestry, thus managing their forests very much on the basis of their own individual and rather disparate objectives. In most cases, the commercial incentive to engage with silvicultural concepts, and to acquire the appropriate knowledge, is rather scant. As far as tending and developing forests is concerned, these are rather unfavourable conditions.

In the past, the yields attainable from forest management – including any existing funding available to forest proprietors – were usually sufficient to cover the burdens of forest protection, reforestation and road safety obligations. However, in many cases, the large-scale forest damage incurred in recent years has distinctly reduced the operating capital available to forest proprietors. Those enterprises that are heavily affected are not likely to make a profit from their timber yields for decades to come. On the other hand, there are social aspects at stake in private forests too, which require sustainable forest management, adapted to the new climatic framework conditions, thus leading to the maintenance or even improvement of ecosystem services rendered by forests.[123]

Against this background – and apart from the expansion of financial support (cf. Indicator FW-R-1, p. 186) – the advisory services offered to private forest proprietors by silvicultural experts play an important part. Such advice must create the prerequisites for the management of private forests to make its own useful contribution to the adaptation of forests. In this light it is essential

FW-R-6: Silvicultural information on the theme of adaptation

To date, there is no bundled information available nationwide regarding the extent and intensity of silvicultural advice. The increasing number of articles published in the practice-oriented journal 'AFZ DerWald' on climate change, conveys a rough idea of the intensity of relevant discussions among forestry professionals. Especially in relation to the extreme drought years of 2018 to 2020, there have been distinctly more expert articles available.



Data source: TI für Waldökosysteme (analyses of the journal AFZ – DerWald) to be aware that it is not possible to transfer the cultivation processes created for and applied in extensive, self-contained and intensively managed state-owned forest complexes in exactly the same way to private forest management, because the baseline conditions are often very different. For example, spruce-dominated stands are often particularly unstable owing to a lack of appropriate thinning. Given the small size of some forest terrain and the unfavourable development of stands, protective measures against browsing by game, such as fencing are usually too labour-intensive and too expensive. Besides, many forest owners continue to find it hard to part with their traditional spruce cultivation or they simply lack the knowledge or time to consider any options of site-adapted forest cultivation.

Silvicultural advice is provided by numerous different organisations. In the individual Länder for instance, there are state forest administration authorities, state forest management offices and forestry associations as well as forest owner associations that are able to impart such advice. Generally speaking, the entire field of silvicultural consultation is as diverse as it is confusing. It is therefore impossible for private forest proprietors to access any collective information, 'bundled' on a nationwide basis regarding the form, extent or intensity of silvicultural advice.

Important organs for the dissemination of relevant information are trade journals which are read in particular by forestry practitioners. One of these forestry journals is entitled 'AFZ Der-Wald' which contains concise articles in German and is therefore most effective in terms of reaching the German-speaking public. Articles published in this journal on the subject of climate change and relevant adaptation are read by a very wide circle of readers who engage with forestry management issues.

In many cases the subjects of climate protection and adaptation to climate change have also been addressed in articles published in journals, which means that a definitive attribution regarding adaptation is not always possible. As of 2018, when it became clear that drought and heat would have severe impacts on forests, a multitude of articles were published dealing specifically with these issues. Even though the terms 'climate change' or 'global warming' are not always mentioned explicitly, the connections with climate change impacts are obvious. As of 2020, the number of articles with references to climate change was twice as high as even in the two years of 2017 and 2018. The thematic spectrum ranged from the analysis of forest conditions and the situation regarding forest protection to recommendations on how to deal with pest organisms, how to treat calamity areas, how to select tree species for the future, as well as wildlife management and risk management in general, while also addressing the question of impacts on the timber market.

The exchange of knowledge with private forest proprietors is important in the interest of building up climate-resilient forests also in respect of privately-owned forests and woodlands. (Photo: © Robert Kneschke / stock.adobe.com)

The data make it possible to infer that issues concerned with climate change have by now gained high priority in practice-oriented discussions among circles of forestry professionals. At the same time, it is not reasonable to infer to what extent such discussions and recommendations are followed up by tangible implementation into practice, especially insofar as the management of private forests is concerned.

Photo: © Karin Jähne / stock.adobe.com

Biological diversity

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

Biological diversity is one of the fundamental requirements for the life of human beings. Animals, plants, fungi and micro-organisms contribute to providing clean water, fresh air, a pleasant climate and fertile soils for the cultivation of crops to produce healthy food. Another useful function of stable ecosystems is that they capture carbons from the atmosphere, binding and storing them long-term, thus contributing to the provision of natural climate protection as long as these ecosystems remain in a stable condition. However, biological diversity is endangered. Next to changes in land use, climate change is one of the major factors of influence on biological diversity. This is because its influence is spread across all levels – from single individuals to communities of species and ultimately to complete ecosystems.

DAS Monitoring –what is happening due to climate change

Increased warming leads to phenological shifts in the seasons. The development stages of plants set in earlier in spring, summer and autumn. In contrast, winters are increasingly becoming shorter and milder. The vegetation period is lasting longer overall (cf. Indicator BD-I-1, p. 202). Abiotic stress due to heat and drought causes major ecological damage: Habitats adapted to cooler conditions are shifting in the direction of the poles (cf. Indicator FI-I-1, p. 122) and in the direction of high altitudes in the mountains. In particular, habitats which provide specific conditions for animals and plants adapted to such conditions are either shrinking or lost entirely, while widespread species but also non-resident species expand their ranges.

Species diversity is at risk in places where reproduction or food sources no longer occur synchronously in space or time and complex interactions among species communities are disturbed (cf. Indicator FI-I-2, p. 124). For example when the supply and demand of food are decoupled from breeding and hatching times, this will also affect the functionality, the existence and the resilience of entire ecosystems. The decoupling of interspecies relationships such as competition, prey-predator relationships, host-parasite relationships or symbioses – which can also exist between animal and plant species – can have far-reaching economic and social consequences which must be responded too. This also applies to important processes in agriculture such as pollination or the natural control of pests (cf. Indicators LW-I-4, p. 156).

Climate change entails changes in species communities. This is demonstrated, for instance, by relationships between birds and butterflies (cf. Indicators BD-I-2, p. 204, and BD-I-3, p. 206): Thermophilic species are on the increase whereas cold-adapted species are in decline. Moreover, the expansion of invasive species (cf. Indicator GE-I-4, p. 46) can become a hazard for native biodiversity.

In general it can be said that it is very difficult to identify or even quantify the direct impacts of changing climatic conditions on the development of biological diversity. The interaction of various factors of influence on ecosystems and the communities involved in ecosystems is highly complex. However, in the estimation of specialists, climate change has a much more indirect impact on biological diversity where changes in land use are involved: Climate protection and adaptation measures can result in changes to land use which can have both positive and negative consequences for biodiversity. Such measures can involve the installation of renewable energy systems, the production of biomass, the increased implementation of agro-forestry measures, or the restoration of natural flood plains for protection from floodwater, as well as the renaturation of moorlands in order to strengthen their function as CO_2 sinks.

Future climate risks – outcomes of KWRA

Already now, a third of the species occurring in Germany are endangered in terms of their populations. Apart from increasing demands on land use by humans, climate change represents a major stress factor owing to changes in temperature and precipitation and the increase in extreme weather events such as prolonged periods of drought or heavy rain. As mentioned in the outcomes section of the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7) it is conceivable that major risks regarding changes in vegetation periods and phenology as well as in the spread of invasive species might arise by the middle of this century. Ecosystems in mountain ranges, aquatic habitats, wetlands and woodlands are estimated to be particularly endangered. In addition, high risks are expected to ensue by the end of this century from losses in genetic diversity, the shift of territories, a decline in populations and the loss of ecosystem services including high risks in coastal ecosystems. In other words, all climate impacts evaluated in KWRA 2021 and covered by the action field 'Biological Diversity' entail high risks emerging by the end of this century.

Where do we have gaps in data and knowledge?

There are knowledge gaps and uncertainties to what extent direct and indirect impacts of climate change will affect biological diversity and how best to counteract such impacts. These gaps and uncertainties are due to the fact that there are numerous other factors to be considered in addition to climate change. There is, in particular, a lack of data on cause-and-effect relationships among changing climatic phenomena (such as increasing summer drought) and the biological response of species, species communities and ecosystems as well as a lack of data on adaptation and expansion options available to any animal and plant species concerned.

The newly founded National Monitoring Centre for Biodiversity (NMZB) in Leipzig has been working since 2021 on establishing a knowledge base by collecting data on the state of species and habitats in Germany and to develop an overall concept for biodiversity monitoring nationwide.

What's being done – some examples

In order to improve the protection of biodiversity under changing climatic conditions, it is essential to maintain sufficiently large populations and their genetic diversity, as well as ensuring that their habitats are available in sufficient quantity and quality and that these habitats are networked well.

The 'Kunming-Montreal Global Biodiversity Framework' (GBF) adopted in December 2022 has set global objectives for the protection and maintenance of biological diversity. One of the objectives is to improve or restore the connectivity and resilience of ecosystems worldwide and to expand the terrain of natural ecosystems substantially. It is up to the 196 signatories to the Convention on Biological Diversity (CBD) to put their resolutions into practice. The EU Biodiversity Strategy for 2030 for the conservation and restoration of wildlife was adopted in 2020 at a Europe-wide level.[124]

The Federal government's core nature conservation strategy is the National Biodiversity Strategy 2007 (NBS). Work is currently ongoing on Germany's NBS 2030. The aim is that issues such as impacts of climate change, adaptation to climate change and climate protection be addressed more forcefully than before. At Länder level, 15 of Germany's 16 Federal States have biodiversity or nature conservation strategies in place – in some cases in the form of action plans which, as at Federal government level, typically address the relationship between climate change and biodiversity. Likewise, there are other relevant national strategies in place: The National Water Strategy[125] (2023) addresses the protection of groundwater, streams, rivers and lakes, as well as the permanent safeguarding of a near-natural water budget. The Federal programme 'Blaues Band' (Blue Belt, 2017) supports renaturation measures in alluvial meadows of Federal waterways; its intention is to create a biotope network. The funding programme 'Förderprogramm Auen' enables municipalities, associations and organisations to apply for funding to further the near-natural development of biotope networks in alluvial meadows. At the same time, the expansion of natural flood plains also benefits the protection from floodwater and the protection from flooding in the event of flash floods[126]. The restoration of natural flood plains by means of dyke realignment enables the reconnection of flood plains with rivers. At the same time, this is also a measure of natural climate protection. In 2020 the terrain of restored natural flood plains amounted to a total of 7,100 ha. Compared to 2019 this represents a gain amounting to 716 ha added to the previous total (cf. Indicators BD-R-2, p. 210).

Germany's National Peatland Protection Strategy (Moorschutzstrategie / 2022) created the political framework for all aspects of peatland protection for years to come. A very low percentage of German peatland is still in a near-natural condition. Consequently, the species diversity typical of peatlands is severely endangered. The aim therefore is to protect near-natural peatlands rigorously, to strengthen their CO_2 sink function, and to improve their hydrological condition in such a way that they fulfil their potential as habitat for species adapted to wetlands as well as for water retention in the landscape, thus contributing cooling effects and meeting the objectives of adapting to the impacts of climate change.

Climate change is also getting more consideration in landscape programmes and landscape framework plans these days (cf. Indicators BD-R-1, p. 208). More than two thirds of the Länder's landscape programmes and 50 % of regional landscape framework plans have incorporated the climate change theme in connection with issues of nature conservation.

Nature reserves and national parks are particularly well protected areas which make them important refuges with, on principle, favourable conditions for the conservation of those species and habitats that are at particular risk from climate change. By 2020, the proportion of strictly protected areas in Germany increased to a total of just under 4.6 % (cf. Indicator BD-R-3, p. 212).

Already since 2004 the Federal Agency for Nature Conservation (BfN) has been organising the conference entitled 'Biodiversity and Climate – Networking the Stakeholders in Germany' with the aim of promoting the exchange of research outcomes among specialists in the overlapping fields of biodiversity, nature conservation and climate change. Specialists use this annual event to discuss in what way measures for the maintenance of biological diversity might also be used in supporting measures for adaptation to climate change and how to shape adaptation measures in ways to obtain synergies with nature conservation.

On 29th March 2023 the federal government adopted the action programme 'Natural Climate Protection' (ANK). Woodlands and alluvial meadows, soils and peatlands, seas and water bodies, near-natural green spaces in urban and rural areas all contribute to capturing CO_2 from the atmosphere and to provide long-term storage. Furthermore, these areas can buffer negative effects of climate change by retaining water in the landscape, by capping floodwater peaks and by providing air for cooling purposes. At the same time, they safeguard important habitats for animals and plants. In towns and settlements, nature provides better air and shade and acts as a cooling agent on hot summer days. Contiguously linked near-natural green spaces form cold air and fresh air channels and provide habitats and refuges for many animal species. Á multitude of measures is intended to ensure that degraded ecosystems are restored to good health, resilience and diversity. The programme is financed largely from the new climate and transformation fund. Up to 2026 there is a total of four billion Euros available. The focus is on the funding of tangible renaturation measures and incentives for climate-friendly and nature-compatible forms of management.

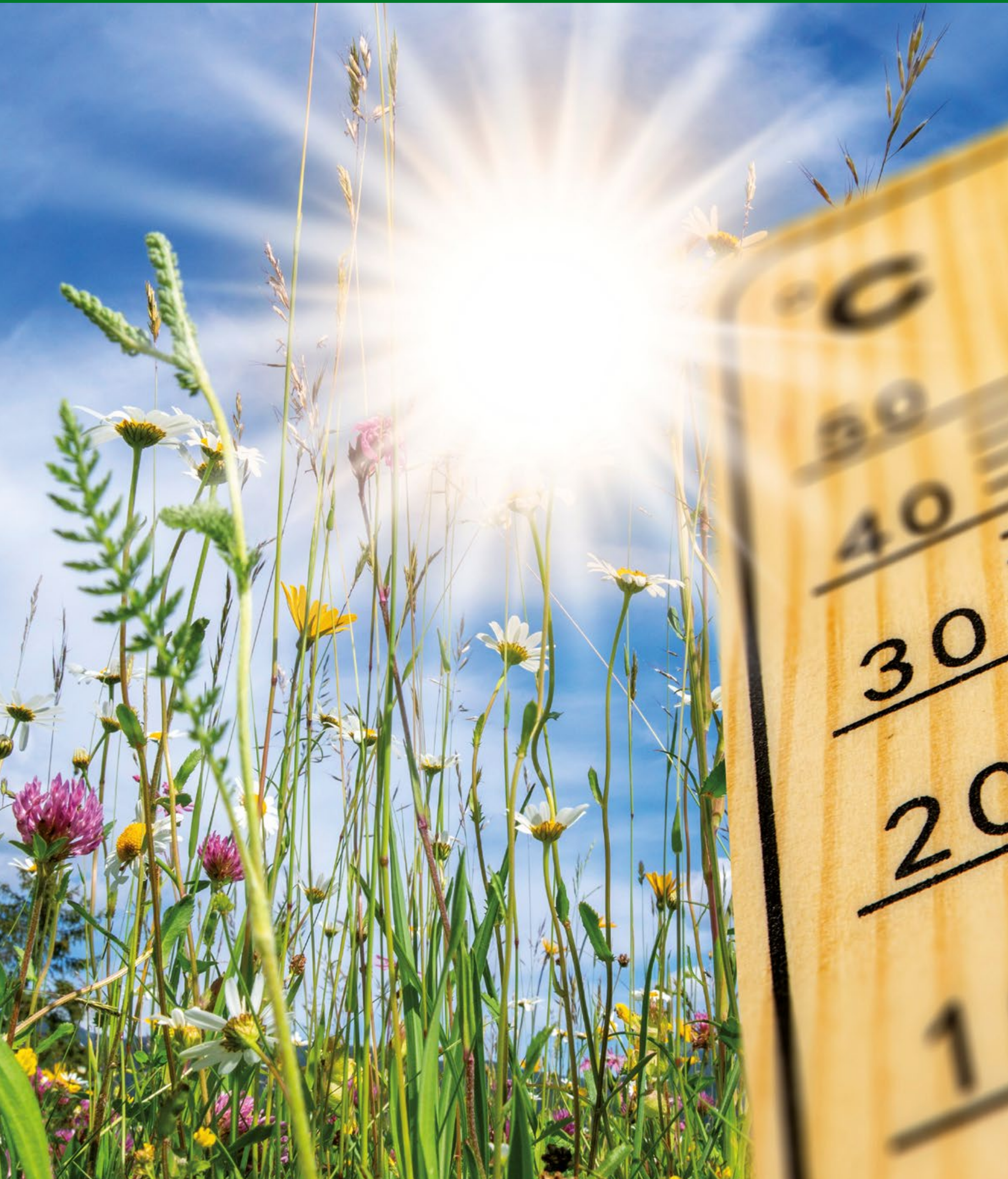


Photo: © Wolfilser / stock.adobe.com

Spring, summer and autumn begin earlier year by year

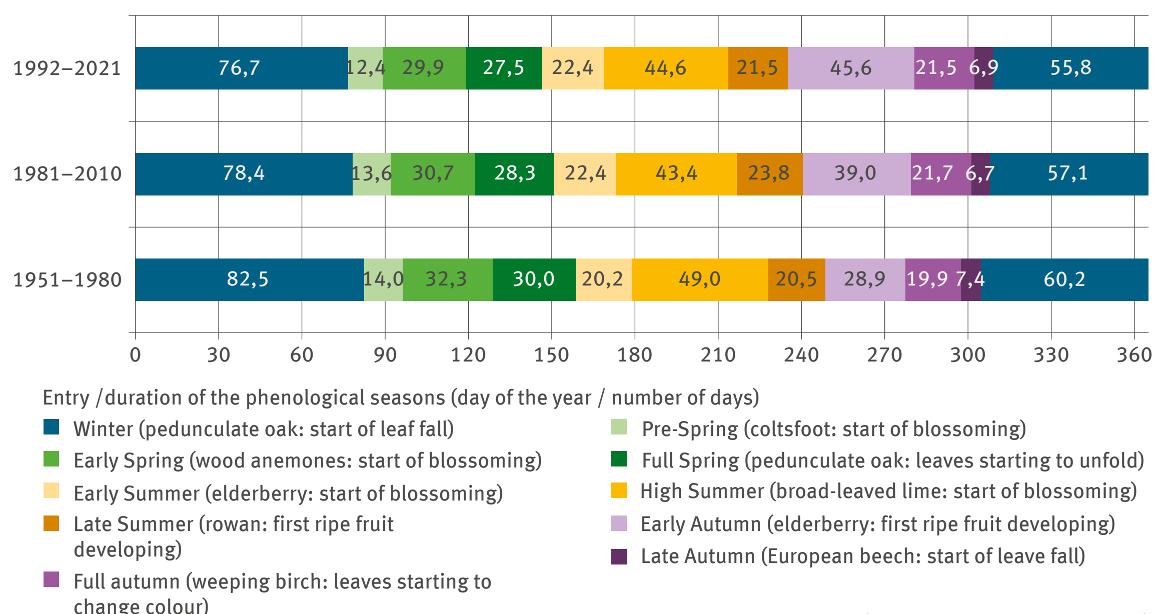
In our climes, the seasonal development of plants is primarily influenced by climate- and weather-related temperature patterns. A warm winter, for example, leads to very early flowering of trees such as hazel (*Corylus avellana*) or common alder (*Alnus glutinosa*). For this development, it is not individual warm or cold days which are crucial; in fact, the crucial parameter is longer-term weather patterns that precede flowering. If temperatures remain high, for instance during several consecutive weeks in winter, a sum total of warmth accumulates thus accelerating a plant's development.

Changes in natural seasonal rhythms and associated temporal shifts in the development of plants have been studied and documented for years by means of so-called phenological observations. These nationwide studies involve the beginning of certain periodically recurring biological phenomena such as leaf and bud formation, flowering, maturity of fruit or leaf fall. The phenological observation network operated by DWD includes the observation of a broad spectrum of wild plants whose specific development phases mark the beginning of phenological seasons. Wild plants are particularly suitable for the observation of phenological shifts, as their responses are free from the influence of human manipulation in breeding processes or from cultivation activities (cf. Indicators LW-I-1, p. 150, and LW-R-1, p. 158).

The interpretation of shifts in seasonal cycles can only produce reliable results if this is done over extended sequences. This is why phenological data as well as climate-related data are averaged over periods of 30 years. Using the so-called phenological clock to compare the mean starting points of phenological seasons for the reference period of 1951 to 1980 and the comparative period of 1981 to 2010 with the starting points of the period from 1992 to 2021, the following pattern emerges: Regarding the phenological seasons from pre-spring via early summer until early autumn, the two periods after 1981 started earlier than in the reference period of 1951 to 1980 whereas the seasons of autumn, late autumn and winter started later. Pre-spring is the only time when the statistical difference is not significant. This means that especially the early autumn in the mean

BD-I-1: Phenological changes in wild plant species

On average, the beginning of phenological spring, summer and autumn has advanced in the course of the past 71 years. While winter has become distinctly shorter, early autumn has become distinctly longer. These changes reflect the adaptability of plants to the changed climate. On the other hand, they can also have consequential effects on biodiversity, potentially leading to a situation which ultimately puts animal and plant species at risk.



Data source: DWD (phenological observation network)

of the years 1992 to 2021 was approximately 17 days longer than in the reference period 1951 to 1980 whereas the winter season was approximately ten days shorter compared to the winter seasons between 1951 and 1980. This comparison also demonstrates that the summer mean of the three periods in question remained almost unchanged amounting to approximately 90 days whereas the beginning and end of summer in the period 1992 to 2021 was on average approximately twelve days earlier than in the reference period 1951 to 1980. An analysis of the starting dates of phenological seasons in the period 1992 to 2021 compared to the reference period 1951 to 1980 reveals statistically significant – and in most cases highly significant – differences between the two periods for all seasons.

On one hand, shifts of phenological seasons reflect the adaptability of plants and animals to changed climatic conditions. On the other, changes in development cycles caused by climate change also indicate consequential impacts on biodiversity. Phenological shifts can, in some cases, decouple the synchronicity of developments between organisms. This affects established interactions, for example between plants and their pollinators or interactions in prey-predator relationships. This effect impacts in turn on the structure and functions of ecosystems and can ultimately put animal and plant species at risk. For example, in the Netherlands it was proven that in pied flycatcher (*Ficedula hypoleuca*) populations the number of individuals declined owing to the decoupling of the time when nestlings are reared from the time when there was an optimal supply of their food source.[127] Pied flycatchers are long-distance migrants which spend winters in Africa; hence they are unable to respond adequately to the changed cycles in the development of their food organisms.

In Germany, there have been no wide-ranging studies or systematic observations of the consequences of such changes in relationships between plants and animals caused by phenological shifts. This is why at this point in time it is only possible to say that further shifts in phenological phases are to be expected.

The same applies to temporal extensions observed in respect of phenological vegetation periods. Those periods are equivalent to the sum of the days of phenological spring, summer and autumn. While the mean vegetation period in the years of 1951 to 1980 amounted to just 222 days, it was extended on average by 8 days to 230 days in the period of 1981 to 2010, and in the period of 1992 to 2021 by an average of 10 days to 232 days. In this context, it is important to note that the duration varies considerably from year to year. For example, an extension of the vegetation period can result in higher productivity of ecosystems which, in turn, can affect the relationships between various species. So far, there have been no systematic nationwide studies in Germany regarding the effects of an extended vegetation period on biodiversity.

In the course of the past 30 years, coltsfoot plants (*Tussilago farfara*) flowered just under a week earlier than in the time period of 1951 to 1980. (Photo: © ELENA / stock.adobe.com)

Bird species communities: thermophilic species predominate

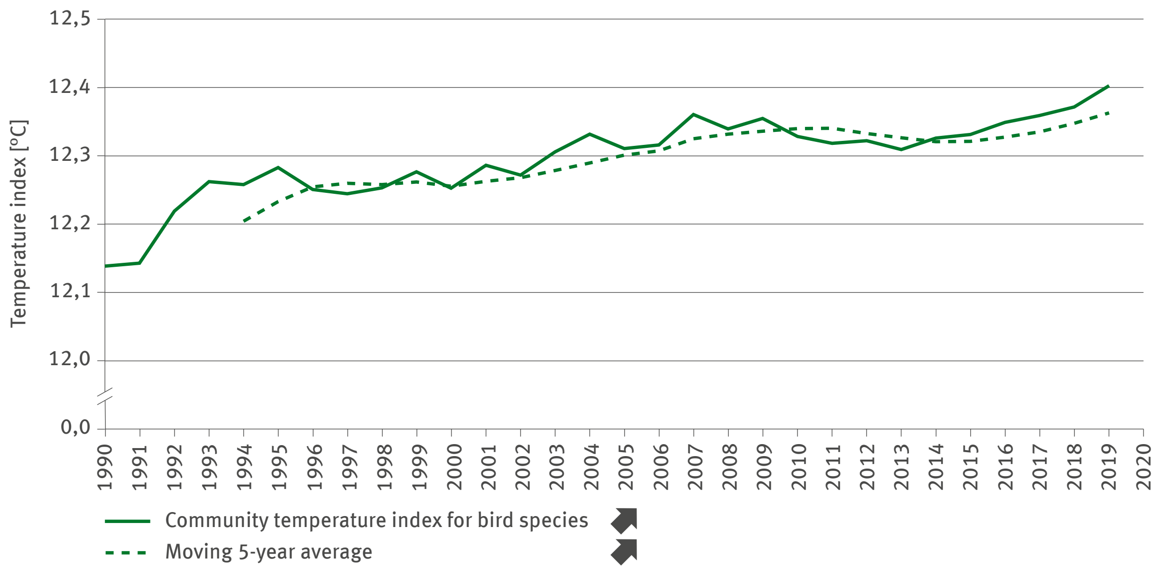
Birds are comparatively sensitive to changes in their environment. This entails that the composition of bird communities can change strongly as a function of environmental impacts. Typically, such changes are the result of various impact factors combined. As a rule, there is no singular cause for a change in species communities and the decline or loss of individual species. There is however evidence from scientific research which indicates that, in addition to changes in land use, climate-related changes can play a crucial role.

Breeding birds require species-specific temperatures at breeding time. These are lower, for instance, in respect of whinchat (*Saxicola rubetra*), thrush nightingale (*Luscinia luscinia*) and icterine warbler (*Hippolais icterina*) than for stonechat (*Saxicola rubicola*), nightingale (*Luscinia megarhynchos*) and melodious warbler (*Hippolais polyglotta*). If, as a result of climate change, temperatures during the breeding season increase in terms of the long-term mean, conditions will become more favourable for thermophilic species which will then become more frequent compared to other bird species. Vice versa, cold-tolerant species are in decline compared to other bird species.

In the period between 1990 and 2019, such a development has been observed in 88 bird species breeding in Germany. As indicated by the temperature index for frequently occurring breeding bird species, the relative frequencies of the birds observed have shifted in this period in favour of thermophilic species or, putting it another way, the relative frequencies shifted to the detriment of cold-tolerant species. From 1994 onwards, the moving 5-year average of the temperature index first shows an increase taking place until approximately 2010, but this was followed by a slightly retrograde development by 2013, whereas this was in turn followed by a distinct increase. However, the development between 2010 and 2013 can be attributed in the first place to effects of weather patterns which had an impact regardless of the long-term climatic trend. In the years 2009 / 2010 to

BD-I-2: Temperature index for bird species communities

Climate change entails changes in species communities. In respect of 88 breeding bird species occurring in Germany, the relative frequencies have shifted between 1990 and 2019 in favour of thermophilic species or, putting it another way, shifted to the detriment of cold-tolerant species.



Data source: Dachverband Deutscher Avifaunisten e.V. (own analysis of data from the monitoring of common breeding birds)

2012 / 13 there were several consecutive hard winters with adverse effects on many breeding bird populations. The developments since 2013 show that the more long-term positive trend reflected by the indicator has continued despite short-term levelling impacts from a number of hard winters between 2009 and 2013. Nevertheless, it is clear that despite progressive climatic warming, the incidence of extreme weather events is of major importance to ecological change processes.

In various phases of their annual cycle, birds are affected by temperature changes, as for instance during breeding, overwintering or the recruitment of new breeding birds into the population. Consequently, climate change is apt to change the phenology, in other words the life cycle, of species. In particular, bird species overwintering in Africa, south of the Sahara, can suffer detrimental effects from such changes. It is known, for instance, that owing to the earlier beginning of spring, pied flycatchers (*Ficedula hypoleuca*) sometimes return too late from their winter habitat to exploit the main abundance of caterpillars as food for their young.

For the purpose of calculating the temperature index, a species-specific temperature requirement value is allocated to each of the 88 bird species occurring in their European distribution area, based on the average temperature for the reference period 1961 to 1990. These species-specific temperature requirement values – weighted according to the relative frequency per species in any particular year – are included in calculating the index. The greater the long-term rise in the temperature index of frequently occurring breeding bird species, the stronger the shift in the relative frequencies among thermophilic species and consequently, the stronger the influence of temperature rise on the group of birds under observation. The index values shown refer to Germany nationwide. This demonstrates that it is not possible to make any statements on a changed composition of regional breeding bird communities.

Likewise, other groups of species such as butterflies or vascular plants can be used as indicators for long-term temperature changes related to climate change (cf. Indicators BD-I-3, p. 206, BD-I-1, p. 202, and FW-I-1, p. 174). In this context species shifts become most obvious in ecologically marginal regions such as mountain ranges. For instance, Europe-wide studies of vegetation in the peak areas of mountain ranges above the treeline show that the composition of species communities of vascular plants in those areas is changing. This is where thermophilic species from areas at lower altitude form colonies. Likewise, in rivers, lakes and seas, changes

The icterine warbler (*Ficedula hypoleuca*) is one of the climate-change losers. By the time this species returns from its winter habitat, the caterpillars they need to feed their young have already become relatively scarce.(Photo: OhWeh / Wikimedia Commons, CC BY-SA 2.5)

are taking place already regarding the composition of species communities (cf. Indicators FI-I-1, p. 122 and FI-I-3, p. 126).

Apart from shifts in the frequency of species within existing species communities, climate change also leads to the immigration and distribution of species which have not occurred in our climes before. These developments take place in respect of both, plants and animals. Examples for this are the melodious warbler (*Hippolais polyglotta*) which emanates from south-western Europe and became a German breeding bird in the 1980s extending its range ever since, or the praying mantis (*Mantis religiosa*) which came from the Mediterranean to Germany in the 1990s and is gradually spreading ever more northwards.

Insect communities show particular sensitivity

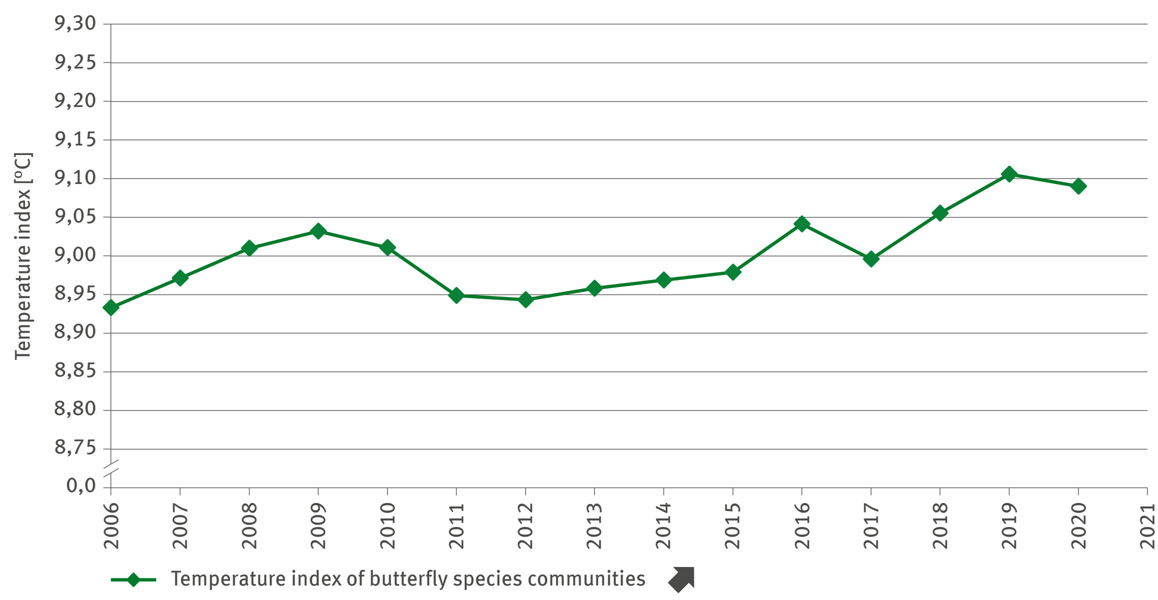
Butterflies are sensitive to a great number of environmental factors. To make matters worse, those factors often interact with each other. Especially those processes which are connected with land use have a major influence on population trends and the composition of species communities. Besides, scientific studies portend that climate change will increase in importance. Like all insects, butterflies belong to the group of poikilothermic organisms whose activity and development is directly dependent on the temperature of their environment. These properties make them particularly sensitive to changes in temperature. Butterflies have very short development cycles; this makes them respond even faster to changing climatic conditions.

Germany has a wide range of native butterfly species which distinguish themselves by having different temperature requirements. This includes both, thermophilic species such as the marbled fritillary (*Brenthis daphne*) and the wall brown butterfly (*Lasiommata megera*) as well as psychrophilic species such as the ringlet (*Aphantopus hyperantus*) and the pearl-bordered fritillary (*Boloria selene*). In the course of climate-change related warming, the habitat conditions for species with requirements for higher temperatures are improving. On the other hand, species adapted to cool environments are confronted with unfavourable conditions. The tendency for increases in thermophilic species and the decline in psychrophilic species is changing the composition of localised species communities.

The temperature index of butterfly communities provides a vivid demonstration of such changes. It reflects the mean temperature requirements of the species present in a species community. In the period from 2006 to 2020 the index shows a significant increase. This means that thermophilic species in the species community have increased whereas psychrophilic species declined. Up to 2012 this development was somewhat ambiguous, whereas subsequently a steady increase in the index is evident. The above-average warm years from 2018 onwards favoured especially the thermophilic species thus entailing a distinct increase in the temperature index. As yet it is not

BD-I-3: Temperature index of butterfly species communities

Rising temperatures influence the composition of species communities. Between the years of 2006 and 2020, the frequency of thermophilic species has increased compared to psychrophilic species. Especially the extraordinarily warm years post-2018 have contributed to an increase in the temperature index of butterfly communities.



Data source: UFZ (analysis of the Butterfly Monitoring Germany) possible to predict any long-term repercussions of these changes in terms of biological diversity.

In order to calculate the temperature index of butterfly communities, it was necessary to first calculate the mean temperature requirement value per butterfly species, which was derived from the average temperature prevailing in the European distribution range of the species within the reference period from 1971 to 2000. Subsequently, the mean was calculated for the index by weighting the species-specific temperature values according to each species' frequency of occurrence. The input contained data for 71 frequent and semi-frequent butterfly species as recorded within the transects used by Butterfly Monitoring (Tagfalter-Monitoring) for Germany as a whole. An annual temperature index for the butterfly communities was calculated for each transect and used as a basis for calculating the mean value for Germany. An index value increasing over time illustrates a shift in frequencies in favour of thermophilic species.

It is not just butterfly communities that have been changing. Dragonfly and bumblebee communities respond in similar ways to increasing temperatures. Climate-change related changes in species communities were also documented for birds (cf. Indicator BD-I-2, p. 204), fish (cf. Indicators FI-I-1, p. 122) and plants. The development often varies from region to region. Especially in northern distribution boundaries of species and in mountain ranges, changes proceed particularly fast. Changes in the composition of species communities can also result from shifts in distribution ranges. One example is the southern small white butterfly (*Pieris mannii*) which occurs mainly in Southern Europe. Since its first occurrence in Germany in 2008 it has spread widely across the country. In many cases, the consequences of such processes remain to be researched. However, it seems safe to assume that particularly interactions between different organisms will change thus producing impacts on various ecosystem functions and services.

The wall brown butterfly (Lasiommata megera) is a thermophilic butterfly species which therefore benefits from climate change. (Photo: © sundodger / stock.adobe.com)

Climate change impacts increasingly considered in landscape planning

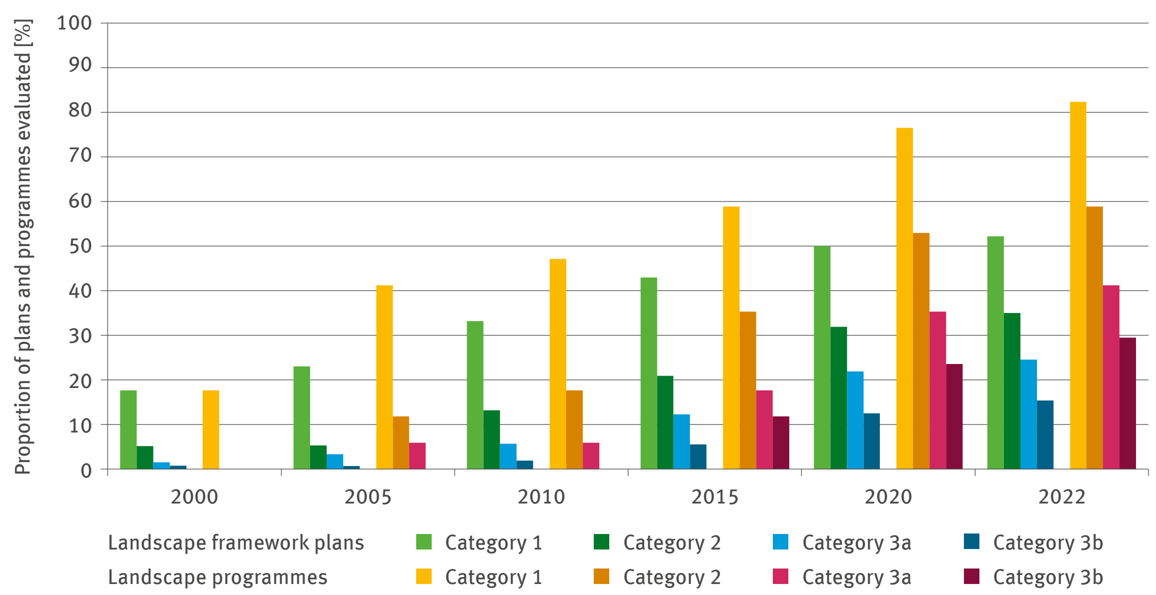
Land use has a major influence on biodiversity, which makes it one of the core starting points for the conservation of animals and plants and for the development of suitable habitats. Climate change therefore presents, in many respects, new challenges for a nature-compatible and future-oriented approach to controlling land use, in view of the fact that the competition for land is certain to increase. The expansion of renewable energies for the purpose of climate protection, but especially the use of biomass for energy generation entails the intensification of land use regionally by means of agriculture and forestry.

In order to safeguard biodiversity it is necessary when making decisions related to nature conservation, to take both direct and indirect impacts of climate change into account, to identify the essential objectives both in terms of concepts and planning and to prepare the requisite measures. Landscape planning therefore plays an essential role as a tool for encompassing contiguous areas in nature conservation (cf. Indicator RO-R-1, p. 302). Programmes related to landscape planning incorporate important co-ordinating functions at the level of federal Länder, setting priorities in stipulations regarding requirements and measures in respect of nature conservation that are of relevance to the federal state concerned. Apart from programme-based objectives and guidelines for the nature conservation policies of a federal state, they also contain spatially tangible illustrations for instance on a specific state's biotope network or on its areas of particular value in terms of nature conservation. Landscape framework plans are generated for planning regions, administrative districts or government districts. They illustrate the requirements of landscape programmes in a tangible form, contain proposals on the designation of priority areas and make statements that are specific to particular regions.

Unfortunately, regulations contained in individual Länder's nature conservation legislation regarding the generation and updating of landscape programmes and

BD-R-1: Consideration of climate change in landscape programmes and framework plans

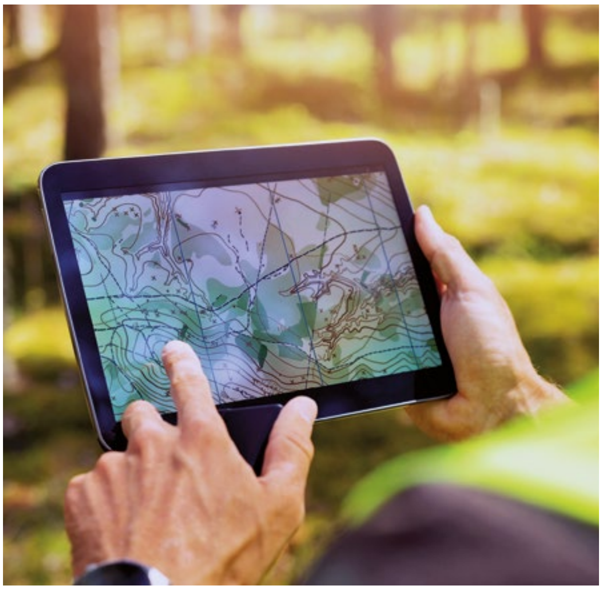
Landscape programmes and framework plans provide a platform for tangible objectives and principles of nature conservation and landscape management at the level of individual states and regions. Climate change impacts and the resulting challenges for the protection of biotopes and species are increasingly being incorporated in planning. However, the majority of plans still show a lack of tangible statements including objectives or measures related to climate change.



Data source: BfN (own analysis)

landscape framework plans are not homogeneous. For example, the city states of Berlin, Bremen and Hamburg as well as the states of Saarland and since 2010 also Hesse have abolished the development of landscape framework plans.[128] In some cases, the current legal position also means that outdated landscape programmes do not have to be updated any more. Besides, the updating cycle for landscape framework plans also varies from one federal state to another. However, as before, there is still a rule in force according to which landscape programmes and landscape framework plans represent the central planning level which serves as a platform in which it is possible to embed any requirements on spatial planning resulting from climate change as well as requirements in respect of nature conservation.

As shown by an evaluation of 16 landscape programmes operated by Länder and the available landscape framework plans – there were 155 in 2020 – the impacts of climate change and the resulting requirements in terms of planning are not yet taken into consideration widely. However, as far as those plans are concerned that were analysed in respect of the period from 2000 and 2020, a distinct increase is noticeable in references to climate change. For example, climate change and themes relating to climate protection and adaptation to climate change in connection with nature conservation issues have been mentioned in slightly more than three quarters (76 %) of landscape programmes. The process of evaluation included statements made in the plans relating to land with both storage and sink functions for carbon. By contrast, a clear majority of plans has so far failed to include any descriptions of tangible impacts of climate change on biodiversity. According to the 2020 status, only approximately 22 % of landscape framework plans provide a rationale for individual nature conservation objectives and measures which are at least in part associated with climate change. The analyses undertaken do not permit any detailed statements regarding the specific technical depth or consideration of climate change in the plans analysed. Nevertheless, it is evident that landscape planning at the level of Länder and regions, with a view to the challenges of climate change, has so far included only scant statements on tangible objectives and measures.



Climate change and its consequences play increasingly important roles in landscape planning.
(Photo: © ronstik / stock.adobe.com)

Consideration categories regarding climate change in landscape programmes and landscape framework plans

1 Areas of land relevant to climate change (with storage and sink function for carbon) are mentioned in connection with nature conservation issues.

2 Impacts of climate change on biodiversity are described.

3a Some individual nature conservation objectives and measures are in part founded on reasons related to climate change.

3b Some individual nature conservation objectives and measures are based exclusively or predominantly on reasons related to climate change.

Increase in natural flood plains benefits biological diversity

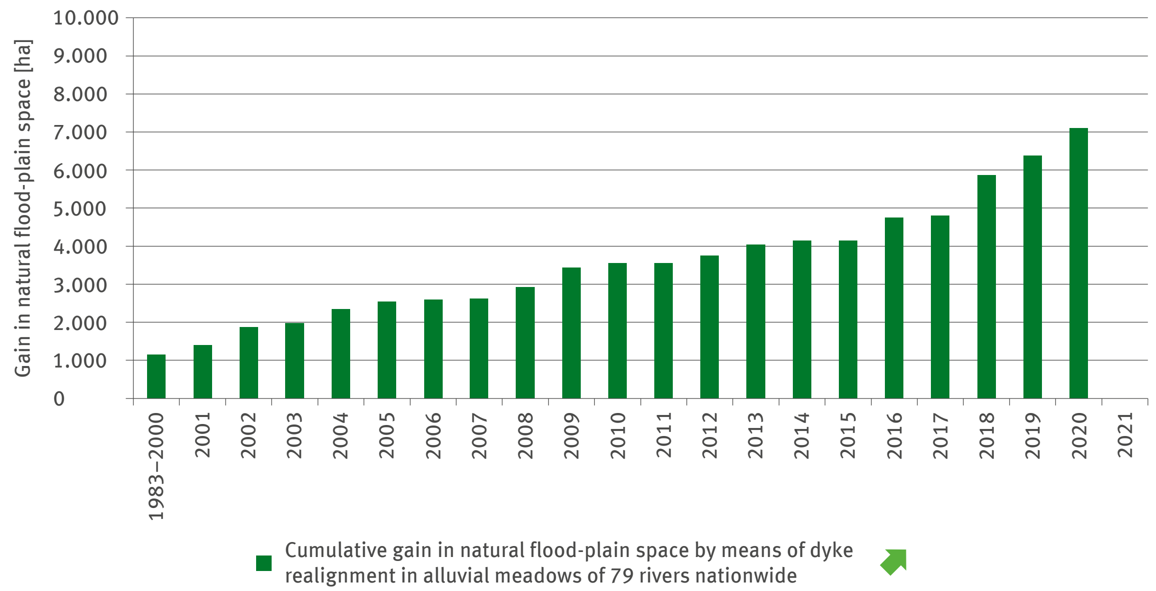
The maintenance of wetland or water-rich habitats and their connectivity in the landscape is of preeminent importance for the conservation of climate-sensitive species. Near-natural alluvial meadows play a key role in this context. Alluvial meadows are lowlands which are clearly characterised by the dynamics of a river and its water regime, and in which phases of high water levels alternate with low water levels. These dynamics induce an abundant mosaic of various habitats which explains the high diversity of animal and plant species in these zones. Typical forms of vegetation in alluvial meadows are alluvial forests characterised by tree species such as willows, oaks or elms which cope well with flooding, even if it lasts for some time.

The restoration of natural flood plains involves substantial synergies between species conservation and biotope conservation as well as floodwater protection. Apart from heightening dykes, the installation of holding ponds or other technically-based measures, the durable restoration of natural flood plains is considered an effective component of comprehensive floodwater risk management (cf. Indicators WW-R-2, p. 92, and RO-R-3, p. 306): Where rivers can spread into such flood plains in case of floodwater events (cf. Indicator WW-I-4, p. 76), run-off is slowed down and the floodwater wave attenuated. In the circumstances of climate change and associated changes in the run-off dynamics of river catchment areas, the restoration of natural retention areas plays an increasingly important role, also as a measure for adaptation to climate change, in order to prevent floodwater damage, for instance in settlements, transport infrastructures or agricultural areas

Such newly gained flood plains had previously been in many cases under intensive agricultural use. Where areas are re-exposed to natural floodwater dynamics, they can be re-colonised by many species of plants and animals typical of alluvial meadow habitats. This includes numerous rare and endangered species which are adapted to the special conditions of frequently alternating water levels, such as beaver (*Castor fiber*), otter (*Lutra lutra*), kingfisher (*Alcedo atthis*), sand-martin (*Riparia riparia*), marsh harrier (*Circus aeruginosus*), various species of

BD-R-2: Restoration of natural flood plains

The realignment, renaturation or slotting of dykes carried out since 1983 has produced an increase in natural flood plains. By their connection to water courses or water bodies and by restoring the dynamics of natural flooding, new and – in terms of nature conservation – valuable habitats have been created for numerous rare and endangered animal and plant species. Likewise, alluvial forests have been created which are just as important for nature conservation.



Data source: Möhring et al. 2012, BfN (own research) duck – especially those sensitive to disturbance – as well as numerous species of dragonfly and amphibians. Besides, habitats that can flood naturally such as alluvial meadows, provide important links in biotope networks and within the system of protected areas designated under Natura 2000.

By means of renaturation, realignment or slotting of dykes in respect of 79 rivers nationwide, an area of 7,100 ha of former alluvial meadows was, in the period from 1983 to 2020, reconnected with the natural flooding dynamics of water courses. As a result they are, during floodwater events, flooded without any human intervention or control. Any installations of controlled floodwater polders or other controlled flooding mechanisms used in alluvial meadows were not taken into consideration. The annual net gain depends on the size of completed projects in the year concerned which makes this figure variable. The distinct annual increases over the past three years should be viewed as positive.

In 2021, the nationwide inventory established in a report on the condition of alluvial meadows concluded that, of formerly approx. 1.6 million ha of alluvial meadowland on riversides, only approx. 511,900 ha today remain available as retention areas for floodwater.[129] Compared to those figures, the restoration of naturally flooded alluvial meadowland in the period from 1983 to 2020 covers a relatively small terrain. Consequently, the requirement for action remains great.

Discussions concerning the importance of restoring natural flood plains and the renaturation of alluvial meadows for adaptation to climate change, contained in the action field entitled 'Biological Diversity' demonstrate how close the connections are between climate protection, adaptation to climate change and the development of biodiversity. In this context, specialists maintain that the indirect impacts of climate change in terms of the implementation of climate protection and adaptation measures are greater than the direct impacts caused by global warming and changes in the precipitation regime. Measures such as the installation of renewable energy plant, the production of cultivation biomass, the implementation of agro-forestry measures, the restoration of natural flood plains for floodwater protection and the renaturation of moorlands for strengthening their CO_2 sink function – which at least partly benefit both climate protection and adaptation to climate change – all these factors bring about both positive and negative consequences for biodiversity.

The restoration of natural flood plains involves substantial synergies between floodwater protection and the facilitation of biodiversity conservation.
(Photo: © Fernbach Antal / stock.adobe.com)

Terrain of strictly protected areas still slightly increasing

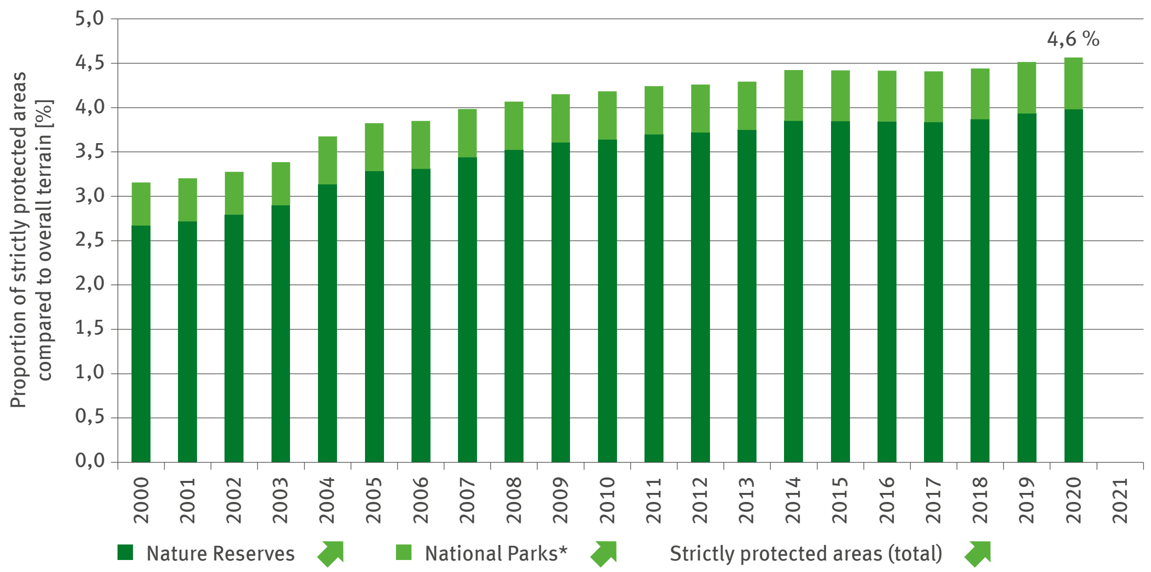
Animals and plants in the wild, as well as their habitats, are exposed to varied influences in German landscapes characterised almost contiguously by anthropogenic use. Apart from the adverse effects of progressive intensification of land use, climate change in many cases causes additional stresses. Given these circumstances, the creation of refuges for the protection of valuable areas of nature conservation is gaining increasing importance for the continued existence of native and, in many cases, endangered animal and plant populations (cf. Indicator RO-R-1, p. 302). Apart from the size and quality of protected areas, the spatial distribution and networking of these areas also play an important role in these times of climate change.

There are strict protection regimes in force in nature reserves and national parks in order to enable the conservation and development of rare and endangered species and biotopes. In national parks it is their large scale which plays a very special role. The majority of the expanse of a national park is supposed to be dedicated to safeguarding the ability of natural processes to take place with as little disturbance as possible. The indicator reflects the overall terrain of these protected areas in Germany. The outcome of this calculation is based on the percentage of land in nature reserves and national parks as a proportion of Germany's overall terrain. Natura 2000 areas as well as core and buffer zones of biosphere reserves are included, provided they have been designated as nature reserves or national parks. In terms of statistics, the overall terrain of these protected areas has increased from 1,129,225 ha in 2000 to 1,632,691 ha in 2020. With reference to the overall terrain of Germany, this represents an increase from 3.2 % in 2000 to 4.6 % of the terrain by 2020.

The increase in the total terrain of these protected areas had been achieved partly by the implementation in the past of the Natura 2000 network. It is expected that in Germany in future, the amount of new designations of protected areas in terms of Natura 2000 areas for the purpose of their legal protection, will probably increase in manageable proportions. This is mainly because most of the Natura 2000 areas have already been placed

BD-R-3: Protected areas

Nature reserves and national parks are specially protected areas which provide refuges in which adverse impacts on animals and plants can be avoided or moderated. In these circumstances, protected areas create favourable prerequisites for the conservation of species and habitats particularly at risk from climate change. The steady increase in the number of these protected areas must be regarded as positive.



*Core and Buffer Zones of Biosphere Reserves listed as National Parks provided they are designated Nature Reserves or National Parks

Data source: BfN

under legal protection, and the Länder tend to choose, apart from nature reserves or national parks, other forms of protection.

While the terrain of nature reserves increased steadily between 2000 and 2014 and has been on the increase again since 2018, the terrain of national parks increased only between 2003 and 2004, as a result of the foundation of the Eifel National Park in North-Rhine Westphalia, the Kellerwald Edersee in Hesse, as well as the creation of the Black Forest National Park in Baden-Württemberg in 2014 and Hunsrück-Hochwald in Rhineland-Palatinate and Saarland in 2015.

The increase in the cumulative terrain of these protected areas must be regarded as positive, especially in view of the new challenges arising from climate change and its impacts on species and biotopes. The formal designation of a protected area, however, although important, is but a first step on the journey towards the adaptation of the protected area system to the challenges associated with climate change. Habitats particularly at risk from climate change such as wetlands or mountain ranges are part of the group of highly valuable nature conservation areas. This is why the aspirations to protect those areas harmonise well with the objectives of adaptation to climate change.

The designation of suitable areas in sufficient proportions has to be combined with an effective management of these areas in order to comply with the declared objectives of nature conservation. The regulations governing individual protected areas can vary a lot and the number of all protected areas in Germany is substantial. To date, it has therefore been impossible to make any comprehensive statements on the quality of the areas concerned and their management. Besides, it is not clear either to what extent some aspects of adaptation to climate change are being taken into account already in the management of protected areas. Potentially, there are even now dynamic developments taking place with regard to climate change which will make it necessary in future to adapt the objectives pursued as well as the management carried out in protected areas.

It is also intended that nature reserves and national parks safeguard parts of the transnational biotope network and that they expand this network, as required by the German Federal Act on Natural Conservation. Adequate connectivity within the biotope network will enable the genetic exchanges among populations. This, in turn, is an indispensable prerequisite for the conservation of species. This is why, in view of climate change, the biotope network is becoming ever more important, in order to improve the migration and distribution opportunities among various occurrences of animal and plant species over a wide area. Both the expansion of the overall terrain of protected areas and of the biotope network make essential contributions to the nationwide endeavour to reconnect habitats, thus supporting the objective of adapting to climate change. All the same, indicators do not help with inferring any statements on whether the specific challenges arising from climate change are given sufficient consideration in current planning and implementation efforts regarding the biotope network.

As far as plants and animals are concerned, climate change constitutes an increasing stress. In strictly protected areas, other stress factors are reduced.
(Photo: © Makuba / stock.adobe.com)

Photo: © Stephan / stock.adobe.com

Building Sector

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

Living and working, commercial activity, trades and services, culture and education, health and leisure – the buildings are used for, or closely connected with, a great variety of human activities. It has always been a core function of buildings to protect users and their properties from impacts of weather conditions. This also applies to the variety of functions which can be carried out in buildings. The existing building standards and norms ensure that buildings meet these requirements when confronted with a variety of climatic conditions prevailing at their location and that they are protected, as far as possible, from any predictable types of damage. Regional differences in terms of snow loads, wind pressures and heavy rain or in terms of summer climate regions are described. Such differences must be taken into account in the design of buildings – at both architectural and engineering levels.

In view of the considerable range of possible interpretations of existing standards, it is particularly the increase in frequency and greater intensity of extreme events which will present challenges to the building sector. Buildings and towns / cities must continue to provide users and residents with comfortable, healthy and safe conditions, whilst facilitating ongoing adaptation to potential weather extremes.

However, the adaptation to climate change is just one of the topical challenges currently facing the building sector. The increasing urbanisation in turn increases the demand for affordable new housing as well as commercial areas, especially in economically strong cities and their peripheries. At the same time, the challenge is to make the building sector greenhouse-gas-neutral by the middle of this century. To this aim, existing buildings are being successively refurbished and updated in the course of the next few decades, in order to reduce their energy requirements and to convert them to using renewable types of energy. Such long-term processes of transforming buildings and towns / cities comprise both the necessity and the opportunity to employ or develop solutions that serve both protection from and adaptation to climate change.

DAS Monitoring –what is happening due to climate change

Recent years have very clearly demonstrated the impacts of climatic change on buildings, settlements and towns / cities. Stresses due to high temperatures have been experienced in the years 2018, 2019 and latterly 2022, especially by city inhabitants. In Berlin, Frankfurt am Main and Munich, hot days with daily maximum temperatures of 30 °C and more, as well as 'tropical nights' with temperatures not decreasing below 20 °C, have generally become more frequent than the nationwide mean (cf. Indicator BAU-I-1, p. 220). This was particularly the case in the years mentioned above when the summer months of June, July and August were hotter than average. Moreover, hot days have occurred in towns and cities as early as May and as late as September. The specific temperature conditions in towns and cities are characterised by the 'urban heat island effect'; the maximum intensity of this effect is closely linked with, among other things, the size and density of a town or city. In 2018 in Berlin, for instance, a maximum temperature difference between the inner city and the city's periphery was observed which exceeded 11 °C. The effect magnifies the urban stresses on a town / city's population, caused by high temperatures. It is so far not possible to ascertain to what extent the urban heat island effect is intensified by climate change (cf. Indicator BAU-I-2, p. 221). The continuous urbanisation and densification of towns and cities goes hand in hand with increasing the area potentially affected by this phenomenon. Nationwide, rising temperatures increase the requirements for heat protection of buildings in summer. This is indicated by the so-called cooling degree days which have been significantly on the increase in Germany (cf. Indicator BAU-I-3, p. 222).

In addition to heat, more frequent and more intensive heavy rain and flooding constitute highly relevant risks to settlements and buildings. In people's collective memory the deluge-like rainfalls of the 'Bernd' low-pressure system in July 2021 will be remembered for its catastrophic effects, particularly in Rhineland-Palatinate and North Rhine-Westphalia, but also in other German Länder. There has been no other year since the beginning of nationwide radar detection of precipitation levels that indicated such a high proportion of settlement areas affected by rainfalls at the severe weather warning level (cf. Indicator BAU-I-4, p. 224). The catastrophic events of July 2021 caused material damage to residential properties, household effects and business premises and led to insurance claims amounting to a total of 8.1 billion Euros, which is the hitherto highest claims expenditure in terms of property insurance for natural hazards. In addition to natural hazards, it is possible to take out insurance cover for material damage caused by storms and hailstones. Issues resulting from individual extreme weather events such as hailstorms in 2013, are a major case in point, with a view to the particularly high claims expenditure arising in that year (cf. Indicator BAU-I-5, p. 226).

Future climate risks – outcomes of KWRA

Concerning the DAS building sector action field, the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7) envisages a high climate risk in terms of the incidence of damage to buildings from floodwater as early as the mid-century. The same applies to the risk of increasing urban climate stresses in conjunction with an expansion of areas affected by the urban heat-island effect. Likewise, the risk of adverse developments of the indoor climate was assessed as high. Any negative impacts from rising indoor temperatures can also affect the air quality and hygiene conditions, as high temperatures can favour the release of hazardous substances and mould infestation. As far as vegetation in settlements are concerned, the risk of adverse effects from rising temperatures, more drought periods and possibly more extreme and more frequent storms was assessed as medium up to mid-century, and as high up to the end of this century. Moreover there is a risk that the vegetation, owing to climatic changes, will become more vulnerable to pest infestation and disease thus losing its ecological function including the improvement of urban climates.

Where do we have gaps in data and knowledge?

The DAS Monitoring Indicators can be used to thematise the challenges to the building sector from increasing heat stresses, especially in urban environments. Such thematisation is also possible with regard to the impacts of extreme events on the building stock. By comparison, the data situation is less favourable with regard to other consequences of climate change. Primarily this concerns the impacts of climate change on the interior climate of buildings. Whilst the existing indicator BAU-I-3 takes cooling degree days (cf. p. 222) into account in terms of the prevailing external conditions, there is currently a lack of reliable data to illustrate changes in terms of climate-related comfort in rooms. Currently there are not sufficient data available to convey a picture based on in-situ measurements for the impacts of climate warming on the building stock. Another important theme that cannot currently be based on adequate data, concerns the impacts of climate change on the condition of urban vegetation. Satellite remote sensing provides opportunities for a nationwide monitoring of the vitality of urban vegetation. It is, for example possible, on the basis of Sentinel 2 data, to calculate the Disease Water Stress Index (DSWI) in order to observe the impacts of drought stress on urban verdure.[130]

As far as response indicators are concerned, satellite remote sensing also offers starting points for new and continued developments. This technology allows the observation of the degree of urban verdure in greater detail than by the current indicator BAU-R-1 Recreational areas (cf. p. 228). In this respect it would seem appropriate to keep developing and assessing the urban verdure grid designed as part of the research project entitled 'How green are Germany's towns and cities?' (Wie grün sind bundesdeutsche Städte?)[131] The indicator BAU-R-2 (page 230) also consults data collected by satellite remote sensing. In this context, it is imperative to keep an eye on further developments regarding the data situation, such as the quest for a higher resolution of satellite images and to be consistent in using them in order to optimise the indicators. In other respects the inadequate availability of data continues to act as a distinct barrier to the development of response indicators. For instance, it would be desirable to know, with a view to hazards to settlements from heavy rain and related flash floods or inundations, to what extent municipalities and districts are prepared to deal with such events in terms of maps indicating hazards from heavy rain. Neither are there any central data sources available for the adaptation of building stock. An apposite starting point might be the database outlining the refurbishment level of the building stock, which is currently being established. In addition to aspects of climate protection and energy efficiency, this data collection might also include precautionary measures applied to buildings, such as the use of materials relevant to adaptation or structural measures for protection from damage caused by flooding, storm or hailstones. Furthermore, regular information on the prevailing state of climate-related knowledge and regarding the attitudes of real-estate proprietors and the real-estate sector at large would seem desirable: For example, what is the current knowledge of climatic hazards to owned buildings and of precautionary measures, and to what extent is there a willingness to take such measures in line with the requirements of climate protection.

What's being done – some examples

In the past, the political focus in the building sector prioritised the provision of sufficient and affordable housing. However, the energy transition currently experienced, made it necessary to include the objective of a successive development of climate-neutral building stock by means of energy-efficient building and refurbishing activities. In recent years, the adaptation to climate change has also become more and more essential with respect to a broad range of issues in town planning and the building sector in general. Dry and hot summers such as 2018 and 2019 as well as incidents of heavy rain in numerous locations have increased public awareness of the fact that buildings, villages and towns/cities have to become more resilient to cope with the impacts of climate change.

In urban areas it is essential to ensure close coordination of any developments in terms of building planning and design at urban, district and infrastructure levels. If town planning is well adapted to climate issues, it will provide ample green and blue spaces in its infrastructure thus offering the basic requirements for a healthy urban climate that facilitates lower stress even when hot or dry weather prevails. Owing to their intense urbanisation, cities face challenges in terms of maintaining or creating spaces which are conducive to urban climate balance and recreation (cf. Indicator BAU-R-1, p. 228). Sufficient green structures and water structures also function as important components in the concept of a 'sponge city'. The term signifies a type of rainwater management which entails, for instance, the creation of retention capacities in municipal parks and other suitable areas where rainwater is stored as close to the location as possible, thus making it available for reuse or for letting it seep into the aquifer or ultimately letting it drain into sewer systems. In case of heavy rain, areas available for flooding help to reduce pressure on the sewage system and to avoid the inundation of settlement areas. At the same time. water retained temporarily on those surfaces increases the effect of cooling by evaporation thus creating a reservoir which, in drought situations, can supplement the grey water supply to municipal green spaces.

The Federal Government supports climate-compatible town planning and development in a variety of ways: In their research projects – the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) as well as the BMBF and the UBA – address issues in respect of research on climate adaptation and urban development. The direct exchange of communications with pilot municipalities is an elementary part of these projects, and their outcomes are regularly made available to towns, cities and municipalities. In recent years, special emphasis was placed on a more precise ascertainment of the volume and quality of urban verdure and its effect on the urban climate. In addition, municipal strategies for the safeguarding and development of urban verdure were assessed. The motivation underlying various activities does not need to arise from climate adaptation, because urban verdure also provides a number of positive effects for health, active mobility, social cohesion and biological diversity (cf. the strategy process for the White Paper 'Weißbuch Stadtgrün'[132]).

In addition to technical and methodological assistance in terms of research projects, the Federal Government and Federal States also support climate-compatible urban development by means of promotional programmes: In the summer of 2022, the Federal Ministry for Housing, Urban Development and Building (BMWSB) started the Federal Programme entitled 'Anpassung urbaner Räume an den Klimawandel'/'Adaptation of urban spaces to climate change' which promotes projects targeting the maintenance and development of publicly accessible green and open spaces. Within the framework of DAS the BMUV launched a programme entitled 'Measures for Adaptation to Impacts of Climate Change' primarily in order to support municipalities and municipal institutions in their efforts to adapt to climate change. Opportunities for advice, continued professional development and networking in the field of climate adaptation are offered to competent persons and stakeholders in municipalities as well as bodies responsible for social services. These opportunities are provided by the Centre for Climate Adaptation / Zentrum KlimaAnpassung (www.zentrum-klimaanpassung.de), founded in 2021 by the BMUV.

In the same way as adapted town planning, climate-compatible continued-development of the building stock is addressed by research and development. An important theme in this context is the greening of façades and roof spaces. Numerous town and municipalities promote the greening of buildings (cf. Indicator BAU-R-2, p. 230). Opportunities for support are already available from Federal Government.[133] Besides, in research and development emphasis is placed on heat protection of buildings in summer, which – if planned correctly – can have synergetic effects on climate protection and adaptation (cf. Indicator BAU-R-3, p. 232). In view of ongoing climate warming, heat protection in summer is gaining ever more importance for the quality of functionality and ambience in both public and private buildings. Another theme that requires to be addressed by research is the need to adapt structural norms or standards and regulations to changed climatic conditions so that climate adaptation is integrated from the outset in planning and construction of buildings.[134] In order to reinforce the role-model function of public buildings in terms of climate adaptation, the Assessment System for Sustainable Building (BNB) is currently being developed further, with the aim to facilitate the quality assessment of planning and building performances in respect of climate-compatible building outcomes, which can then be reflected in the certification system.

State

Photo: © Nelson Antoine / stock.adobe.com

Climate changes relevant to the action field

Heatwaves

Since 1951 there has been an increase in the number of hot days in terms of the surface area mean for Germany, from a mean of approximately three days per annum to a current mean of approximately ten hot days. Notwithstanding great variability of this index from year to year, this increase is backed up by statistics. Four of the five years indicating the greatest number of hot days occurred since 2015. Regarding Germany's nationwide increase in hot days, it is to be noted that since the 1990s towns/cities have displayed a greater frequency of extreme heatwaves, indicating a day temperature mean in excess of 30 °C within a period of a fortnight (cf. figure 7, p. 24).

Impact

Photo: © rh2010 / stock.adobe.com

Impacts of Climate Change

BAU-I-1 Heat stress in urban areas – case study

Owing to the heat island effect of large, contiguous built-up urban areas, the heat stress experienced by the population in cities is in most cases distinctly more severe than the nationwide average. In most years towns / cities have experienced more hot days; the differences being particularly significant in years with extraordinarily warm summers such as 2015, 2018 and 2019. For example, in 2018 the nationwide average was 20.4 hot days, whilst Frankfurt am Main experienced 42 hot days. One reason for this is that in cities, an increasing frequency of hot days can be observed even beyond the meteorological summer months of June, July and August.

Adaptations – activities and results

BAU-R-2 Green roofs in cities

Response

Photo: © Heiner / stock.adobe.com

Vigorous verdure on roofs and building façades produces several positive effects thus making it an important adaptation measure for urban spaces. In view of increasing heat stress in towns and cities, the cooling effect of greening, on the building concerned and, in the case of verdure on façades, on the adjacent urban environment, is of particular importance. In respect of a verdure-covered building, this effect results from the reduced direct impact of irradiation by sunlight on the building's envelope and the fact that plants – subject to adequate irrigation – evaporate water through their leaves. Moreover, a verdure-covered building reflects less heat into the environment, as the irradiated energy is in part absorbed by the greening.

BAU-R-3 Investments in the energetic refurbishment of building envelopes

Response

Photo: © Marco Becker / stock.adobe.com

Measures taken for precautionary protection from summer heat are intended to preempt heating impacts on buildings. For example, the proportion of window surface areas and the orientation of a building need to be carefully designed; furthermore, blinds and roller blinds as well as anti-sun glass on the outside of windows are able to reduce irradiation. Likewise, good heat insulation and high energetic building standards can keep temperatures in buildings low. Since the mid-2010s, investments in energetic refurbishment have been on the increase. This applies both to residential and non-residential buildings, latterly owing to increasing prices in the building sector. Such investments include measures to insulate façades and roofs.

Specific heat stresses in cities

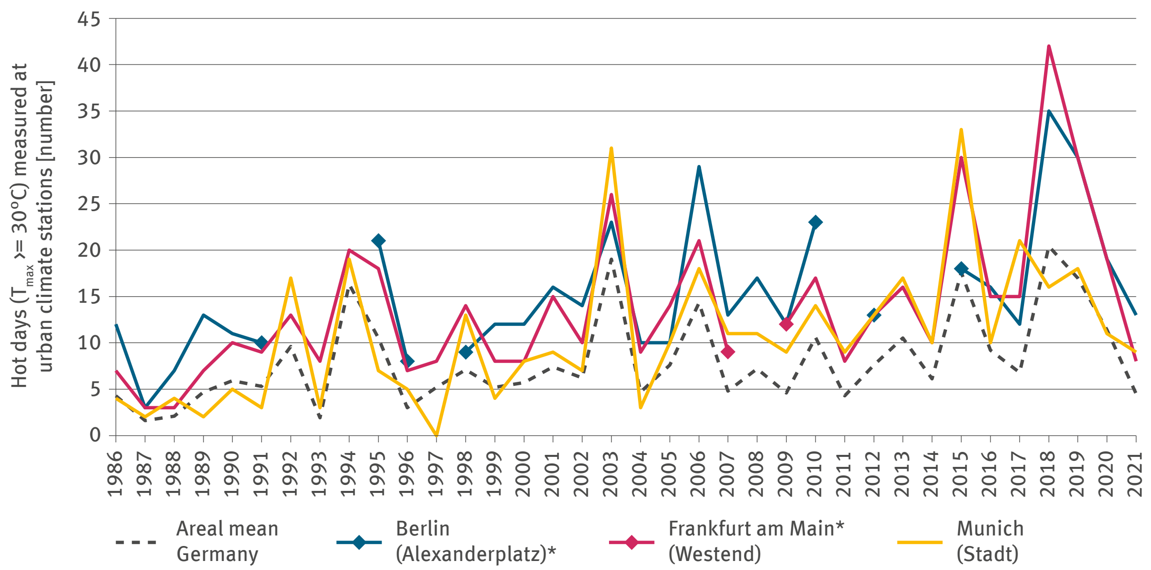
Cities are often subject to climatic conditions which are very different from the climate prevailing in their periphery. For example, the relative air humidity tends to be lower, and the mean temperatures tend to be higher. In respect of temperature differences between urban and rural areas, climatologists refer to 'urban heat islands'. The intensity of the urban heat island effect is largely dependent on the size of a town or city, its density of buildings, their height, degree of insulation, the proportion of green space and the construction materials used. Also cloud cover and wind patterns play important roles in terms of urban heat stress.

In hot summer months this can entail health problems for the population in cases where – owing to their characteristics – urban spaces heat up considerably during daytime without cooling down over night to the same extent as it happens in their rural periphery (cf. Indicator GE-I-1, p. 40). This type of situation may occur more frequently in future. As indicated by climate projections for Central Europe, mean temperatures will rise and the overall weather characteristics will change too. For example, extreme thermal values are expected to occur more frequently. For instance, the frequency of so-called 'hot days' is expected to increase, with maximum air temperatures reaching or exceeding 30 °C. Besides, the population will experience stress on so-called 'tropical nights' when the thermometer will not go below 20 °C and there is little chance of enjoying a restful night.

As far as Germany's surface area mean is concerned, the mean number of hot days has increased from approximately three days per annum in the 1950s to currently approximately 10 days per annum (cf. page 23). The time series from urban climate stations in Berlin, Frankfurt am Main and Munich were ascertained on the basis of daily maximum air temperatures as recorded in the course of daily observations at those stations, and for tropical nights on the basis of daily minimum temperatures. These records do not go back as far as 1951. It is therefore not possible to make a direct comparison with the development at a nationwide level over that period. However, there is evidence from shorter time series that cities are exposed to special circumstances. Here, hot days – albeit with regional differences – clearly occur more frequently

BAU-I-1: Heat stress in urban areas – case study

In the cities examined – allowing for regional variations – hot days and (not illustrated) tropical nights clearly occur more frequently in most years than indicated by the areal mean for Germany as a whole. Especially in years such as 2015 and 2018 with above-average hot summer months, records show increased frequencies of situations in cities, which are liable to expose the population to heat stress.



* insufficient data for Berlin-Alexanderplatz for the years 1992–1995, 1997, 2011, 2013, 2014; ditto for Frankfurt am Main in 2008

Data source: DWD (CDC)

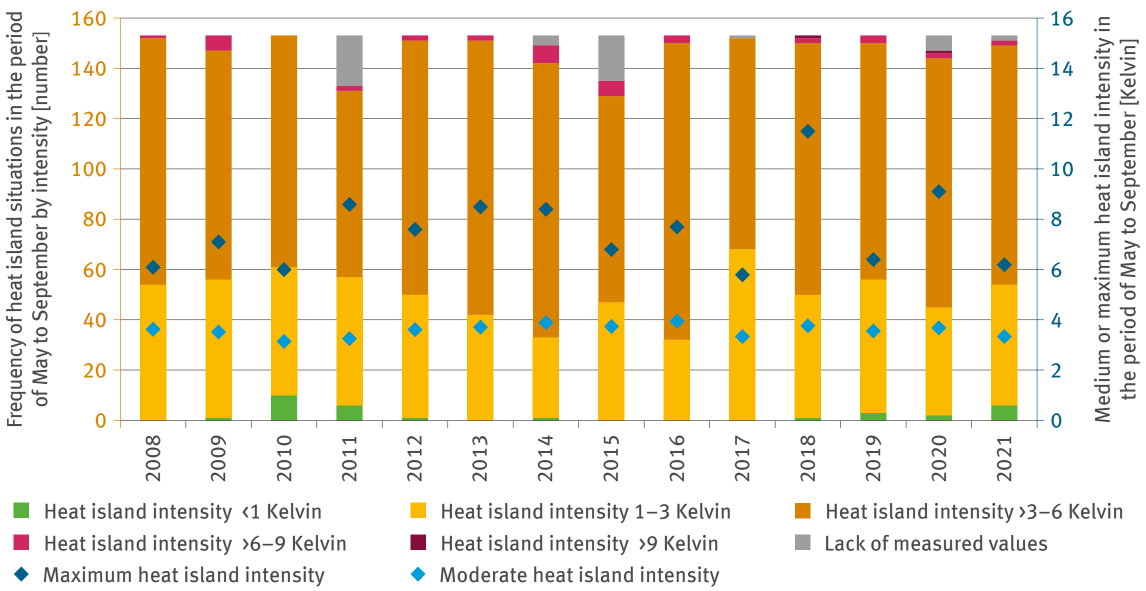
in most years than compared to the nationwide mean. In years with above-average hot summers, such as 2003, 2015 and 2018, the differences are particularly distinct. In 2018 the hitherto highest nationwide mean in Frankfurt am Main was exceeded more than twice, with a record of 42 hot days. This is to some extent due to the fact that increasingly, hot days in towns and cities occur even beyond the meteorological summer months (June until August). In other words, it has been noted that in Berlin and Frankfurt am Main, hot days have been observed more and more frequently as early as May and as late as September. As against hot days, the difference is even more striking in a comparison of tropical nights – not illustrated here – in cities with the areal mean for Germany. While Germany's nationwide mean was between 1 and 1.5 tropical nights for the years mentioned, in Frankfurt am Main, as many as 13 and in Berlin as many as 20 such nights were recorded.

In contrast with hot days and tropical nights, the time series for urban heat island effects – on the basis of values measured every 10 minutes for the city of Berlin – does not refer to the frequency of times when the threshold value was exceeded. In fact, it refers to the maximum daily temperature differential between the centre and the city's immediate periphery. In the summer months of June to August, these values are on average between 3 and 4 Kelvin. However, on peak days, temperature differences of almost 11 Kelvin, as for instance in 2018, are possible. Overall, high temperature differences occur especially in the evenings and at night. In other words, the inner city cools down distinctly more slowly and to a lesser degree than the periphery. This means that it is often too hot for the city population to get a sufficiently restful night.

So far the time series does not make it possible to judge whether climate change exacerbates the urban heat island effect. This may be because heat stress is increasing with equal strength in both cities and their periphery. This is roughly confirmed by indications contained in projections for Frankfurt am Main[135]. Even without an increase in the intensity of urban heat islands, this would mean for the future that stressful situations will in all likelihood continue to be most frequent wherever the heat stress is already high at present. Provided the temperature gradient between town / city and periphery does not change, it is furthermore to be expected that rising temperatures will mean that an ever-increasing part of the urban area and thus its inhabitants will be affected by heat stresses.

BAU-I-2: Summer-related heat island effect – case study

Between the city centre and the urban fringe of Berlin, a maximum day-time temperature difference of up to 11 Kelvin is possible in the months of May to September. It is so far not possible to judge whether climate change is exacerbating the heat island effect. However, even if the air temperatures in the city and its vicinity rise 'only' with equal strength, heat stress, especially among the city population, will very frequently be high.



Data source: DWD (climate measuring stations Berlin-Alexanderplatz and Berlin Brandenburg)

Increasing demands on summer heat protection

2018 and latterly 2022 have so far been the hottest years in Germany since meteorological records began. So far 2018 has been the only year in which more than 20 hot days were recorded when the mean temperature recorded nationwide amounted to 30 °C and more. The manufacturers of air-conditioning equipment and fans were blessed with a bumper summer in terms of revenue as in many offices and homes temperatures sored clearly beyond the comfort zone.

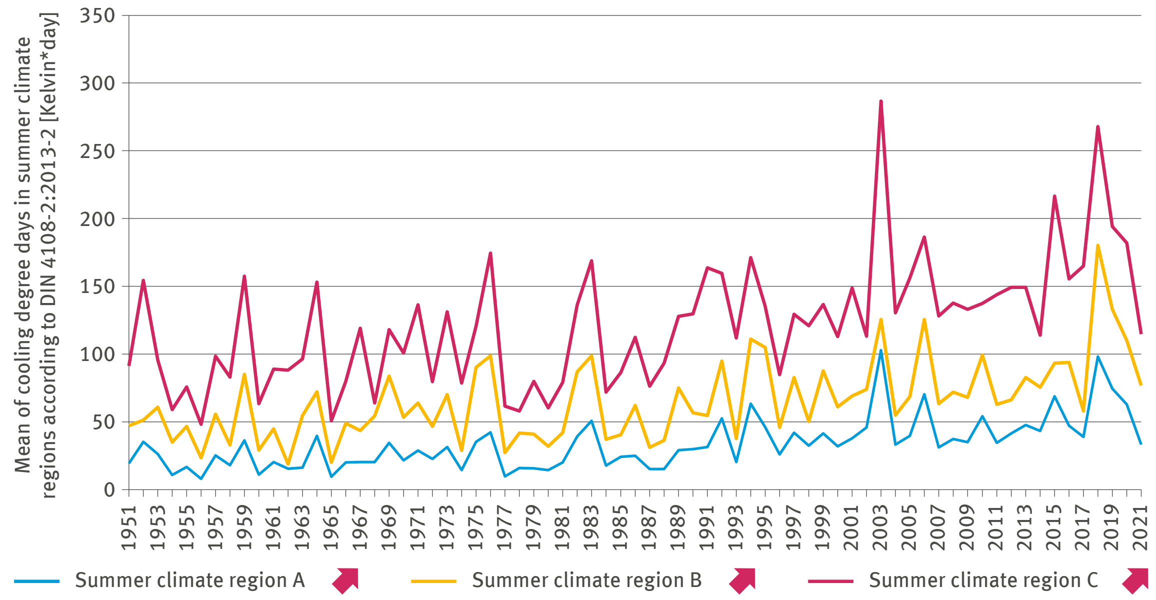
Heat protection by means of building design is to ensure amongst other things that this type of situation remains the exception to the rule and that the interior climate of buildings remains bearable even when the external summer temperatures are high. The Minimum Requirements for Protection from Heat (Mindestanforderungen an den Wärmeschutz) including heat protection in summer, are described in the relevant DIN (standard) 4108-2:2013-02 which bears the same name. The requirements laid out in this standard are also referred to by the Gebäudeenergiegesetz (GEG/Buildings Energy Act) which came into force in 2020 as a minimum requirement for heat protection of buildings in summer. They are to be observed both for new builds and for significant extensions.

In order to differentiate these minimum requirements spatially, this DIN standard divides Germany into three summer climate regions, i.e. A, B and C. The summer climate region A comprises the coastal areas of North Sea and Baltic Sea as well as the upland areas of the Alps, i.e. areas which tend to be relatively cool. Summer climate region C comprises areas which tend to be warmer. This includes Lake Constance and the Upper Rhine Graben (rift valley), the Rhine-Neckar and the Rhine-Main areas, the Moselle and the Middle Rhine Valley, the Ruhr Valley and the urban regions of Leipzig / Halle and Dresden. The other regions are comprised in Region B.

These three summer climate regions provide the spatial background to the time series illustrated for cooling degree days which were calculated based loosely on one of the procedures adopted by the European Environment Agency (EEA)[136]. The evaluation of cooling degree days was used as a basis for estimating the temporal

BAU-I-3: Cooling degree days

In the three summer climate regions according to DIN 4108-2:2013-02 , i.e. the authoritative standard for summer heat protection of buildings, the number of cooling degree days is increasing thus reflecting a significantly rising trend. Since 1999 the cooling degree days in the three regions have been consistently above the mean of the climate normal period 1961–1990. The requirements made for summer heat protection are increasing throughout Germany.



Data source: DWD Regionales Klimabüro Essen (own calculation) development of cooling requirements or the extent of heat protection required in these regions in summer. The cooling degree days constitute a derived value represented in Kelvin * day. This value – based on the amount of exceedance of a temperature threshold value which in this case amounts to 22 °C – is calculated by totalling the amount of exceedance per day for all days of the year in a weighted form. In this context, the weighting depends on whether the daily maximum, the daily mean or even the daily minimum exceeds the threshold value. In the case mentioned first, the weighting is lowest, in the case of the daily minimum it is highest. The data for the time series of summer climate region A were provided by the DWD stations Bremerhaven and Stötten in the Swabian Alps. For the summer climate region B the values from the DWD stations Potsdam, Essen and Hamburg-Fuhlsbüttel were used while Region C is represented by the Mannheim station.

Since 1951 all three time series have shown a significantly rising trend. A comparison shows that the cooling degree days in summer climate region C (i.e. the Mannheim station) increase faster than in the two other regions. Notwithstanding the above, a comparison with the climate normal period 1961–1990 shows that since 1999 the cooling degree days in all three regions were consistently above the mean of the period 1961–1990. This means that the requirements in terms of summer heat protection are increasing throughout Germany. Judging by current climate projections, this development will continue for the rest of the 21st century.

In the light of this perspective and bearing in mind international and national commitments to successively and significantly reduce the emission of greenhouse gases from buildings, it is imperative for experts involved in building design, to keep the demands on heat protection always in the forefront of their mind. However, DIN standard 4108-2:2013-02 defines only the requirements to be fulfilled by new builds, building extensions and add-on modules such as conservatories, referring only to the climate prevailing between 1988 and 2007. It is worth noting that, among other endeavours, and in view of the extraordinarily hot years of 2018, 2019 and finally 2022, and also in view of the GEG regulations to summer heat protection which refer directly to that DIN, there are currently moves afoot to drive forward an advanced development of DIN 4108-2:2013-02, in order to give more adequate consideration to the projected climate warming and associated impacts, with the objective to adapt the minimum requirements appropriately to summer heat protection. In the meantime, with a view to ever-increasing temperatures, it behoves developers to take adequate precautions and make appropriate provisions that go beyond the minimum requirements laid down in this standard. Starting points might be, for instance, a reduction in the amount of window space, adequate window tilt and orientation as well as the use of light surface colours on roofs and façades, the type of nocturnal aeration and the use of verdure on buildings as well as external shading, anti-sun glass and passive cooling systems (cf. Indicators BAU-R-2, p. 230, BAU-R-3, p. 232). If supported by preventative urban planning and neighbourhood-based planning practices – including the provision of appropriate aeration and adequate provision of a green-blue infrastructure in urban spaces – the interior climate of buildings will be able to remain in the comfort zone even if temperatures keep rising (cf. Indicator BAU-R-1, p. 228).

Roller blinds, anti-sun glass or anti-sun foil as well as numerous other measures can be employed to reduce the heat influx into buildings. (Photo: © MATTHIAS BUEHNER / stock.adobe.com)

Heavy rain – a risk to settlements

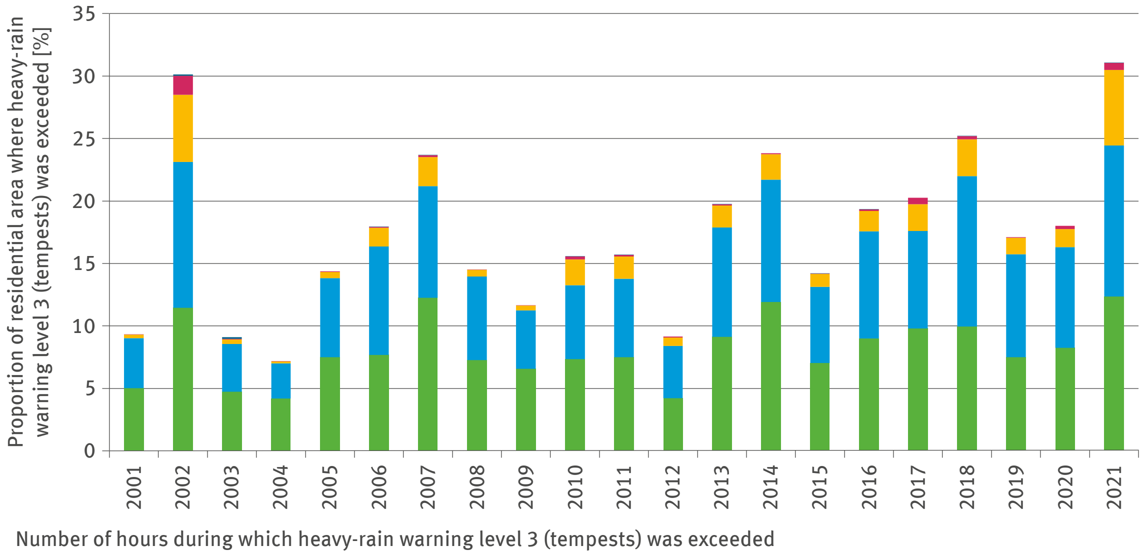
Heavy rain is a weather event in which massive amounts of rain fall within a very brief period of time. The DWD issues torrential rain warnings when it is expected that within one hour more than 25 litres per square metre (l/m²) or in six hours more than 35 l/m² rain is expected to fall. Amounts of rain amounting to more than 40 l/m² in one hour or 60 l/m² in three hours falling in these time periods are classed as extremely severe weather. Frequently these cloud bursts occur when massive clouds – formed as a result of convection – open their floodgates causing torrential rain to fall on mostly small areas.

Typical examples showing the impacts of short-term heavy rainfall are depicted in images existing for Braunsbach in Baden-Württemberg (May 2016) or from Berlin (June 2017): It can be a matter of just a few minutes for torrential rain to make sewers overflow and flooding entire street networks. Torrential rain can cause flash floods engulfing cars and devastating streets and buildings. In extreme cases, such events can endanger life and limb of the local population and cause significant material damage. In 2021 for example, the insured damage to residential properties, household effects and business premises from flooding and heavy rain totalled approximately 9.2 billion Euros.

During or after heavy rainfall, damage is caused primarily by so-called flash floods. These are extreme floodwater events as a result of heavy rainfall. They occur in lowland areas when rainwater cannot drain or seep into the ground fast enough. In those cases water accumulates on the surface or it dams up owing to overburdened sewage and drainage systems as their ultimate design loads are exceeded. Water levels can rise very rapidly then, especially in hollows and underpasses. On sloping terrain this can cause so-called 'mountain flash floods'. The quick-draining water will accumulate in gutters or stream beds and can swell extremely rapidly forming surge-like floodwater waves. These waves are able to reach areas where no rain had fallen previously.[137] When such mountain flash floods sweep away material such as trees or rocks, they can cause massive damage to houses or culminate in the complete loss of buildings.

BAU-I-4: Heavy rain in residential areas

The high number of hours triggering heavy-rain warnings in 2021, is linked, in particular, with the devastating rainfall events which struck the Rhineland-Palatinate and North Rhine-Westphalia as well as Saxony and Bavaria in mid-July. However, the heavy-rain warnings only indicate part of the threat to settlements: The DWD uses the additional warning criterion of persistent rainfall for extended and prodigious rainfall.



Data source: DWD (Radar Climatology RADKLIM (RW) Version 2017.002), BKG (DLM250)

Heavy rain and flash floods can, however, damage buildings in other ways too. For example, standing water can reach levels which exceed the design threshold thus enabling water to enter the building, for instance through entrance doors at ground level, cellar windows or owing to tailbacks in the sewage system. The ingress of water then leads to the distribution of mud and detritus which may be polluted additionally by a mixture of mineral oil, chemicals and faeces. Above and below the earth's surface, standing water or high soil humidity can cause typical floodwater damage to the fabric of buildings, such as moisture penetration and linear water level marks, efflorescences on surfaces, detached coatings or fungus. In order to prevent damage, house proprietors can take a number of measures, possibly by placing building apertures at a sufficient height above ground level, the use of waterproof building materials and appropriate drainage systems with backflow preventers.[138]

According to current scientific knowledge, collated by the IPCC as published in February 2022 in the second part of the 6th Assessment Report[139], it is possible to discern an increase in the frequency and intensity of extreme weather events as a result of climate change. As climate warming keeps progressing, climate risks will increase worldwide and that includes Germany. Experts in the fields of meteorology and climate research expect more frequent and more extreme heavy precipitation events to occur in Germany in the future. One reason for this is that at higher temperatures the air can absorb more water – approximately seven per cent more water with each temperature increase per Kelvin. Furthermore, it is to be expected that owing to changed meteorological circumstances during the formation of showers and thunderstorms, the formation of clouds and precipitation will intensify. During the second half of the 21st century, Germany – albeit with major regional and seasonal differences – will experience a distinct increase in the incidence of daily precipitation amounts compared to the relatively infrequent occurrence experienced at present.[140]

It is difficult to assess the frequency and intensity of heavy rainfalls and whether climate warming already has an impact on these events. Heavy rain events often just occur in spatially limited localities and therefore are not all recorded by the meteorological station network. This is one of the reasons why the DWD has developed a method of radar-based precipitation recording which since 2001 has enabled the acquisition of almost comprehensive precipitation data.[141] This dataset contains nearly all heavy rain events that occurred in Germany since 2001. The prolongation of this system of data acquisition will in future also facilitate trend analyses of the frequency of cases when the warning thresholds applied by the DWD are exceeded (cf. Table 2, p. 25).

In hot and dry summers it is of particular importance not just to ensure protection from heavy rain but also to provide rainwater storage facilities. (Photo: © Budimir Jevtic / stock.adobe.com)

In the illustration for the indicator concerned, the annual data from the radar-based precipitation measurements were superimposed on the data for Germany's residential terrain. The years of 2002 and 2021 stand out from the overall picture with a particularly high number of built-up areas being affected by many hours of heavy rainfall. This is linked to extensive areas with persistent rainfall (in terms of the warning criteria applied by the DWD for rainfall during a period of 12 to 72 hours), in which the threshold values for heavy rain warnings were also exceeded temporarily. In 2002 numerous events of heavy rainfall during an extended period in Saxony and South Bavaria caused floodwater disasters involving the rivers Elbe and Danube. In July 2021 massive rainfalls triggered flooding in the Ahr and Erft valleys which had disastrous consequences. During a period of stable low-pressure weather conditions almost 95 litres of rain per square metre fell in the Ahr's entire catchment area within just 24 hours. Some meteorological stations in other parts of the Rhineland-Palatinate and North Rhine-Westphalia measured values in excess of 150 litres of rain per square metre falling within 24 hours. Owing to humid weather conditions having prevailed in the preceding weeks, soils were unable to absorb much rain; moreover the existing geological circumstances generally impede seepage.
On the steep slopes of the upland region, the rainwater quickly ran off the surface, accumulating in narrow – in some cases heavily built up – river valleys where it left a trail of destruction (cf. Indicator BAU-I-5, p. 226).

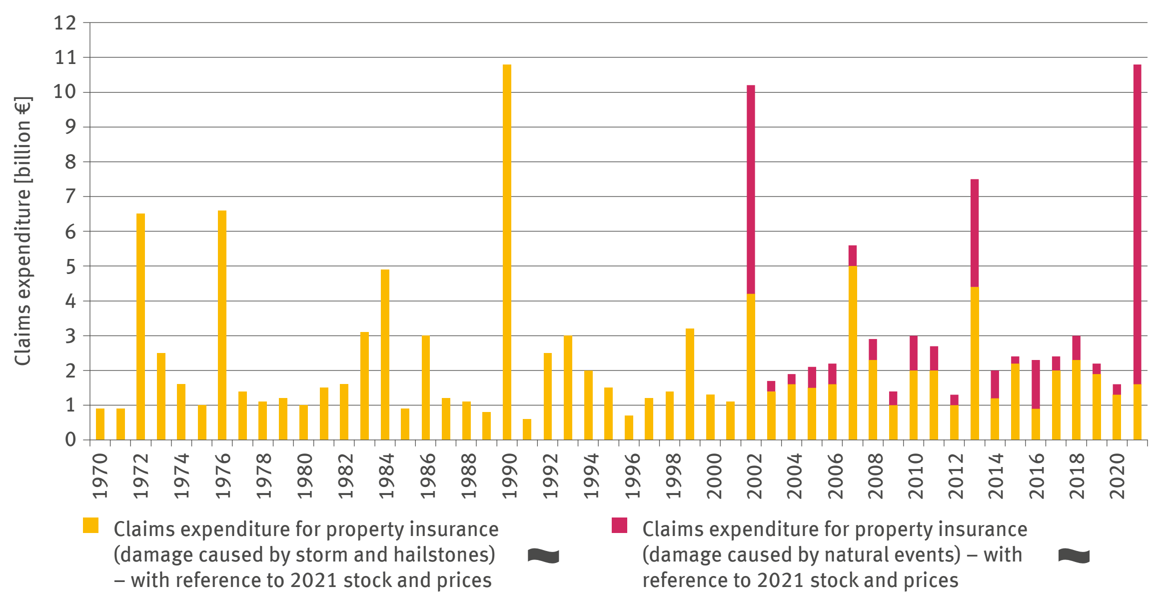
Time and again – years with severe damage from natural hazards

Extreme weather events can damage a building's envelope and the interior of a building. Typical storm damage to buildings includes torn-off roof tiles and ripped-off parts of cladding as well as broken glass panes in windows or doors. Indirectly, buildings can be affected by fallen or broken trees and masts or by damage to buildings in the neighbourhood. Depending on their size, hailstones can have enormous powers of impact capable of damaging roofs, photovoltaic units, window panes or facings. Especially if water penetrates to the interior of buildings – either due to floodwater or heavy rain – this can also cause considerable damage in interior rooms of buildings, in particular to household effects. As a result of such events, the highest single claims for damage to a one-family house, can be as high as 100.000 Euros; but in particularly extreme cases such as the flooding disaster in 2021, an individual damage to a one-family home can total ten times that amount.[142]

As far as the development of frequency and intensity of heavy rain events and storms is concerned, it has not been possible so far to identify a clear trend for Germany. Likewise – contrary to temperature predictions – pertinent projections for the future are still fraught with problems. As far as regional climate models are concerned which were examined by the network of experts linked to the BMDV, it is possible to discern a slight decrease in extreme wind speeds, especially in summer. However, these changes are negligible, whilst statements on wind speed should, on principle, be viewed with caution.[143] Whether storms such as Hurricane Frederike experienced in the winter of 2017/2018 will occur more frequently or more intensely in future, is therefore currently impossible to predict with certainty for Germany. However, as far as heavy rain is concerned, climate researchers expect more frequent and more extreme cases of heavy precipitation in Germany in future (cf. Indicator BAU-I-4, p. 224).

BAU-I-5: Claims expenditure for property insurance

Floodwater can cause massive damage to buildings and their contents which can be covered by taking out property insurance. Individual extreme weather events represent a major factor in property insurance, and the related claims expenditure leaves its imprint on the time series, although it has so far not been possible to discern a significant trend.



Data source: GDV (branch and risk statistics, Naturgefahrenreport)

The extent of damage to buildings and their interiors caused by extreme events is reflected by the amounts of money involved in claims settled by the insurance industry. In particular with regard to high insurance densities as for instance in the insurance of private buildings against storm and hailstorm damage (in view of 95 % density, it would be correct to speak of near-saturation of the market), even regionally limited damage events are reflected well in statistics. Any change in reported claims and associated damage – settled by insurance companies with policyholders – can therefore be linked directly to changes in the frequency and intensity of damage events.

In respect of damage covered by customary property insurance, the amounts claimed due to fire, lightning strike, explosion and tap water have remained more or less consistent over the years. In cases of storm and hail damage and other natural hazards, caused by earthquakes, landslides, subsidence, snow pressure or avalanches as well as flooding due to a river breaking its banks or heavy rain, damage amounts fluctuate strongly from year to year. In some years damage events can be cumulative as a function of weather patterns, and some particularly violent events can cause major damage. By comparison, other years are relatively 'quiet'.

Included in claims expenditure for property insurance – apart from private residential buildings and their household effects – are also commercial and industrial premises and associated contents as well as operational interruptions due to damage events. This expenditure covers payments and provisions for any damage caused in the relevant business year including any expenses for claim settlements. Regarding the time series, the stock and prices valid in 2021 were extrapolated in order to offset any inflationary effects or changes regarding the stock insured and to permit a comparison of the figures recorded for individual years.

The time series examined with regard to claims expenditure for property insurance has so far not shown any significant trend either for damage from storm, hailstones or other natural hazards. However, from time to time there are years when individual extreme events push up the claims expenditure. After the turn of the millennium this applies in particular to 2002 when the August floodwater as well as several hurricanes (especially Hurricane Jeanett) caused massive damage. In January 2007, the low-pressure system, known as Hurricane Cyril, affected public life in large parts of Europe claiming 47 lives in Europe as a whole. In 2013 there were as many as five major hailstorms which pushed up the total amount of claims: Manni and Norbert in June, Andreas and Bernd

In July 2021, the flash floods occurring as a result of the low-pressure system known as Bernd caused enormous damage to residential properties, household effects and business premises. (Photo: © GordonGrand / stock.adobe.com)

in July as well as Ernst in August. The flooding in June of that year – extrapolated to the stock and price information for 2021 – caused losses amounting to 2.38 billion Euros. In January 2018, the low-pressure system known as Hurricane Friederike caused damage in Germany totalling 900 million Euros.

The highest claims expenditure in terms of property insurance for damage from natural hazards in Germany so far, occurred in July 2021 as a result of the water masses deposited by the low-pressure system known as Bernd, in a two-day period, on the Rhineland-Palatinate and North Rhine-Westphalia. This caused insured material damage to residential property, household effects and business premises totalling 8.1 billion Euros.[144]

Urban green to cool the urban climate

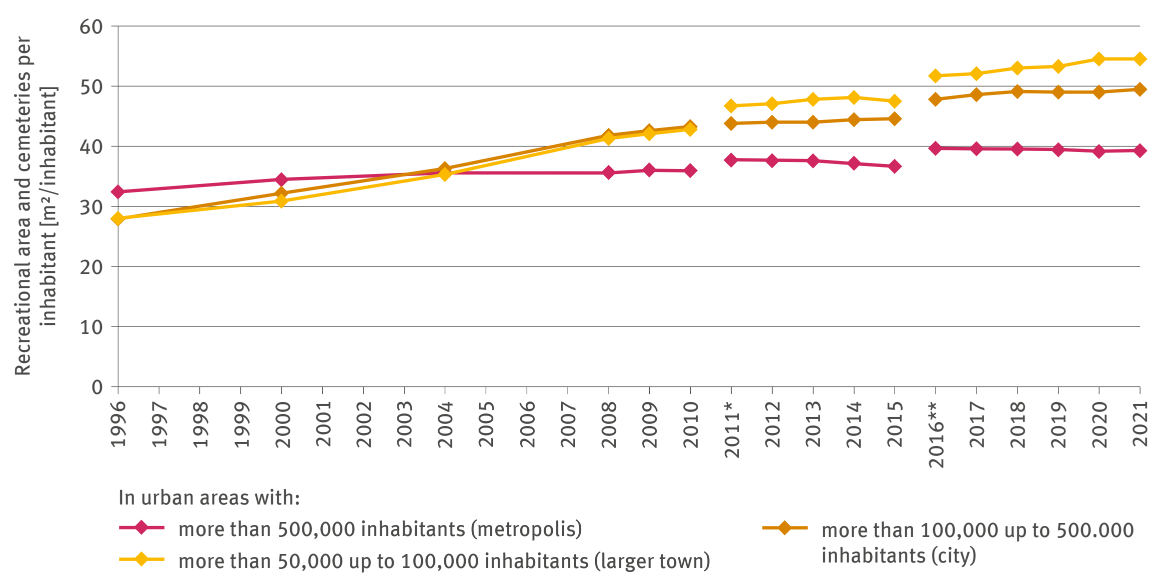
Exposure to thermal stress can cause health problems in the population and, in extreme cases, can increase mortality figures. Categories at risk are primarily older people, people with chronic illnesses, children and people who live in isolation. However, other population categories can also be affected by the more frequent heat stress expected to occur in the future (cf. Indicators GE-I-1, p. 40, GE-I-3, p. 44). Heat stress is also and in particular, caused by high nocturnal temperatures which prevent or hamper a good night's rest (cf. Indicator BAU-I-1, p. 220). Moreover, impacts on the economy can be caused by staff suffering from fatigue, impaired concentration and stress on the cardio-vascular system, making them less productive when temperatures at their workplace are too high (cf. Indicator IG-I-1, p. 264).

It is expected that climate change will further intensify urban climate effects (cf. Indicator BAU-I-2, p. 221), potentially leading to an increased incidence of heat-related health problems. Measures can be taken at various levels to counteract or pre-empt such impacts resulting from climate change. The appropriate design of urban spaces and residential areas can make important contributions to curb such impacts, by ensuring – both in terms of quantity and quality – the provision of 'green' and 'blue' infrastructures, i.e. with public and private green spaces and water bodies. Mostly green, sparsely sealed terrain such as recreation areas dedicated to sports and games, park-like areas and campsites or even cemeteries, fulfil important functions in localised micro-climates, especially in cases where they are inter-connected.

The positive effect of green spaces on the urban climate and air quality as well as noise abatement depends on the size, structure and composition of areas enhanced by vegetation. Compared to the built environment, even areas just covered in grass achieve positive changes in terms of radiative and heat regimes, provided there is ample provision of water. Shrubs and vigorous, shade-giving trees with a high crown reinforce the positive bio-climatic effects, at the same time as increasing an individual's thermal comfort. Compared to the built environment, lower surface and air temperatures can develop. In addition, green spaces, especially those

BAU-R-1: Recreation areas

For the quality of life of populations in large town, cities and metropoles, it is of particular importance to create and maintain sufficiently large and well distributed green spaces thus creating an equilibrium for the urban climate and for recreation purposes. In recent years, the provision of recreation areas in cities and metropoles with a population density in excess of 100,000 remained largely the same, while in larger medium-sized towns the degree of provision improved.



* as per population statistics based on 2011 census
**Change of methodology of land use statistics, transition to ALKIS

Data source: LiKi with data from the AK UGRdL of the statistical offices of the federal states (indicator C4 – recreation area) containing trees have greater relative air humidity than sealed areas. For plants and trees to develop their full potential, they depend on sufficient root space and a good water supply.

As far as Germany's towns with population sizes in excess of 50,000 inhabitants are concerned, the public recreation areas are on average greater in smaller towns whereas larger towns tend to offer less space for recreation. The current provision of recreation areas in metropoles with population sizes of more than 500,000 is actually the smallest. The larger medium-sized towns with population sizes between 50,000 and 100,000 currently enjoy, quantitatively speaking, the best provision of recreation areas.

The temporal development of recreation area per inhabitant is difficult to interpret. Reasons for this are to be found in changes regarding the assignment and valuation of land which were adjusted when the Authoritative Real Estate Cadastre Information System (ALKIS) was first introduced in 2015. This process has led to changes in land use statistics which were not based on actual changes of use. Especially in 2000 and 2008 some Federal States (Länder) carried out massive reassignments which have had significant impacts on the data series. Nevertheless, the data series for the years of 2011 to 2015 shows that the extent of provision of recreation areas in the metropoles and larger medium-sized towns was ultimately in decline. Since 2016 the provision in cities and metropoles with population figures in excess of 100,000 has remained largely the same, while the degree of provision in medium-sized towns has improved. It has proved impossible to arrive at a detailed identification of the reasons for these developments on the basis of data underlying this indicator.

In principle, municipalities with specific responsibility for the settlement's climate are able to exert a positive influence on the development, for instance by maintaining existing green spaces, by networking them, and by creating additional green spaces. Ideally the green spaces should be connected by fresh-air corridors to areas such as meadows and fields in the rural environment where cold air is produced. This way, municipalities enhance the ecological functions of residential areas thereby increasing the area's quality of life and housing quality. In view of the currently prevailing drive for housing development, municipalities face particular challenges to their endeavour to create sufficiently large green spaces for the population thus counteracting the densification of built-up areas. Especially in metropoles it is of vital importance to keep an eye on and control these developments in order to prevent this type of growth from occurring at the expense of the urban climate thus affecting the local quality of life.

Park-like spaces that are networked and distributed across the entire urban area and are rich in vigorous trees and shrubs are of vital importance for towns and cities during hot summers. (Photo: © marcus_hofmann / stock.adobe.com)

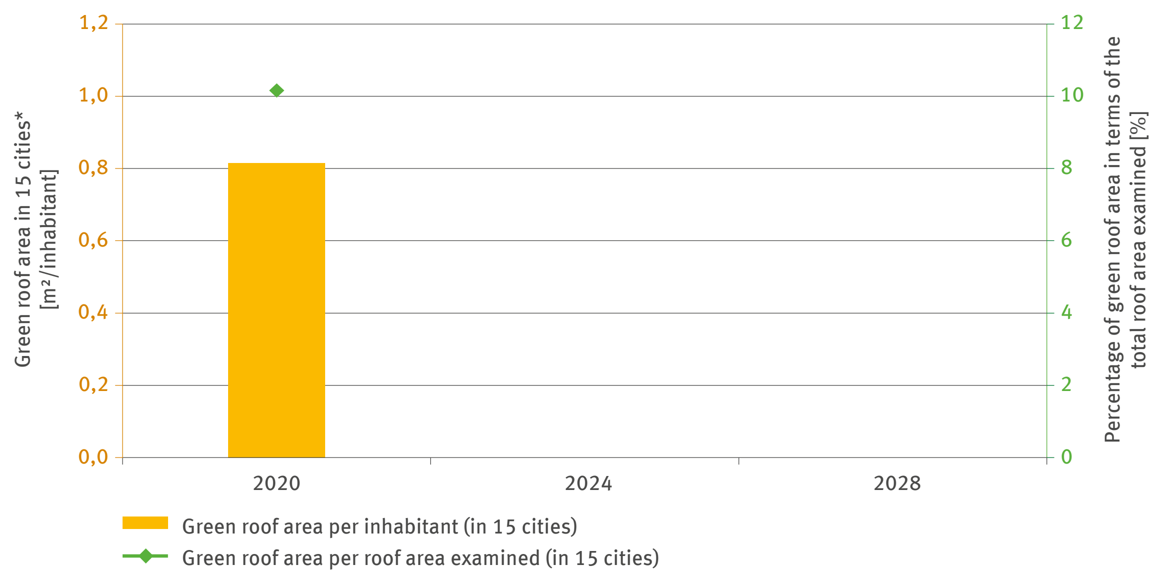
Green roofs in cities – good for adaptation to climate change and for biodiversity

The greening of urban areas is not restricted to parks and park-like zones or to the greening of roadsides and private gardens. Façades and rooftops of buildings also provide a lot of space for greening. For façades there is a range of greening options, from climbing plants to densely planted vertical gardens. Building statics permitting, roofs can be planted with a great variety of largely self-maintaining vegetation, ranging from mosses, herbs and grasses to dense planting schemes with crop species, shrubs or trees. Resilient greening schemes on roofs and façades can have multiple effects which are capable of mitigating adverse impacts of climate change thus benefiting individual buildings and properties. In urban areas these beneficial effects can also – at least partly – be transmitted to the environment of the buildings concerned.

By reducing the influx of sunlight and the fact that plants evaporate water through their leaves, greened roofs and façades effectively cool down buildings as well as their surrounding air[145]. On one hand, this is beneficial to users of buildings on hot summer days or during periods of great heat. On the other hand, the greening of buildings – thanks to the absorption of irradiated energy and transpiration – reduces urban heat island effects, especially in densely populated and densely built-up towns and cities.[146] NB: The evaporation effect and any associated urban climate effects can only materialise provided the substrate of 'greened' roof vegetation can absorb and retain moisture. This has to be taken into account especially, where greening is done extensively, because as a rule, this type of greening is maintenance-free; however, in hot summer months it may require watering. The greening of façades – in addition to the general urban climate – is an essential component in the endeavour to achieve a beneficial effect on the immediate environment at street level. Another beneficial consequence of greening is its air-quality effect. The vegetation surface slows down the air current so that particulate matter and pollutants can precipitate more easily.[147]

BAU-R-2: Green roofs in cities

Resilient roof and façade greenings can have many beneficial effects – both on the climate in an urban district and on the building itself, also on rain retention, the air quality and on biological diversity – thus mitigating local impacts of climate change. Densely built-up and 'sealed' cities depend on this, and they are in a position to provide targeted funding with the purpose of counteracting the impacts of climate change.



* with reference to 15 cities with a population in excess of 500,000 inhabitants

Data source: CAU Kiel, Brockmann Consult GmbH (analysis of satellite images and of LOD2 data of the BKG)

Green roofs also serve a useful purpose in downpours. Depending on their design and technical layout, green roofs can potentially store considerable amounts of rainwater for gradual evaporation once precipitation stops. With a view to potentially frequent and more intensive heavy rainfall, greening systems provide a buffer which absorbs rainwater like a sponge thus slowing down the water cycle. In this way, green roofs can contribute to lightening the burden on drainage systems for properties in entire districts as well as reducing water build-up and flooding-related damage.

Furthermore, greened roofs and façades contribute to the protection of components of buildings and entire modules. For example, they can reduce damage from heavy rain and hailstones to façades and roofs, and they slow down or prevent the weathering of roof seals. As a 'bonus', green roofs and façades also provide habitats for flora and fauna. Such greening systems provide nesting and foraging spaces for birds, wild bees, butterflies and ground beetles thus increasing biodiversity in urban areas.

For this indicator, 15 cities with population sizes in excess of 500,000 were evaluated in combining satellite images in a 10 metre resolution with data from 3D building models. To put it in a simplified manner – by using satellite images, the vegetation areas were located within cities and tailored to buildings with flat or monopitch roofs, with the aid of 3D building models. It was not possible to consider any greened basement car parks on the basis of these data. In order to avoid misinterpretations, the evaluation included – in view of the spatial resolution of the satellite images – only roofs of a minimum size in excess of 400 m² and a minimum greening proportion of 20 %. This was to avoid the mistaken inclusion of, for instance, tall trees projecting above a flat roof space, in the classification. Restricting this process to the inclusion of flat and monopitch roof sizes in excess of 400 m² meant that just about 60 % of flat and monopitch roof areas or indeed 30 % of the entire roof area were examined in the 15 cities covered by this process.

Regarding the roof area examined in 15 cities with an average population density in excess of 500,000, approximately 10 % was classified as greened (equivalent to an area of approximately 0.8 m² per inhabitant). The range amounted to approximately 5 % to 19 % (equivalent to an area of 0.3 to 1.3 m² per inhabitant). Regardless of the data-technical limitations mentioned, the baseline situation from 2020 demonstrates that to date only a comparatively small part of flat and monopitch roofs have been greened.

Many municipalities subsidise greened roofs and façades thus furthering the multifarious beneficial effects on, for instance, the urban climate und biological diversity.
(Photo: © Heiner / stock.adobe.com)

In order to increase the proportion of greened roof areas, many cities subsidise the greening of roofs and façades either directly or indirectly, for instance by means of reducing the sewage fees charged to compliant proprietors of buildings with greened roofs. Besides, many town or city administrations lay down specifications on the greening of buildings in their building / development planning. The objective is to drive forward a successive expansion of greened roof spaces thus opening up the potential of multifarious beneficial impacts on a particular town or city, also in terms of adaptation to climate change.

Apart from individual municipalities, the greening of buildings is also incentivised at the level of the Federal and Länder (Federal States) governments. As far as Federal Government is concerned, the programmes for the promotion of urban development support both the subsidisation of roof and façade greenings and various funding programmes offered by individual departments in order to facilitate for instance the adaptation to climate change or to improve the efficiency of buildings. For its part, the Federal Government has adopted an objective for real estate under its own remit, to explore the potential for and – where appropriate – implement more greening systems in future development projects. In doing so, the Federal Government has also adopted the important role model function for other stakeholders in its capacity as developer and proprietor.[148]

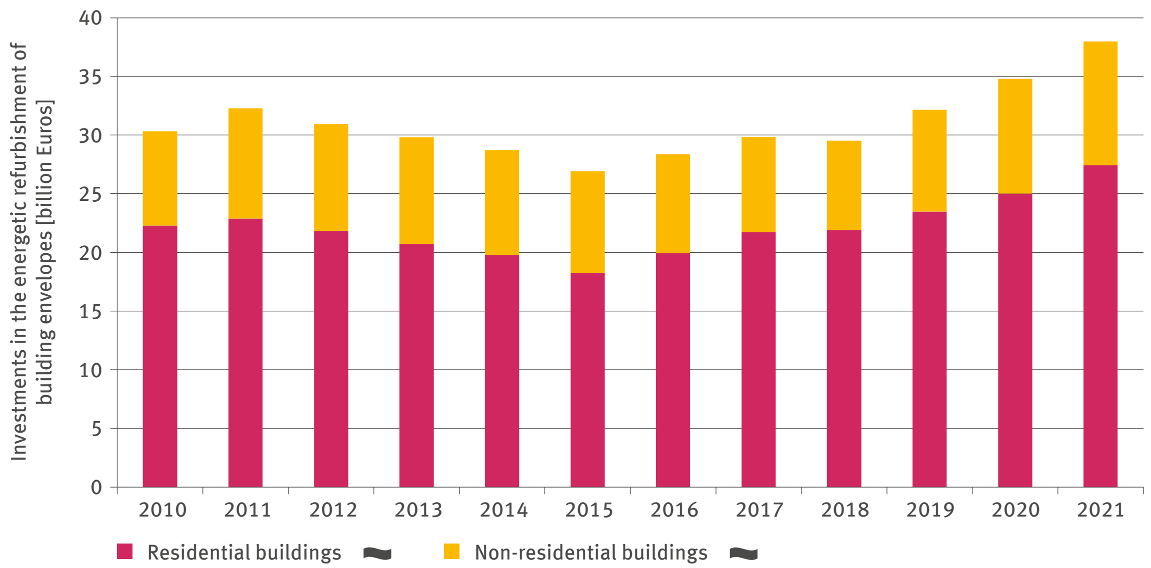
Energetic refurbishment supports the adaptation of buildings

Climate-compatible urban planning and design safeguarding the retention and enhancement of an urban green-blue infrastructure is one approach towards avoiding or at least mitigating heat stress. Other measures approach the issue by tackling the extant building stock. In order to protect interior rooms from overheating, active technical cooling methods are used in residential and working premises in warmer climate zones. During the hot summers of recent years, it was clear to see that this response was also applied in Germany. There was an exceptionally high sales volume in mobile air-conditioning units for active cooling in apartments and houses. It must be said, however, that the use of air-conditioning is associated with increased electricity consumption which, in turn, leads to increased CO_2 emissions, unless the electricity mix is not largely derived from renewable energy sources. Such measures are therefore apt to run contrary to the efforts of increasing climate protection. In addition, the abstracted air from air-conditioning systems warms up the local urban atmosphere further thus exacerbating bio-climatic problems. Passive cooling measures should therefore be given greater priority both in refurbishing extant building stock and in the design of new builds.

In order to safeguard the interior climate by keeping it in a comfortable state while protecting the building from summer heat, planning and implementation of construction measures should be based on adopting two strategies simultaneously: The first strategy is to prevent the interior of a building from heating up in the first place, while the second ensures that warmth existing indoors is discharged to the outdoors with a minimum of energy use. Examples for a pre-emptive protection of buildings from summer heat – the first strategy – include the painstaking design of window surface area proportions as well as the orientation of buildings, to use external shade-giving elements and anti-sun glass, the greening of the façades and roofs of buildings or providing buildings with good heat insulation, and last not least, ensuring conformity with high energetic building standards. The dissipation of heat as a second strategy can be achieved for instance by natural aeration and ventilation systems, controlled aeration at night or counter-cyclical storage / discharge of hot or cold air. Further measures can

BAU-R-3: Investments in the energetic refurbishment of building envelopes

Ever since the mid-2010s, investments in the energetic refurbishment of building envelopes – in other words, façades and insulations as well as exterior doors and windows – have been on the increase, both in residential and non-residential buildings. In 2020 and 2021, however, the development has also been affected by rising prices in the building sector. On the other hand, it is not possible to discern a significant trend in the two respective time series.



Data source: DIW (own analysis based on data from the construction statistics and construction activity statistics of the StBA and from survey results from Heinze GmbH) consist in decreasing available heat sources or using solid components for temperature equilibration.

As far as new builds are concerned, there are legal regulations contained in the German buildings energy act (GEG) in conjunction with various technical specifications such as DIN-4108-2:2013-02 on the minimum requirements for heat protection, with the aim to ensure that the interior delivers appropriate thermal conditions even under prevailing hotter climatic circumstances. In respect of older buildings this is – depending on a building's age – not always the case. Whenever structural work is carried out in such buildings in order to improve a building's energetic envelope, for instance by insulating its roof and façade and by fitting modern windows and exterior doors, these measures are usually combined with improving heat protection. This is due to the fact that carrying out such measures requires compliance with legal and technical regulations stipulated by the GEG or by DIN 4108-2:2013-2. Besides, the GEG requires compliance with minimum standards to be achieved when carrying out structural changes. In the course of carrying out the energetic refurbishment of roof and façade, climate adaptation measures such as additional exterior shading or greening of the building should be carried out at the same time.

The indicator illustrates the financial investments for residential and non-residential buildings, which are expended annually on energetic refurbishment of building envelopes. This indicator takes into account investments in products such as insulation of façade and windows / exterior doors, which usually reduce the heat loss of a building and improve its heat protection in summer. The data underlying the indicator are based on a special evaluation of the construction volume statement issued by the German Institute for Economic Research (DIW)[149]. After a decline at the beginning of the time series, the mid-2010s experienced an increase in investments in the energetic refurbishment of both – residential and non-residential properties. Even though the time series has not been price-adjusted, and although the increase partly reflects the high prices resulting from a high demand for new builds and a scarcity of building materials, this development seems to indicate that measures are now increasingly implemented in respect of building stock thus benefiting – in addition to energy efficiency – summer heat protection and, in turn, adaptation to climate change.

In addition to summer heat protection, a wide range of other measures are required in order to equip new and extant buildings for the impacts of climate change. The structural adaptation of buildings in Germany is essential – especially in view of ever increasing extreme weather events such

The insulation of roofs and façades as part of energetic refurbishment also improves summer heat protection.
(Photo: © Marco Becker / stock.adobe.com)

as heavy downpours or driving rain, storms and tornados, hailstones or snow loads. Such adaptation measures are essential, despite high standards of building design, construction technology and implementation. For this purpose, some buildings might allow the fitting of safety grilles and safety glass for protection from hailstone damage, in conjunction with an additional safeguarding of solarthermal and photovoltaic units or alternatively, the storm-proof incorporation of such facilities into the roof structure. Measures for protection from floodwater and heavy rain range from waterproofing buildings by means of fitting moisture barriers or waterproof concrete structures over drainage units or pumps, and backflow preventers in sewage systems. It is equally essential for such safeguarding measures to be considered, for instance, in the planning stage for new builds, so that they can be implemented from the outset e.g. by selecting particularly robust materials and employing more stable construction methods. Above a protection target, usually 30 cm above the design water level, more ecological and regionally typical construction methods can be used. In respect of extant buildings, the adaptation usually involves retro-fitting, for instance in the case of actively sealing cellars to protect them from water pressure – as a rule trickier and more expensive to achieve. Nevertheless, it is presumably possible to get a grip on climate-related problems even with regard to extant building stock. Basically, it is the responsibility of a principal commissioning the building, or its proprietor, to implement such construction measures with the aim to safeguard the building from climate risks.

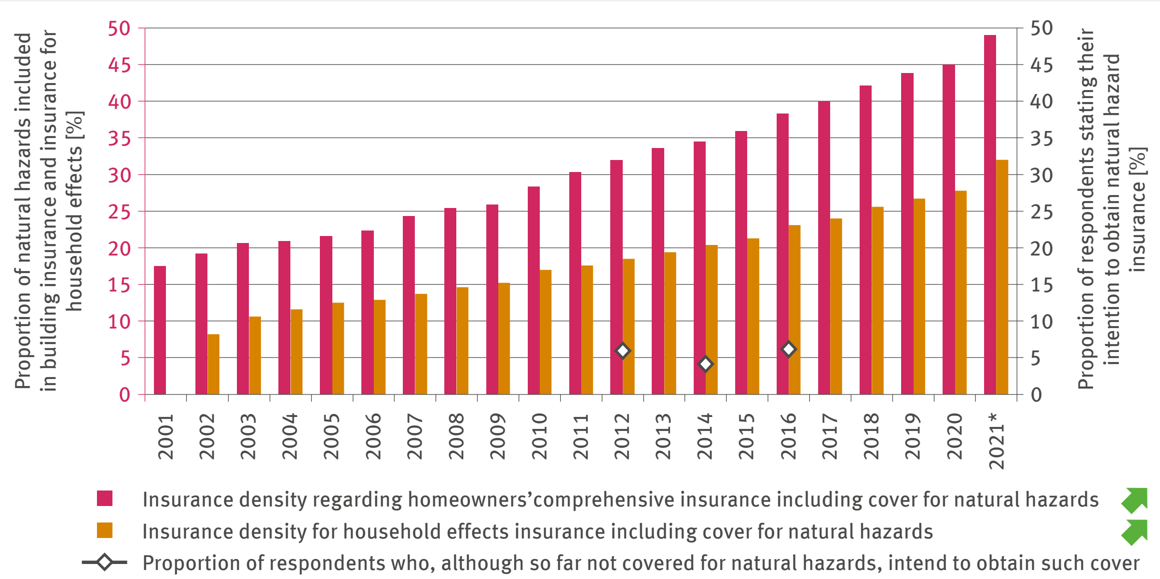
Stock of natural hazard insurance policies expandable

By now, taking out homeowners insurance for storm an hailstone damage has become almost a matter of course. Likewise, the conclusion of insurance contracts for other extreme natural hazards such as heavy rain and floodwater is also catching on. As far as these hazards are concerned, an increase is to be expected in view of climate change. Moreover, heavy rain events can occur regardless of location (cf. Indicator BAU-I-4, p. 224). Likewise, damage to real estate or household effects can happen to anyone. In past cases of damage, both private individuals and traders who incurred the damage, have received government and non-government aid, for instance after the flooding events affecting the rivers Elbe and Danube in May and June 2014. The flooding caused damage amounting to more than 8.2 billion Euros in total for damage caused to public infrastructures, the industrial economy and private households. Not all of these were insured (cf. Indicator BAU-I-5, p. 226). For damage repair and reconstruction work, a joint fund was set up by the Federal Government and the Länder Governments, entitled 'Aufbauhilfe' (Reconstruction Aid) with a volume of 8 billion Euros. In the period to 2021, approximately 500 million Euros from this fund were spent on the refurbishment of damaged residential buildings and on the replacement of damaged or destroyed building components. After the 2021 flooding disaster in the Rhineland-Palatinate and in North Rhine-Westphalia, the Federal Government and the Länder (Federal States) made available emergency aid amounting to approximately 770 million Euros. For reconstruction work in the floodwater regions, Federal Government added a reconstruction fund, up to 30 billion Euros of which was made available from the specially established fund 'Aufbauhilfe 2021' (Reconstruction Aid 2021). For the support of private households and housing associations some 1.5 billion Euros of this were either assigned or expended in the meantime.

In view of the considerable government expenditure which is spent repeatedly on flooding aid, governments and society have a keen interest in appropriate personal provision made by homeowners and tenants in an attempt to reduce government aid as much as possible. The state is unable to ensure that in cases of damage, all private damage incurred is covered. Moreover, there are legal obligations for private provision: According to the WHG (Federal Water

BAU-R-4: Insurance density of extended natural hazard insurance for residential buildings

The inclusion of insurance cover for natural hazards (eEV) complements the home-owner's comprehensive insurance and the insurance for household effects covering damage for instance caused by flooding, heavy rain, snow load and avalanches. The insurance density in respect of eEV has increased steadily and significantly since 2001. However, nationwide percentages of 49 % for buildings insurance and 32 % for household effects respectively are still rather low.



* preliminary value
** The intention of taking out insurance was not covered by the 2021 survey.

Data source: GDV (branch and risk statistics); BMUB & UBA (study ,Umweltbewusstsein in Deutschland')

Act), whoever might become affected by floodwater, will have to make precautionary provisions well in advance of such risk materialising[150]. Alongside structural improvements to the prevention or reduction of ensuing damage (cf. Indicator BAU-R-3, p. 232), private provisions include making sure that adequate insurance cover in place.

Damage from natural hazards such as flooding as a result of heavy rain and floodwater, snow pressure, avalanches or even landslides, subsidence and earthquakes – so-called damage from natural hazards – can be insured against by taking out extended natural hazard insurance (eEV). This type of insurance has become an established product in the insurance market. However, by late 2021 only 49 % of residential buildings in Germany were covered by this type of insurance (eEV). As far as tenants are concerned, it is relevant to conclude insurance policies covering household effects for damage caused by natural hazards, because damage to buildings – caused by natural hazards, especially if this damage occurs in rooms at ground level or in cellars or souterrains – can also be caused to a tenant's household effects. By the end of 2021, 32 % of all insurance policies for household effects incorporated cover for damage from natural hazards. Nevertheless: Since 2001, both types of insurance policies have experienced a continuous and significant increase in terms of insurance density. Presumably in response to the flooding disaster in the Ahr and Erft valleys, this density experienced another distinct boost in 2021.

Notwithstanding this increase, it is not clear whether the awareness of the need for eEV cover is deeply enough engrained in the population's consciousness. For instance, in 2016, as part of a population survey entitled 'Environmental Awareness in Germany' (Umweltbewusstsein in Deutschland) – the last year in which this question was asked – just under 6 % of respondents answered that although they had not yet concluded an eEV policy, they would like to conclude such an insurance policy in the future[151]. In the past, extreme events only ever resulted in a short-term increase in the population's willingness to take out insurance. Generally speaking, the hazards are underestimated by the public, and their knowledge regarding which kind of damage is actually covered by an insurance policy, is woefully inadequate. It is interesting to note that underwriters are actually in a position to insure almost any buildings and homes in Germany and, most of them would also be able to offer cover for natural hazards at affordable prices. Exceptions are only made in respect of a few areas where the hazards are particularly great. But even in those cases, individual insurance solutions can be found, i.e. by incorporating high elements of 'excess' (a pre-determined amount deducted from the total settlement received by the claimant) and higher, risk-congruent insurance premiums.

Insurance for damage from natural hazards to buildings and household effects is part of precautionary provision for material damage from climate risks and floodwater.
(Photo: © Christian / stock.adobe.com)

In many Federal States (Länder), joint campaigns and initiatives were fielded in terms of politics, associations, the insurance sector and consumer protection in order to strengthen personal provisions for buildings and building contents by means of eEV in view of the expected increase in extreme weather events. After the floodwater disaster of 2021 in the Ahr and Erft valleys, discussions on legal measures for a wider distribution of eEV and even a legal obligation for taking out insurance gained impetus once more. However, a legal obligation to take out insurance cover remained as controversial as before.[152] Nevertheless, even in the absence of such a legal obligation it would be possible to promote eEV coverage, for instance by means of lowering the tax rate for the extended insurance cover for damage from elementary hazards or by means of the opportunity to reduce insurance costs by taking personal precautionary measures. At the same time, this would give incentives for strengthening the extent of personal provisions.

Irrespective of any insurance cover, all citizens ought to protect themselves by making targeted provisions for potential damage. For its part, the state sector is obliged to enhance the building law ensuring that hazardous areas are kept effectively free from new building projects in future (cf. Indicator RO-R-6, p. 312).

Photo: © Andreas Gruhl / stock.adobe.com

Energy industry

Impacts of climate change – Impact

On the relevance of the action field

A secure, affordable energy supply, compatible with environment and climate requirements, is of elementary importance for Germany's economy and society. The energy turnaround aims at converting our energy systems and ensuring the permanent supply of energy in a way that meets these requirements, by employing renewable energies and by using energy sparingly and more efficiently. In order to achieve the energy turnaround, a decision was made to end the use of fossil and nuclear sources of energy: The withdrawal from the nuclear energy programme was achieved in 2023, and by 2038 the generation of electricity and heat from the use of coal will be terminated. The conversion of the energy system requires far-reaching structural and infra-structural adaptations in all areas of the energy industry. This includes the expansion of transmission and distribution networks, the conversion of electricity, heat and cold supply systems into renewable energy sources, and making the energy system more flexible. Russia's war of aggression against the Ukraine has made it necessary to take additional actions in order to secure energy supplies.

The priority use of renewable energy has led to an increase in the stock of plant and equipment which are exposed to the weather, weather patterns and consequently to changing climatic conditions. When planning and implementing the requisite measures, it is essential to take climate-related changes into account, in order to avoid – also with a view to the long-term return on investments – any negative impacts and the potential costs of adaptations required at a later date.

DAS Monitoring –what is happening due to climate change

Extreme weather conditions, that are expected to increase with climate change, are apt to confront the energy supply with challenges. This includes hot periods, as witnessed, for example in 2018 and 2022, when in Germany and other member states of the trans-European electricity network, the power generation in nuclear and coal-fired power stations was in some cases massively restricted. Owing to the high temperature of water sources, a two-fold problem occurred: on one hand there was not sufficient coolant water available, and on the other, coal supplies were restricted by low levels prevailing in waterways used by inland shipping. A renewable energy supply system brings about a distinct reduction in water-dependent risks. On the contrary, hydropower stations can indeed be affected as a user of renewable energy: their generation output decreased markedly for instance in 2018 and 2022 owing to drought.

Overall, Germany's electrical energy supply is very secure. However, extreme events such as hot periods, storms, tempests with lightning and heavy rain, which are all becoming more likely in the course of climate change, are apt to lead to interruptions in the power supply. The indicator for weather-related unavailability of power supply illustrates the cumulative duration of weather-related interruptions to the supply. The hitherto highest value was recorded in July 2021, which was primarily a result of impacts from the 'Bernd' low-pressure system; this value amounted to an average of just under 23 minutes per end consumer within the meaning of the Federal Law on the Energy Industry (EnWG) (cf. Indicator EW-I-2, p. 241). However, 'Bernd' did not have a marked impact on the frequency of weather-related disruptions as compared to the total of unscheduled disruptions recorded in that year (cf. Indicator EW-I-1, p. 240).

Future climate risks – outcomes of KWRA

In respect of the DAS action field 'Energy industry' the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7) found that, both for individual climate impacts and overall, the climate risk identified is low. For the assessment it is essential to take into account, amongst other factors, the withdrawal from nuclear energy in the run-up to 2023 and, according to current expectations, from coal by 2038. The conversion to renewable energies makes the power and heat supply in general less dependent – both quantitatively and qualitative – on the availability of sufficient water for cooling purposes or in terms of the transportation of primary energy sources.

In this context, energy demand is seen in terms of the essential climate-change related change in the demand for coolant energy. Apart from climatic impacts it is factors such as building stock and consumption behaviour which determine the amount of energy demand. Any concrete statements regarding the future coolant energy demand are therefore subject to major uncertainty. However, it is assumed that owing to the small amount of coolant energy as a proportion of the overall energy demand, it is not expected that there will be any power deficits. The 2021 KWRA did not identify any urgent requirements for action in respect of the climate impacts analysed.

Where do we have gaps in data and knowledge?

Implementing the energy turnaround involves the complete conversion of the energy supply system to renewable energies. In addition, the demand for electrical energy will increase significantly in order to replace fossil energy sources in various applications. For example, it is intended that increasingly electric heat pumps will be used for generating heat. As far a vehicular mobility is concerned, fossil-fuelled vehicles with internal combustion engines are to be replaced by electric vehicles. The reliability of electricity generation from renewable energies and any flexibilisation options available in the system will therefore acquire ever-more relevance.

There are uncertainties as far as any potential impacts of climate change on electricity generation are concerned, in particular with regard to the revenue situation. According to the findings of the 2021 KWRA it is understood that as before, strong wind events will in the future hardly ever lead to power supply disruptions owing to wind turbines. However, so far it has not been possible to make any sufficiently reliable statements in respect of wind energy in general, given that any projections regarding future wind speeds are subject to major uncertainty. Principally, it is assumed that wind scenarios will change only to a limited extent.[153] Nevertheless, a more precise presentation of wind projections would be desirable in future – especially at the turbines' hub height – in order to have a better chance of estimating the impacts of climate change.[154] . It remains to be examined to what extent it would be possible to obtain more specific projections with the aid of other meteorological measuring systems such as wind measurements recorded at wind turbines. Hydropower makes only a minor contribution to the renewable energies mix. In drought years such as 2018 and 2022 power generation from hydropower is sometimes severely restricted. Likewise, restrictions in the production of biomass are conceivable.[155] A more precise estimate of any relevant climate-change impacts would be helpful. In an energy system based on renewable energies, the market-related supply security can be affected, especially during long phases of cold dark doldrums, when a wintry weather scenario is accompanied by a lack of wind and solar energy. To date no research findings have come to light regarding the influence of climate change on the frequency and duration of dark doldrums. A data-based monitoring of dark doldrums would be desirable.

The resilience of renewable energy systems is closely bound up with their flexibility. Storage power stations and battery storage plant can provide flexibilisation options just as much as the generation of hydrogen or other energy sources emanating from surplus renewable electricity. Likewise, flexibly disconnectable or controllable consumption sites are included in these options. The further expansion of electricity networks and the trans-European electricity network play a relevant role in balancing electricity supply and demand at a large scale and in making it possible to buffer frequency fluctuations. In critical weather scenarios, meteorological data can help to indicate large-scale balancing opportunities.[156] Flexibilisation options support the resilience of the electricity system by protecting it from disruptions including meteorological extremes. In this context, the diversification of precautionary measures is of great importance as it enables the system or systems to react adequately to a variety of different situations. For the future it would be desirable to have a comprehensive monitoring system in respect of the actual utilisation of flexibilisation options thus illustrating the system's responsiveness. However, this would first require some methodical deliberations.

What's being done – some examples

In view of the challenges posed by the energy turnaround, climate adaptation – as a factor in further enhancing the energy supply system – tends to recede into the background. Nevertheless, the transformation process leads to a situation in which the climate risks involved in a largely fossil-based or nuclear energy supply for Germany will diminish in future – as shown with regard to coolant and low-water level issues – and measures are taken which increase the general resilience of the energy supply system. Part of the energy turnaround is for instance the expansion of the flexibilisation options mentioned above, for example by expanding battery and other storage capacities or by means of hydrogen production from surplus electrical energy. Such measures increase the resilience of electricity supply systems vis-a-vis fluctuations in electricity supply and demand as these are bound to increase owing to the intrinsic sensitivity of renewable energies to weather events. Likewise, the energy demand is also a focus of the energy turnaround. In a renewable energy supply system, reduced energy demand and increased energy efficiency can help to make it easier to safeguard the balance between energy conversion and application. In a similar way this is also true when changing climate conditions require reinforced balancing of electricity demand and supply.

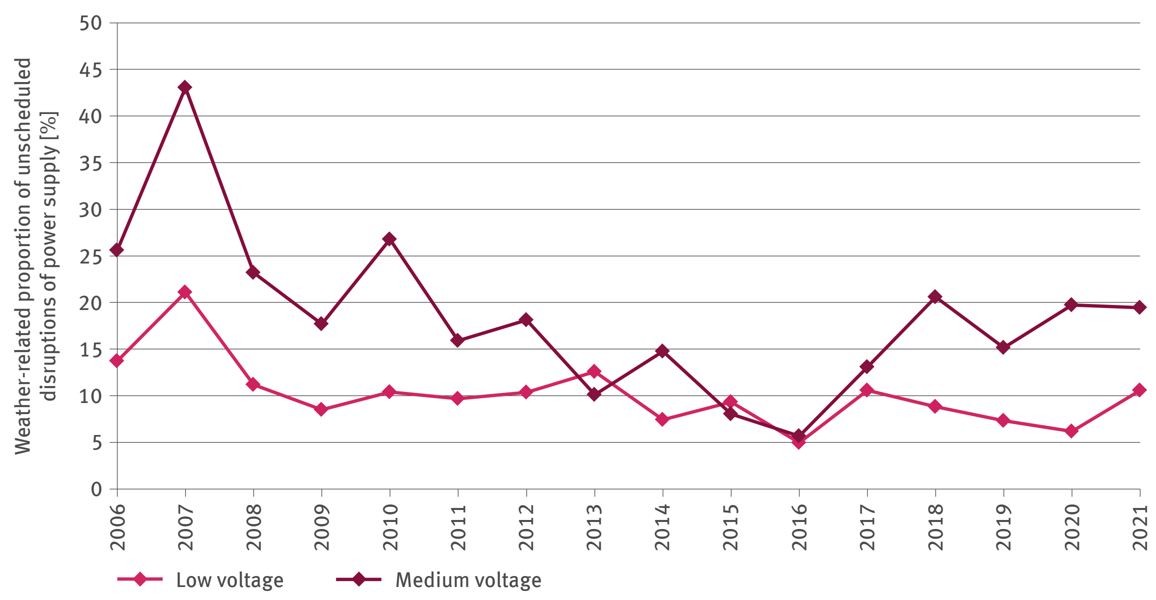
Extreme weather events affect the electricity supply

Overall, Germany's electricity supply is very reliable. It is characterised by the fact that disruptions are infrequent and very brief. In Germany, the Federal Network Agency (BNetzA) keeps records of any disruptions. As part of its remit the BNetzA evaluates reports made by grid operators on disruptions of more than three minutes' duration regarding medium- and low-voltage supply which make up the distribution network for the consumer. The BNetzA differentiates between various causes of disruption in the supply network. For example, the agency categorises wind and temperature effects or overvoltages due to lightning strikes collectively as 'atmospheric impacts'. Events of particular severity such as extraordinary floodwater or hurricanes are classified as 'force majeure'. Such events, in particular, can entail prolonged adverse effects; for example when grids are disrupted over long distances, essential repairs can sometimes take a long time. Nevertheless, transmission and distribution of electricity can be affected by extreme weather events and weather patterns in Germany, despite this being one of the most stable power supply systems in the world. The impacts of hurricane Cyril in 2007 were particularly striking. In that year, the proportion of weather-related disruptions was more than twice the average recorded for the period from 2006 until 2021, both at the level of low-voltage and medium-voltage supply. No similarly high value has been reached since then. In 2007 end consumers had loss of electricity – within the meaning of the EnWG – on average just under 22 minutes at a time, resulting from weather-related and weather-pattern related events; in most years this value amounts to less than 10 minutes.

In other years there is no such direct correlation between the number of disruptions and their cumulative duration. In 2013 for example, the electricity supply had to be switched off temporarily owing to flooding in some of the power supply areas, which meant that end consumers were without electricity for on average approximately 20 minutes nationwide. Likewise, the heavy rainfall events caused by the low-pressure system Bernd in July 2021 brought about extreme flooding in some river basins. For example, the floods reached several electricity substations which had to be shut down for safety reasons. This resulted in large-scale power outages, temporarily

EW-I-1: Weather-related disruptions in power supply

Until 2010, extreme weather events such as hurricanes Cyril (2007) and Xynthia (2010) stood out clearly among weather-related disruptions of power supply; low-pressure related storms that occurred thereafter, such as Friederike (2018) and Bernd (2021), do not stand out in the same way. As far as low voltage is concerned, the proportion of weather-related disruptions declined significantly from 2006 onwards whereas in respect of medium voltage the proportion rose again lately.



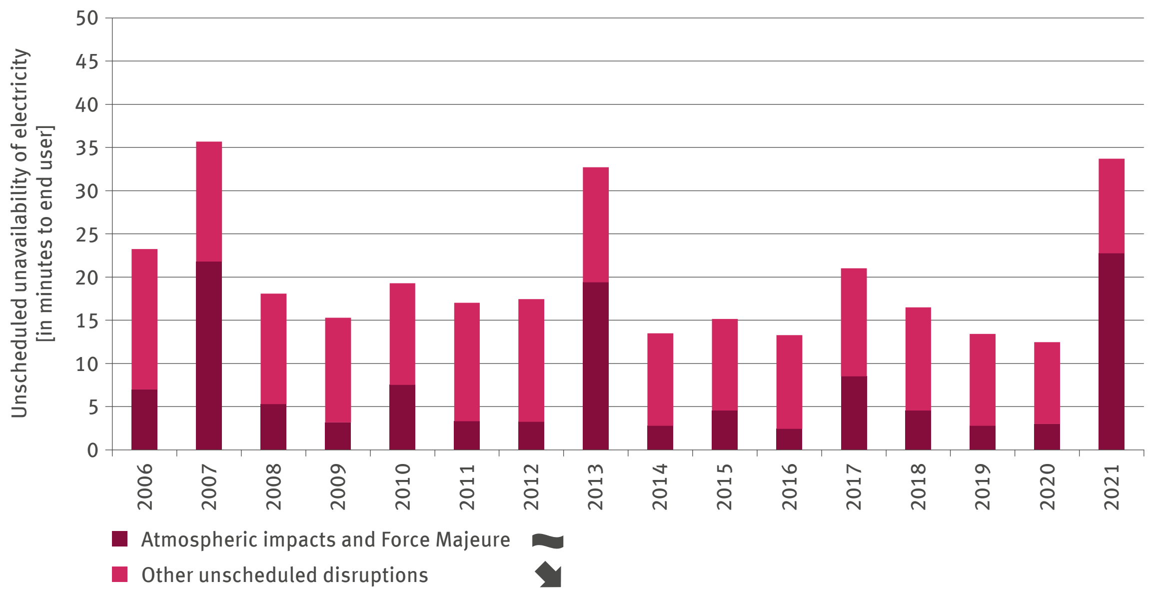
Data source: BNetzA (failure statistics) affecting more than 100.000 households. With periods of just under 23 minutes on average nationwide, the weather-related unavailabity of electricity reached the highest value hitherto. The number and proportion of weather-related disruptions was less conspicuous in those two years.

If extreme weather situations – such as severe storms, hurricanes and heavy rain events – become more frequent owing to climate change, associated disruptions in power supply may become more frequent and their duration may increase, unless networks are appropriately engineered and maintained. Whether electricity networks become affected depends, apart from atmospheric impacts, also on the quality, maintenance condition and age of technical components used in the network. Since 2010 investments in and expenditure on new installations, expansion, extensions, maintenance and upgrades have distinctly increased. Some 10 billion Euros have been invested in the German electricity network annually since 2015; in 2021 the investment amounted to some 13.6 billion Euros.[157] The condition of power lines, transformers and circuit breakers contained in the electricity network is therefore estimated to be functionally appropriate.

Another key determinant is the network structure. To date, approximately 91.5 % of extra-high and high-voltage transmission lines are routed above ground thus being directly exposed to wind and weather. However, the nodes of this grid are interconnected (meshed). A high degree of meshing contributes to high reliability of supply. In case of the failure of individual lines, the supply can usually be re-routed via other, so-called redundant lines (n-1- safety). This is why the end consumer does not usually suffer any power outages from disruptions in the transmission network. Effective protection from storms, snow loads or ice loads can be achieved by routing electricity lines (cabling), in particular medium- and high-voltage lines, underground. At the extra-high voltage level, priority has been given since 2015 – as embedded in the planning principles of Federal sectoral planning – to underground cabling of extra high voltage direct current transmission lines (HGÜ). Apart from increasing the acceptance of the network expansion, this can also improve the resilience of networks to climate-change related impacts. Concurrently, there is ongoing research on selected pilot routes in order to identify to what extent underground cabling might be used with regard to three-phase current lines.

EW-I-2: 'Weather-related unavailability of electricity supply

In 2021 the highest value amounting on average to just under 23 minutes per end consumer was reached in respect of weather-related unavailability of electricity supply in Germany. This outcome was caused primarily by the impacts of the low-pressure system Bernd in July 2021. While the unavailability of electricity owing to other unscheduled disruptions is declining, there is so far no significant trend discernible for weather-related causes.



Data source: BNetzA (failure statistics)

Photo: © Carola Vahldiek / stock.adobe.com

Transport, transport infrastructure

Impacts of climate change – Impact

On the relevance of the action field

A modern industry and services-oriented society such as Germany is highly mobile. Most people travel on a daily basis; either they commute to their place of work, walk, cycle or drive to their school or training establishment. Likewise, they cover more or less long distances for recreation and for shopping purposes. The functioning of economic systems depends on reliable goods transport; this includes the transport of energy carriers and raw materials, operating materials and intermediate products, and the delivery of end products to sales outlets or delivery direct to the end customer.

Transport infrastructures and means of transportation are usually both directly exposed to weather conditions. Extreme weather and extreme weather patterns often go hand in hand with mobility disruptions, which in some cases, can threaten life and limb of transport users. In less threatening cases, disruptions take the form of slowing down or delaying traffic. In exceptional cases, transport links can become unavailable for extended periods such as weeks or months or even fail entirely as a result of damage to the infrastructure. Such restrictions to the mobility of goods and passengers can entail various economic consequences such as increased costs and losses incurred by companies, supply bottlenecks and shortages, or rising prices for motor fuels and energy.

DAS Monitoring –what is happening due to climate change

In recent years, extreme weather and extreme weather patterns have repeatedly caused major disruptions in goods and passenger transport. These events are increasingly associated with changing climatic conditions thus indicating that impacts from climate change will affect both transport carriers such as road and rail, inland and marine shipping as well as air transport.

As far as goods transport by inland shipping is concerned, the Rhine and its tributaries play a major role in Germany. In excess of 75 % of goods transported by Germany's inland shipping are conveyed via the Rhine. Floodwater events affect inland shipping whenever they exceed the highest navigation level (HSW) and when the relevant section of the river Rhine is completely blocked to shipping (cf. Indicator VE-I-1, p. 248). In respect of Upper Rhine stretches, shipping was blocked on a total of 18 days in 2021 – the highest value since 1999. As far as Lower and Middle Rhine stretches are concerned, closures lasting for more than five days were the exception. In contrast, restrictions owing to low water levels can persist for considerably longer periods (cf. Indicator VE-I-2, p. 249). Contrary to high-water level closures, inland shipping is usually still possible. However, in these cases, profitability depends on the permitted draught of the vessel concerned. In 2018 – a particularly hot and dry year – the highest number of low-water restrictions was recorded so far. Goods transport by inland shipping was only possible with restrictions on the Upper Rhine on 80 days and on well over 100 days on the Middle and Lower Rhine. Regarding the Lower Rhine, low-water restrictions have been increasing significantly since 1997.

Any adverse effects on road transport and damage to road infrastructures, that occurred in recent decades, were primarily due to hurricanes and flooding resulting from heavy rain and floodwater. In Germany, torrential rain events occur every year affecting between 5 to more than 30 % of federal trunk roads (cf. Indicator VE-I-3, p. 250). This type of heavy rain events also played a role in the emergence of the floodwater disasters which created havoc in 2021. Even when they are less extreme, such downpours can impact road conditions and visibility thus increasing the risk of road accidents. However, in the course of the past 25 years, the severity of slippery road conditions caused by rain as a contributory factor in road accidents has been decreasing (cf. Indicator VE-I-4, p. 252). As far as road maintenance services are concerned, the ímpacts of hurricanes Cyril (2007) and Xynthia (2010) have so far brought about the heaviest workloads. Nevertheless, some tempests involving storm, hailstones and heavy rain also inflicted heavy workloads, especially latterly in 2018 and 2021.

Such tempests are also relevant factors in terms of rail transport; they can adversely affect traffic flow or cause damage to infrastructures. Other relevant events are winter storms with heavy snowfall and drifting snow or inundations resulting from floodwater and heavy rain. In years of high heat exposure, adverse effects can result from breakdowns of technical components in track switch operation mechanisms and switch points, but they can also occur in the rolling stock. Another hazard is the vegetation on embankments catching fire; this too can entail restrictions (cf. Indicator VE-I6, p. 256).

Future climate risks – outcomes of KWRA

As far as the transport, transport infrastructure action field is concerned, the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7) suggests that by the middle of this century, climate risk concerning low-water level issues regarding the navigability of inland waterways will be high. As far as other climate impacts such as damage to or obstacles on roads or railway lines resulting from floodwater or major gravitational mass movements are concerned, a medium climate risk has been identified by this analytical process to arise by mid-century. Likewise, with a view to traffic management systems, overhead wires and power supply systems, a medium climate risk has been identified. Nevertheless, it has to be said that these risk assessments are subject to considerable uncertainties.

Where do we have gaps in data and knowledge?

In addition to road transport and inland shipping, the 2023 Monitoring Report allowed for the first time the inclusion of a third transport carrier, and this concerns weather-related disruptions in the railway infrastructure. The issue of air transport has again not been included as a theme This is due to the fact that at the time when the DAS Strategy was first developed, various analyses showed that climate changes were expected to have only limited impacts on this sector[158]. In the meantime, potential impacts of climate change on air transport have been examined more closely, both at national and international level, leading to the identification of various relevant themes which are being examined in cooperation with the DWD within the framework of effects research. On the basis of the outcome of these assessments it may be possible to expand the indicator set by incorporating the air transport theme[159]. To date, another transport sector, i.e. public transport (ÖPNV) has been addressed only partly within the indicator on disruptions of the railway infrastructure. This is because there has so far been a lack of data and information on ÖPNV with a view to potential climate change impacts and adaptation measures required, to allow illustrating the theme within the indicator set.

Substantial impacts of climate change on transport include damage to transport infrastructures arising, in particular, from extreme weather events and consequential disruptions to traffic flow as well as accident risks. As far as road transport is concerned, data available from accident statistics allow a tentative approach to these themes. However, to render a clearer picture of the impacts of traffic flow, it would be necessary to obtain data on frequency and duration of traffic obstructions or congestions arising from causes such as heavy rain or storm. As far as the situation regarding road accidents is concerned, more in-depth information on potential impacts of summer heat and heat periods on driving behaviour and accident scenarios are required in order to bring the relevant indicator into sharper focus. For railway transport some of the data on disruption causes are not available in sufficient detail; for instance, in case of major disruptions, it is not possible to capture and record all the information required. In terms of DAS Monitoring, the indicator would be improved by incorporating the duration of disruptions.

In general, there is to date, in respect of all transport carriers, a shortage of systematically captured and evaluated data which would allow a quantitative description of the impacts of weather extremes on transport infrastructures. In respect of road, rail and shipping, it would be helpful to have cause-related information detailing, for instance, the costs of remedying damage or of maintaining infrastructures. The same applies to air transport infrastructures insofar as this theme will in future be integrated within the DAS Monitoring system. As a matter of principle, it would be desirable to have data available that allow a differentiated illustration of diverse regions such as floodplains, coasts or uplands in order to show their various vulnerabilities.

In the transport sector, it has not been possible so far to illustrate adaptation measures in terms of response indicators, although it is true to say that targeted adaptation activities are in progress for this action field. However, adaptation measures which are in the process of being carried out are, in many cases, beyond the scope of continuous data capture which would serve as a basis for regular illustration by means of indicators. This applies just as much to information-related measures such as offering data services, management tools or guidance notes as to regulatory measures such as the adaptation of technical standards and assessment bases. In order to facilitate the assessment of engineering measures such as the mitigation of problems in roads with poor drainage or safeguarding a minimum water level in waterways by means of river engineering, it would be desirable to introduce an ‘adaptation marker’ which would facilitate the allocation of targeted finance available for climate adaptation.

The expenditure required for measures to be carried out regularly for the operational management of transport infrastructures, such as maintenance-related dredging works in waterways or the management of vegetation on railway embankments, varies in accordance with a number of variables including climatic factors. Many of such measures will require adaptation to the challenges of climate change. For a quantitative illustration of the varying extent of such measures it is essential to ensure a differentiated capture of expenditure in terms of hours of work and costs. The illustration of operational measures for the optimisation of traffic flows and for temporal, spatial or intermodal relocation of passenger- and goods transports, would require a sophisticated assessment of fine-grained data on transport flows. This would require further research in order to obtain targeted guidance on suitable approaches to the development of monitoring indicators.

What's being done – some examples

As far as the action field 'transport, transport infrastructure' is concerned at federal level, this is the remit of the BMDV. It is a superordinate objective of climate adaptation in the transport sector to safeguard the efficiency of the transport system vis-à-vis changing climatic challenges and more frequent extreme weather events, thus enabling the system to meet the future requirements raised by a mobile society. This objective is reflected in the BMDV's strategic framework of departmental research in respect of the 20th parliamentary term under the motto 'Transforming mobility sustainably and promoting digital efficiency' ('Mobilität nachhaltig transformieren und die digitale Leistungsfähigkeit vorantreiben'). This includes research activities to develop an infrastructure resilient to the impacts of climate change, developing adaptation measures for the improvement of data capture and forecasting, as well as the further development of alert message systems. Furthermore, the strategic framework incorporates the focal points 'further development of digital applications' and 'resilient transport and data systems and transport safety'.

Starting in 2016, research activities have been bundled – insofar as they figured in the context of climate change impacts on the transport infrastructure and resulting adaptation requirements – under Theme 1 'Climate change impacts and adaptation' of the BMDV's experts network 'Knowledge – Skill – Action'. The network comprises seven superior authorities as well as the BMDV's departmental research facilities who cooperate in the quest of finding solutions for substantial challenges and future issues in the field of transport and mobility. The involvement of the BMDV's experts network in addressing the challenges – entailed by climate change – facing transport and the transport infrastructure, is defined as a measure embedded in the third action plan 'Adaptation' (APA III) adopted by Federal Government. Further measures under APA III addressed or supported by the BMDV's experts network include the DAS basic service (Basisdienst) 'Climate and Water' – an operational data and advice service – as well as the Federal Waterways and Shipping Administration's (WSV) strategy for adaptation to impacts of climate change on federal waterways and other related infrastructures, which is provided data by the DAS basic service, as well as the 'Rhine low-water levels action plan'. Measures covering other transport carriers under APA III include the assessment of vulnerability of the railway transport networks and an evaluation of the adaptation of regulatory frameworks of the railway company DB Netz AG. With regard to road transport, APA III covers the promotion of extra investments into the road transport infrastructure within the framework of federal road transport planning. This is aimed at making the existing road transport infrastructure more robust against potential damage from extreme weather events. In future, a prognostic scenario entitled 'extreme weather events 2080' is to be incorporated in the planning process.

As far as railway transport is concerned, Federal Government, in its capacity of proprietor of Deutsche Bahn AG, is also active in terms of climate adaptation. Deutsche Bahn AG is currently in the process of developing a climate resilience strategy. The measures concerned include, for instance, optimised vegetation management along railway lines and the use of a more robust technology for track switch operation mechanisms or power units.

Other actors involved in climate adaptation in the transport sector are the Federal States (Länder) which address measures within the framework of their relevant competences. These measures span a wide range, from determining climate risks to transport routes to planning and implementation of actual engineering or management measures.

State

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Climate changes relevant to the action field

Heat and Drought

Germany is experiencing an increase in the frequency of hot and dry years. When high temperatures occur in tandem with negligible precipitation in summer as for instance in 2018, 2019 and latterly also 2022 (cf. figure 4, p. 22), this can entail intensive and also extensive dry phases with low soil humidity. In Germany, the mean of days recorded with low soil humidity has increased significantly since 1961 (cf. figure 10, p. 27). In the years mentioned, there were other drought symptoms such as little groundwater recharge and low groundwater levels (cf. Indicator WW-I-2, p. 72) as well as distinct low-water phases; the hot and dry summers of 2018 to 2020 have entailed three years in which extremely low water levels were recorded (cf. Indicator WW-I-6. page 80).

Impact

Photo: © kathomenden / stock.adobe.com

Impacts of climate change

VE-I-2 Low-water restrictions to shipping on the Rhine

In cases when large areas of the Rhine catchment area lack precipitation over extended periods, combined with long spells of high temperatures, this can bring about long-lasting situations when water levels remain low. As far as shipping is concerned, low water levels in the Rhine require low payloads, as the low water levels enforce constraints on a ship’s draught. This may lead to supply bottlenecks and price increases for goods transported by inland shipping.

Adaptations – activities and results

Action Plan ‘Rhine Low-Water Levels’

In summer 2019, a year after the massive constraints imposed on Rhine shipping owing to low water levels and the economic impacts associated with this problem, the Rhine low-water levels action plan was proposed by the BMVI (Federal Ministry for Transport and Digital Infrastructure) – in authority at the time. Eight measures were developed in cooperation with representatives from major industrial enterprises in the Rhine catchment area and entities with responsibility for the inland shipping sector, in order to configure a more reliable and future-proof design of the requirements for goods transport on the Rhine.

Response

Picture: © BMDV

The maintenance and further development of forecasting systems formed a major building block in this process. Early detection of extreme drainage situations plays an important role in the management of medium and low water levels and in transport planning. This enables enterprises to revise their planning in time, or – subject to availability – to allocate smaller ships with more convenient draught specifications for this scenario. Besides, additional storage capacities can assist in bridging bottlenecks in cases where shipping is exposed to severe constraints.

Extended low-water phases have very severe impacts

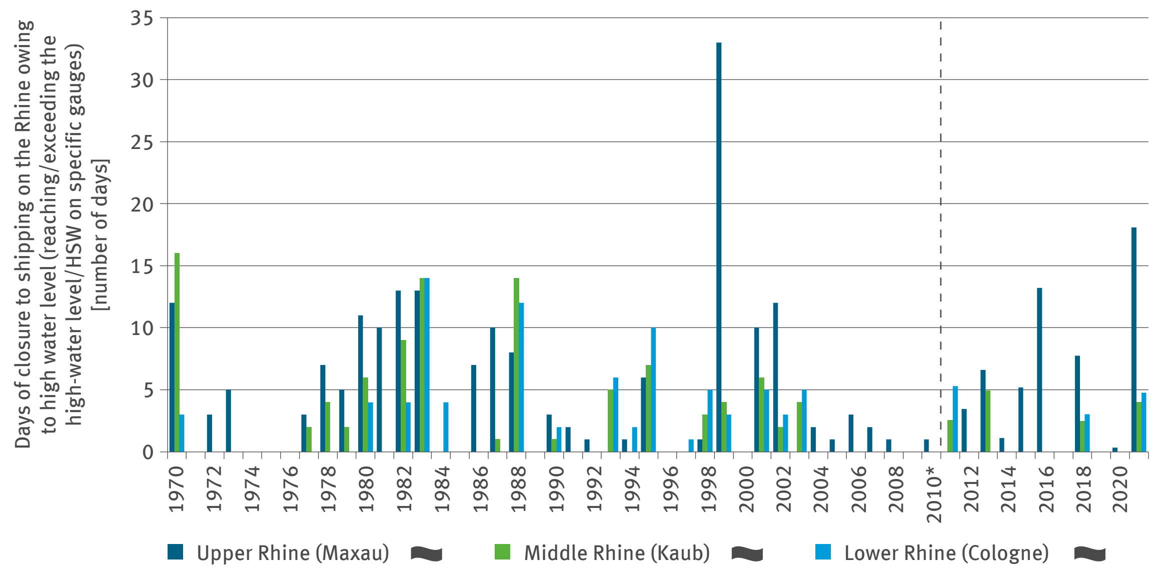
In meteorological and hydrological terms, 2018 was an extraordinary year which demonstrated how dependent Rhine navigation is on the weather and on weather patterns. Great amounts of precipitation fell in the mild month of January, mostly as rain, making streams and rivers swell immediately. The Rhine's water levels exceeded the relevant floodwater marks so that shipping had to be suspended temporarily on all sections of the river. As the year progressed, temperatures remained high whereas precipitation largely failed to materialise until the beginning of December. On the Rhine, this led to an unusually long low-water phase in late summer and autumn which was associated with draught restrictions being imposed on inland shipping. Consumers suffered the consequences in terms of rising fuel prices. As it was no longer possible for tank barges to navigate the Rhine fully laden, and because around the same time a Bavarian refinery stopped production for an extended period, fuel sold at filling stations in southern Germany became scarce and expensive.[160] In 2018, the total freight carried by Germany's inland vessels was down by approximately 25 million tonnes compared to the previous year, representing a decline by 11.1 %.

The Rhine is Germany's most important inland waterway. The river enables cost-effective and environmentally sound transport of goods, facilitates imports and exports via North Sea ports in Belgium and the Netherlands, and it links important industrial centres within Germany[161]. More than three quarters of goods transported by Germany's inland shipping are conveyed via the Rhine[162]. Whenever high or low water levels lead to restrictions imposed on Rhine shipping, this can entail – in some cases considerable – impacts on individual companies or on entire production chains and delivery chains. Primarily solid and liquid bulk commodities are transported on waterways. These are difficult to re-allocate to other transport carriers, while some of these commodities can only be re-allocated to some extent.

The rules governing Rhine shipping are contained in the pertinent police regulation (Rheinschifffahrtspolizeiverordnung). According to this regulation, ships will have to reduce their speed and must be equipped with a radiotelephone installation in cases where the water level exceeds the high-water mark I. In cases where the HSW is exceeded,

VE-I-1: High-water closures to shipping on the Rhine

Over the past 30 years or so, high-water closures have affected Rhine shipping, especially on the Upper Rhine. In 1999, 2016 and 2021 inland shipping was unable to navigate the Upper Rhine for an extended period owing to high water.



*up until 2010: number of days with high-water level closures; since 2011: aggregated duration of closures in days, based on ¼-hourly measurements of the water level

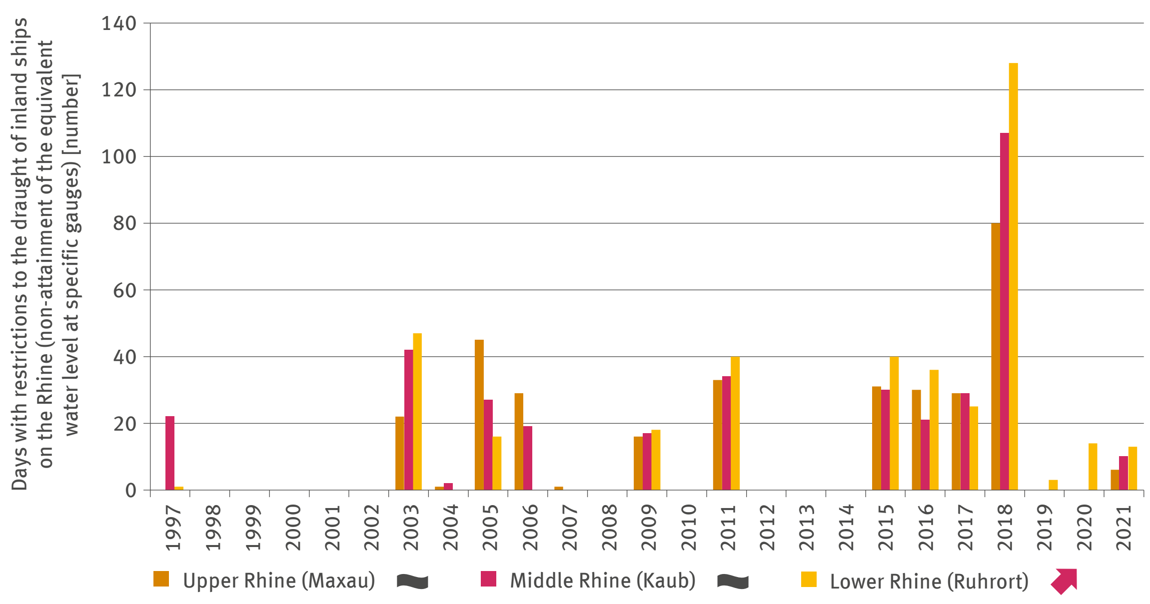
Data source: GDWS (clousures to shipping) the sections affected will have to be closed to shipping. The closures imposed in late winter and spring of 1999 were particularly incisive, when the Upper Rhine was closed to shipping for several weeks owing to two high-water phases. In 2021 there were extended closures on the Upper Rhine owing to abundant falls of rain, first at the end of January, and later in July. On the Middle and Lower Rhine, there have been only brief closures since 2000 which, in most cases, were rescinded after less than a week. So far no significant trends towards more high-water closures have been discerned for the Rhine.

In cases where water levels fall below a threshold value set for a specific section of the river, at which the target depth of the navigation channel is still safely given (in the Rhine this threshold is defined by the so-called equivalent water level) shipping is usually still possible. However, this involves various degrees of restrictions subject to the extent of non-attainment of the mark and according to the size and construction of the inland shipping vessel. On the Rhine such low-water phases usually occur in late summer from August until October. However, in recent years there has been an increase in the frequency of low-water phases lasting well into November or December. This is true for 2011, 2015 and latterly especially in 2018. For the Lower Rhine, the time series starting in 1997 shows a significant increase in low-water restrictions.

The risk analysis entitled ‘Drought’[163] carried out at Federal Government level in 2018, spells out the potentially grave impacts of long-lasting low water levels on inland navigation. The simulated scenario of the risk analysis – an at times extreme drought phase lasting six years – shows long-lasting and significant low-water phases on the Rhine. In such cases, inland shipping is subject to restrictions while in some stretches of the river, it has to be temporarily suspended. In southern Germany and in Switzerland, this can lead to supply bottlenecks regarding bulk commodities. Enterprises in various industries can suffer commercial losses: transport costs rise, while in some cases production has to be curbed or suspended owing to lack of raw materials; and there are problems with the despatch of finished products. Likewise, there can be restrictions and price rises with regard to the supply of power, heat and fuel, owing to constraints in the transport of coal, heating oil and mineral oil products. 2018 was a year which provided graphic examples of the potential consequences entailed by low water levels.

VE-I-2: Low-water restrictions to shipping on the Rhine

Prolonged low-water phases have repeatedly placed incisive restrictions on shipping in the Upper, Middle and Lower Rhine sections. These phases were particularly long-lasting in 2018. This was typically caused by summer drought and heat. In some cases, the impacts lasted well into December. Regarding the Lower Rhine, low-water restrictions clearly indicate a trend that has been increasing significantly since 1997.



Data source : GDWS (restrictions to shipping)

Heavy rain events can occur anywhere

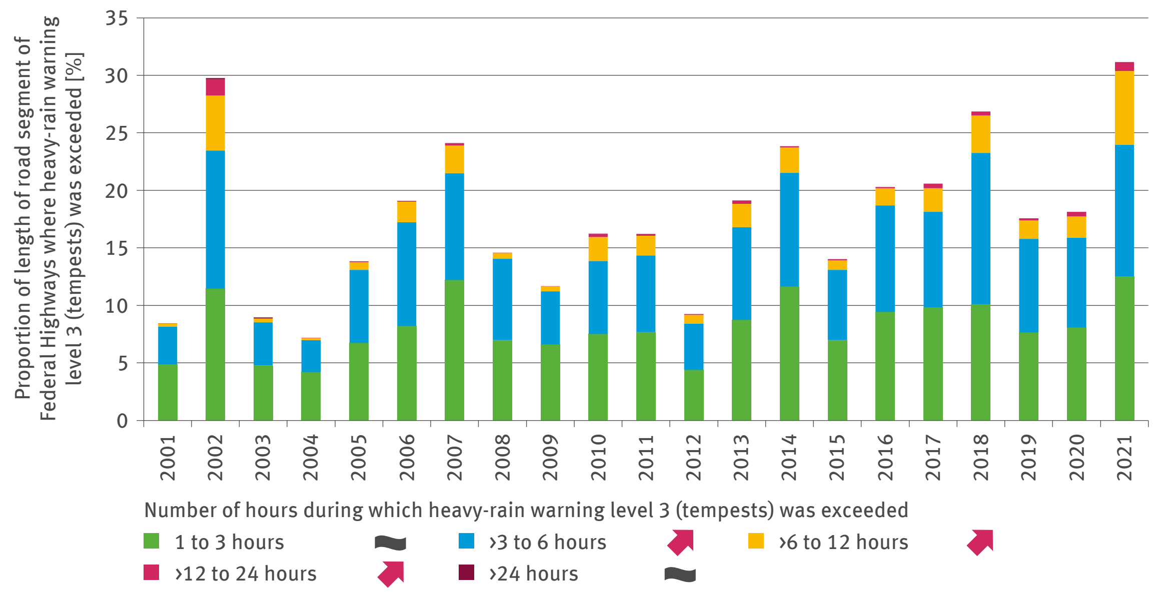
In 2021, the flooding disasters in the Ahr and Erft valleys demonstrated in the most graphic way how vulnerable transport infrastructures really are when they extend through a topographically unfavourable valley location exposed to extended heavy rain events causing flash floods and floodwater. Numerous bridges and roads were damaged or destroyed and have required reconstruction. Countless transport links suffered disruption for weeks and months; in some cases they still suffer disruptions. Nevertheless, even short-lived precipitation events can seriously impact road transport. In June 2021 for instance, roads had to be closed in Landshut, Darmstadt, Krefeld and Magdeburg owing to violent tempests, either because they were inundated by floodwater or swamped by mudslides so that they had to be cleared before they could be re-opened to traffic.

The DWD issues warnings when such sudden and intensive rain events are expected necessitating such closures, by using the term 'heavy rain' in their warnings. Such events can be over in a relatively short time period (according to the DWD warning criteria these events can last up to 6 hours), and more often than not, they occur in a limited locality. In Germany the heavy rain season comprises the months of May to September, and is most significant in the months of June to August. Heavy rain events occur often combined with violent thunderstorms; the technical term for this is 'convective precipitation events'.

Such short and violent rain events can have grave impacts on the transport infrastructure and traffic flows. The nature of these consequences and the specific damage caused, depend on the specific location as well as the relative intensity and duration of rainfalls. On level ground the water cannot run off quickly, and the soil is unable to absorb it completely. The result can be long-term flooding of roads in trough-like hollows and underpasses. That is where water will collect when it can no longer be absorbed and conducted away by drainage systems. As a rule, in upland or alpine regions, depending on the incline, water tends to run off the surface quite rapidly. Very violent heavy rain can turn minor streams into torrential rivers, where rising flood waves force their way through narrow beds of streams. Time and again, the tail ends of

VE-I-3: Heavy rain impacting on roads

Heavy rainfalls can have serious consequences impacting on road traffic. In Germany, from 5 to more than 30% of federal trunk roads are affected every year by heavy rain at warning level 3. For most of the road sections affected, the overall temporal extent of these events amounts to between 1 and 6 hours per year.



Data source: DWD (Radar Climatology RADKLIM (RW) Version 2017.002), BASt (BISStra) these flash floods reach areas which had not actually been affected by heavy rain. In extreme cases, the flow of the massive water runoff or, as described above, high water pressure can damage infrastructures.[164]

More frequently it happens that given such poor road conditions and visibility, accident hazards increase, as for instance in respect of aquaplaning. Equally, heavy rain events can cause obstacles in the road, for instance when driftwood or other flotsam gets stuck in a bottleneck at bridges or underpasses causing logjams and congesting the transport network. Obstructions can also occur when after heavy rainfall slopes and embankments start slipping or are washed out thus covering roads in mud or damaging them in some way.

Between 2001 and 2021 heavy rainfalls have occurred practically all over Germany. It seems obvious therefore that this phenomenon is not limited to upland or mountain areas (cf. map, p. 25). This is reflected in the outcomes of an assessment based on the DWD's radar climatology (RADKLIM).[165] It is expected by climate researchers that in future the frequency of heavy rain and its intensity will in general increase. One reason for this is that at higher temperatures the air can absorb more water – approximately 7 % more water at a temperature increase by one Kelvin. Furthermore, the changing meteorological conditions give rise to the intensified formation of clouds and precipitation.[166] As far as Germany is concerned, it is expected that especially in the second half of the 21st century, there will be – albeit with major regional and seasonal differences – more instances of daily rainfall in high quantities and frequencies compared to the relatively low values recorded in current times. The comparatively strongest increase is expected for events which are currently still infrequent.[167] If these developments materialise, the risk of road traffic disruptions and – in extreme cases – damage to roads and infrastructures will increase. So far, there are no data in the public domain which might enable a reliable and cause-related illustration of the extent of such disruptions and damage. Therefore, the indicator illustrated here in this context provides 'just' an insight into the temporal extent to which the network of federal trunk roads was affected by tempest-type heavy rainfalls as recorded by means of radar data for specific spatial areas. In other words, the indicator is limited to describing just the risks involved.

It is not very likely that infrastructures would be damaged in all heavy rain events covered by the indicator. The DWD issues warnings against tempest-like heavy rain whenever rain amounts of more than 25 litres per square meter (l/m²) are expected to fall in one hour, or when more than 35 l/m² are expected to fall in 6 hours. If these warning levels are exceeded in only moderate amounts, the intensity of heavy rain is usually not likely to damage traffic infrastructures. However: the DWD marks weather situations as warning level 3, i.e. 'tempests' when they are categorised as very hazardous, in which case the DWD recommends that people avoid venturing outdoors.

Heavy rain can very rapidly lead to aquaplaning or flooding of roads and highways.
(Photo: © DRBURHAN / stock.adobe.com)

Weather and weather patterns affect road safety

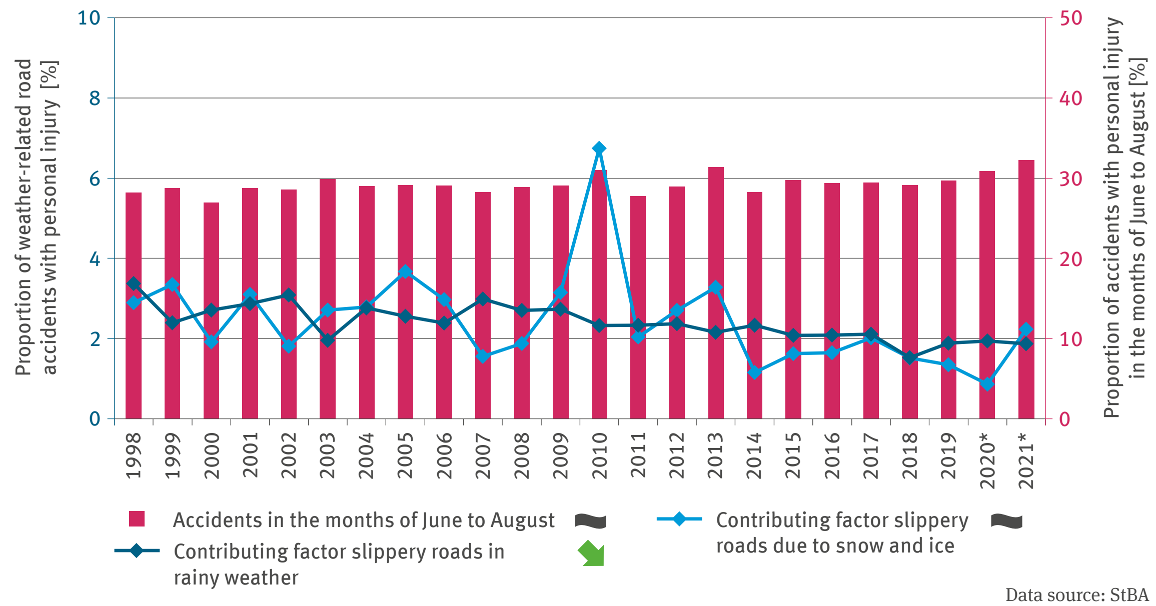
Road safety and accident scenarios on Germany's roads depend on numerous factors of influence. Apart from the existing infrastructure as well as the density and structure of traffic and the behaviour of road users, these also include the weather and prevailing weather patterns. Rain and snow, as well as ice and hailstones impact road conditions, making for adverse driving conditions such as aquaplaning or slippery roads, also on pavements and cycle lanes. Precipitation and fog reduce visibility. The risk of accidents is therefore usually greater in the autumn and winter months than in spring and summer. Overall, there are more accidents in those months. However, as road users tend to adjust their speeds to hazardous conditions, there are fewer accidents causing personal injury during that time than in the warmer months. This situation is furthermore influenced by the choice of one's mode of transport: Humans prefer travelling by car or public transport. The latter reduces the number of unprotected and particularly vulnerable road users from exposure to road traffic.

During the warm season, it is possible to observe contrary behavioural patterns. People make use of pleasant temperatures and longer days. They move about more in public spaces and do more errands on foot or by means of a bicycle, e-bike or motorbike. Traffic situations are becoming generally more complex while the proportion of more vulnerable road users is increasing. Moreover, in good, dry weather road users with power-driven vehicles tend to drive faster than in slippery or wet road conditions, thus provoking more serious accidents. Although over the summer months the number of accidents – compared to the year as a whole – is average, the proportion of accidents where people are injured or killed is particularly high at that time of year.

The accident situation in 2010 as assessed by the Federal Statistical Office (StBA)[168] demonstrates the various ways in which the weather and weather patterns can affect road safety. During the months of January, February and December, the prevailing road conditions tended to be very wintry. As a result, snow and black ice were joint causes of almost twice as many accidents involving

VE-I-4: Road accidents due to weather conditions and weather patterns

In 2010, very wintery road conditions both in January and February but also in December, were the cause of an unusually high number of accidents partly owing to slippery conditions on roads covered in snow and black ice. For this time series, no significant trend can be identified, nor for accidents involving personal injury in the months of June to August. The relevance of slippery roads due to rain as contributory factor to the cause of accidents decreased significantly.



*The years 2020 and 2021 of the Covid-19 pandemic were not included in the trend analysis.

Data source: StBA (statistics of road traffic accidents) personal injury as in other years during the period in question. However, the overall picture shows that in those months (as indeed throughout 2010) there were comparatively few accidents involving personal injury so that in those months the relative proportion of accidents involving personal injury was the lowest since 1991. Overall, the number of accidents was much higher, but thanks to basically more cautious driving, the accidents involved only material damage. By contrast, the proportion of accidents involving personal injury reached an above-average high level in the summer months of 2010 and 2013. As far as 2010 is concerned, part of the blame can be apportioned to the weather, because June and July of that year were generally very sunny while the first weeks of July were very hot. Compared to the past ten years, there were overall fewer accidents in 2013 involving personal injury. The relatively hot July of 2013 was, in fact, the most accident-prone month of the entire period examined and it accounts for the high proportion of accidents in the summer months of that year. The increase in 2020 and 2021 should be categorised as a side effect of the Covid-19 pandemic. Owing to the introduction of less stringent regulations in the summer months, and compared to pre-pandemic times, the decline in accident figures was less distinct in the months from June to August than in most of the months of those years. This is reflected in the higher proportion of summer months compared to the annual accident situation.

In view of the influence which weather and prevailing weather patterns can have on accidents happening, it is currently under discussion whether climate change might have relevant impacts on road safety and the incidence of accidents. In this context, wintry hazards are expected to diminish in future whereas in spring, summer and autumn it is expected that greater heat and increased heavy rainfall might contribute to increasing the frequency of accidents. In recent years, dust and sandstorms caused accidents in some regions. Given the increase in dry soil conditions, such incidents might become more frequent in future. So far, no significant trends have emerged from the illustrated time series for road accidents involving snow and black ice as contributory factors. Since 1998, accidents involving slippery roads in rainy weather as a contributing factor show a significant falling trend while the number of road accidents in the summer months has been rising significantly, presumably as a consequence of the above-mentioned pandemic effect.

It is up to road users to inform themselves of prevailing hazards, to take note of warnings and to behave correctly and appropriately in extreme situations. On the other hand, road users do rely, in principle, on transport infrastructures functioning even under extreme conditions and no damage being caused by weather extremes. It is part of the remit of the Federal and Länder governments, to adapt transport infrastructures to changing climatic conditions. In order to lay the appropriate foundations, a research programme was launched by the Federal Highway Institute (BASt) in 2011. This programme is entitled 'Adaptation of road transport infrastructure to climate change' (AdSVIS). The first phase of this programme included the project entitled 'RIVA – a risk analysis of important transport routes in the federal trunk road network in the context of climate change', a methodology developed with the aim to make the assessment of climate risks for the federal trunk road system easier.[169] Since 2016 any climate-change related activities carried out by the BASt are embedded in Theme 1 'Climate Impacts and Adaptation (Klimafolgen und Anpassung) of the BMDV's experts network 'Knowledge – Skill – Action'.

Just like summer heat, poor road conditions can – due to rain, snow or ice – impact the incidence of accidents.
(Photo: © Animaflora PicsStock / stock.adobe.com)

Clean-up operations after storm and heavy rain

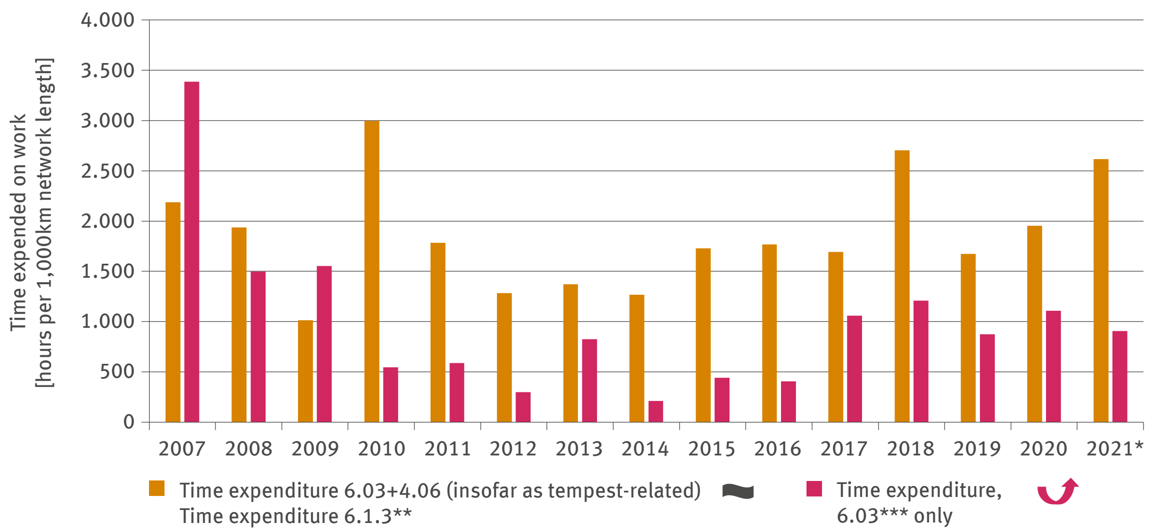
In recent years road transport infrastructures in various parts of Germany were affected repeatedly by tempests and their aftermath: Rivers broke their banks flooding transport routes including federal trunk roads and motorways. Heavy rainfalls triggered flash floods which effectively washed cars away and undermined roads, damaging infrastructures such as rainwater retention basins (cf. Indicator VE-I-3, p. 250); mudslides, toppled trees and windthrows; on some occasions accumulations of hailstones blocked roads and left a lot of dirt and damage behind on roadsides, so that roads had to be closed to traffic.

The total extent of damage to roads and infrastructure often does not reveal itself until a tempest has passed or the high-water level has receded. The task to remedy such damage falls into the remit of highway maintenance administrations at Länder level, whereas responsibility for motorways has been, since its inception in 2021, the remit of the Autobahn GmbH des Bundes (AdB) at federal government level. Major restoration work on buildings or embankments is usually entrusted to private companies. Minor repairs and cleansing jobs are carried out by highway maintenance services. Highway maintenance work is carried out by employees of motorway and road maintenance depots. They make sure that the road network is safe and functioning. All measures required to ensure adequate control, servicing and maintenance of Germany's roads are implemented under the premise that the smooth flow of traffic is affected as little as possible.

The new version of a specification detailing the requirements for work to be carried out by highway maintenance services on federal trunk roads is contained in the 'Leistungsheft für den Straßenbetriebsdienst auf Bundesfernstraßen, edition 2021'[170] published in the beginning of 2022. According to the amended item 6.1.3 'Measures to be taken for extraordinary weather events and disasters', the removal or repair of any road damage immediately after tempests is the remit of highway maintenance services. Highway maintenance services are also required to remove any obstacles from roads, such as tree branches or limbs, and to remove any detritus or pollution, to restore any damaged road signs or markings, to restore road banks and to clear ditches. Where specific road

VE-I-5: Impacts on roads due to weather conditions and weather patterns

Highway maintenance services were extraordinarily busy in 2007, 2010, 2018 and 2021. In 2007 and 2010 the main task was to remedy the damage wrought by hurricanes Cyril and Xynthia respectively. In 2018 the impacts of storm, hailstones and heavy rain kept the highway maintenance services in Hesse, Rhineland-Palatinate and North Rhine-Westphalia exceptionally busy. In 2021, the 'Bernd' low-pressure system was responsible for the high expenditures on working time.



*not including motorways
** RP since 2007; HE since 2013; MV since 2014; ST since 2017; BW since 2021
***BB since 2007; BY since 2010; SN since 2011; NI since 2012; BW 2017–2020; NRW since 2018

Data source: Länder (working time recording of road maintenance service), BMDV (length statistics for supra-local roads) sections are impassable, highway maintenance services will handle traffic control using appropriate signage and barriers or cordons.

Subject to the availability of data for the individual Länder, the indicator shows the expenditure for services rendered in connection with extraordinary weather events under the remit of various Länder. In this context it must be borne in mind that in connection with such events in some Länder, only the services rendered for ‚traffic control measures in specific weather events' (item 6.03) were covered, as per the specification dating back to 2004 (item 6.03). In other Länder the necessary measures – in relation to extraordinary weather events – for the removal of detritus from road surfaces obstructing and endangering traffic – were covered in addition (item 6.03, plus selected expenditures as per item 4.06). The latter formulation is a forerunner for the capture of expenditure under item 6.3.1 of the new specification. Given the differences in the scope of services rendered, the diagram illustrates the two approaches separately. In order to make the expenditure incurred in various Länder comparable, the values were in each case calculated in relation to the length of the road network under the remit of each highway department.

The time expended on dealing with extraordinary weather events and disasters was particularly high in the years 2007 and 2010, and latterly also in 2018 and 2021. In the first-mentioned decades, a large area of Germany was struck by hurricanes Cyril and Xynthia respectively. In woodlands and forested areas, a great number of trees were uprooted and branches were ripped off. This resulted in obstructions and damage to roads which had to be remedied by highway maintenance services. The labour involved caused a distinct amount of additional time expenditure. In May 2018, a considerable number of violent tempests occurred in many German Länder. Particularly hard-hit were the Länder Hesse, Rhineland-Palatinate and North Rhine-Westphalia, where the highway maintenance services incurred high expenditures in the course of remedying the impacts of flooding, mudslides, hailstorms and heavy rain. By contrast, the time expenditure on work carried out in 2021 seems to be only a partial reflection of the impacts caused by the low pressure system known as Bernd. The reason for this is the disastrous extent of floodwater and inundation events. Now as before, in order to remedy damage, measures are taken which fall outside the gamut of services rendered by highway maintenance services, as this work is undertaken by private enterprises and therefore not reflected in the time series.

Once the upgraded specification is established and applied by all Länder as well as by the AdB (Autobahn GmbH

When tempests occur, the highway maintenance services close impassible road sections, remove mud and branches from road surfaces and repair minor damage.
(Photo: © Chris / stock.adobe.com)

des Bundes), it will in future be possible to make comparable statements on time expenditure incurred by highway maintenance services in the aftermath of extraordinary weather events and disasters. To that end, the Federal-Länder Working Party BEKORS (Calculation of operating costs incurred by highway maintenance services / Betriebskostenrechnung im Straßenbetriebsdienst) has revised and enhanced the relevant specification to incorporate the collation of data on time expenditure in a homogeneous and comparable manner. For this purpose, the services to be rendered were described in detail, including a clarification stating that the time expended under item 6.1.3 'Measures to be taken in cases of extraordinary weather events or disasters' is to be allocated not only to initial measures but also to follow-up measures.

On this basis, the scope of this indicator can in future be expanded to cover all Länder of the Federal Republic of Germany. This will make it possible to assess whether the labour expended on highway maintenance is increasing because nationwide, Germany is experiencing a greater amount of road damage and obstructions as a result of extreme weather events – a consequence of the expected climate change impacts on the transport sector.

Climate change impacts on the railway infrastructure

Just under 9 % of passenger transport and approximately 19 % of goods transport (expressed in passenger and tonne-kilometres respectively) as recorded in the pre-crisis year 2019, make railway transport an important building block of Germany's transport system. On one hand, the railway entities are themselves keen on safeguarding largely disruption-free railway operations, and on the other hand, enterprises and passengers who use railway services for their logistics and mobility depend on punctual and disruption-free train services.

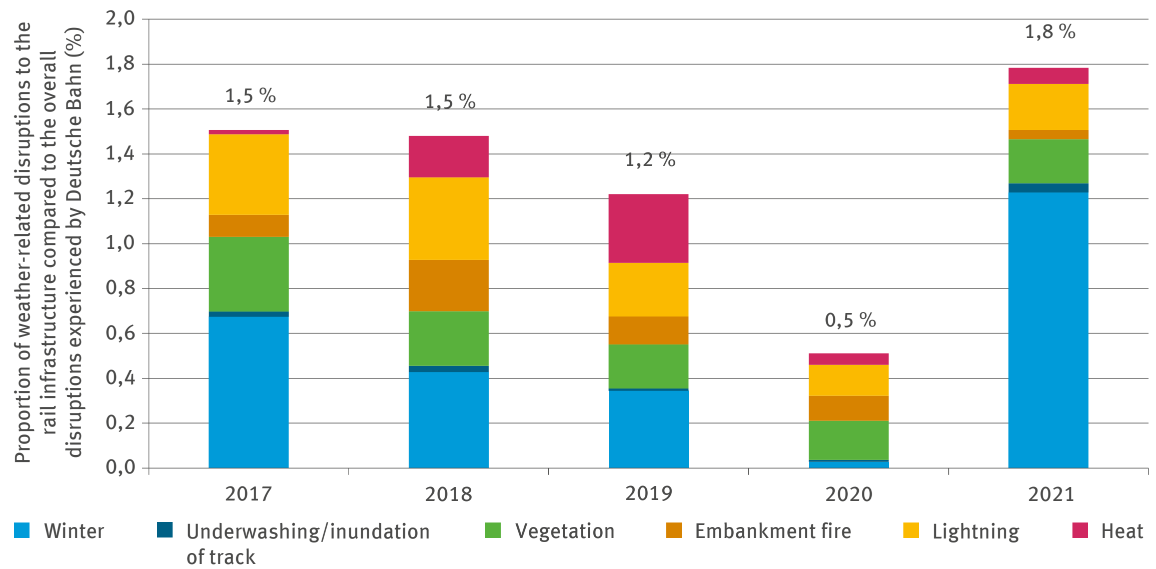
The weather and weather patterns rank among the important factors which can cause disruptions to the railway infrastructure and to railway transport, if they counteract the concept of 'normal' operations. As part of an analysis of climate change, the disruption scenario was explored by the Potsdam Institute for Climate Research (PIK) on behalf of the Deutsche Bahn company. The outcomes show that, in future, Germany's railway infrastructure will be exposed increasingly to extreme and more intensive weather events, and that in the past, heat, heavy rain and storm were often the cause of repeated reports of disruptions.[171]

Heat can affect the railway infrastructure, for instance in cases when it causes the failure of electronic circuit components or actuation and switch point surveillance systems. Heavy or persistent rain can, as demonstrated graphically by the disasters in the Ahr and Erft valleys in 2021, trigger floodwater waves inundating railway lines which run through valleys and if they are located in the vicinity of river beds thus underwashing railway tracks as well as affecting embankments and track beds. In cases where railway lines run along steep embankments, such precipitations can trigger landslides, ordinary mudslides or mudslides coming down from high mountains, which damage or completely destroy the transport infrastructures and control systems.

The indicator is based on data emanating from the disruption database maintained by the DB Netz AG. This shows the proportion of disruptions related to the weather and weather patterns in the company's railway infrastructure covering all disruptions recorded by DB. In this context, disruptions are understood as events resulting in trains being late or cancelled. The disruption database serves for capturing disruption events occurring in the railway

VE-I-6: Weather-related disruptions to the railway infrastructure

2021 stands out due to numerous disruptions to the railway infrastructure caused by weather events and weather-related patterns, not just in comparison to the low figures recorded in the pandemic year of 2020. In that year, winter storm Tristan caused massive disruptions to railway traffic due to freezing rain, snowfall and snowdrifts. In 2018 and 2019, the summer heat caused a noticeable number of disruptions. A trend analysis is not yet possible for the short time series.



*Disruption event which is clearly allocated to one of the cause categories 'lightning', 'heat', 'embankment fire', 'vegetation', 'winter' or 'underwashing/inundation of track'.

Data source: DB Netz AG (disruption database) infrastructure as well as stating their primary cause. The disruptions are covered in the indicator according to one of six distinct cause categories: 'lightning', 'heat', 'embankment fire', 'vegetation', 'winter' as well as 'railway track underwashing'.

In the time series which as yet is rather short, the year 2021 stands out on account of its high number of disruptions due to wintry conditions. These are due to winter storm Tristan which brought very heavy falls of snow and snowdrifts: Overhead wires and switch points were iced up, trees threatened to fall on to overhead wires and on to tracks while snowdrifts made tracks impassable. In order to prevent trains from getting stuck somewhere on the track, the railway company provided numerous alternative connections and made available accommodation trains in railway stations for any passengers who were unable to make their onward journey on the same day. The impacts of floodwater in the Ahr and Erft valleys in that year are only partly reflected in the indicator, because trains deleted from train schedules are not recorded in the underlying disruption database in view of the long-term line closure.

Apart from a slightly below-average occurrence of extreme weather events, the negligible disruption incidence in 2020 can be accounted for by the reduced traffic volume during the Covid-19 pandemic. Given the overall reduced amount of travel, it is obvious that fewer train journeys were affected by extreme weather events and associated impacts. Any damage occurring due to weather effects was frequently remedied before causing any disruptions to train operations.

In 2018 and 2019, however, high temperatures were largely responsible for disruptions to the rail network. The heat contributed to disruptions by causing points and signals to overheat. Moreover, work scheduled for track sections had to be rescheduled, given that tracks are only allowed to be fitted or removed within specified temperature ranges in order to avoid putting too much pressure or tension on steel during seasonal temperature fluctuations. Additional cancellations were caused by embankment fires flaring up along railway lines owing to drought and heat. Likewise, technical defects in air conditioning equipment and other structural components can lead to heat-related train cancellations. However, these are not covered in the indicator concerned with the railway infrastructure.

Disruptions due to branches and trees falling on overhead wires or on to railway tracks owing to storm and strong wind (vegetation category), occurred in relatively consistent volumes in the years illustrated. In order to prevent disruptions due to windthrow, it is important to carry out adapted track maintenance which curbs the growth of trees and bushes in the vicinity of tracks.

Trees and branches in the track or overhead wires are a potential cause of disruptions to the railway infrastructure.
(Photo: © Turner / stock.adobe.com)

As far as the future is concerned, the PIK analysis of climate impacts carried out for Deutsche Bahn shows that heat situations will occur more frequently and will become more intensive. Likewise, progressive climate change is expected to entail an increase in heavy rain events. With regard to strong wind and storm, there are uncertainties to what extent the frequency of their occurrence is likely to change. However, there is a potential for seasonal shifts causing more disturbances, for instance when storms occur more frequently in summer or autumn, striking trees when they are in full leaf. At the same time, distinctly wintry conditions are on the wane thus becoming less frequently the cause of disruptions, although individual extreme weather events may continue to occur. [172]

In order to counteract the challenges to the infrastructure threatening to arise from climate change, the railway transport sector is already implementing a variety of measures. These include solutions at the level of planning and technical solutions, with the aim to minimise climate risks affecting restoration, extension and renewal of railway tracks or to raise the technical standards for components used in track switch operation mechanisms and switch points as well as air conditioning equipment. Likewise, adapted vegetation management along railway tracks to avoid windthrow and reducing the incidence of embankment fires, are also part of these measures.

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Trade and industry

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

Trade and industry (in this context defined as processing industry) constitute an important economic sector of Germany's national economy. In 2022 roughly a sixth of employees in Germany generated more than 20 % of Germany's Gross Value Added. Companies active in the processing industries are therefore highly integrated in global production and supply chains. Raw materials and intermediate products from numerous countries are imported to Germany to be processed here. By the same token, numerous products manufactured by German companies are exported worldwide. It is thanks to the high demand for products 'Made in Germany' – especially for machinery, motor vehicles and associated components as well as chemical products – that Germany's balance of trade is regularly boosted by export surpluses.

In many respects, the intensifying climate change is a major challenge to companies. Apart from changes in the market environment owing to increasing requirements for protection from climatic changes, companies also face – according to their individual branch of industry, location and size – increasing risks from climate change impacts. This applies to both risks of damage or limitations caused by weather extremes and risks from changing market conditions jeopardising value-added and business models. Forward-looking entrepreneurial action can mitigate such risks at the same time as providing opportunities to develop new value-added potentials.

DAS Monitoring –what is happening due to climate change

The general rise in temperatures resulting from global warming is apt to affect the efficiency of employees in their workplace. Scientific research exploring the scenario prevailing in central Europe has indicated that productivity at work – depending on the intensity of heat stress – can in some cases fall by up to 12 %. For 2018 and 2019 it was estimated that – on the basis of this assumption – direct damage resulting from productivity losses owing to summer heatwaves amounted to a total of 5 billion Euros.[173] Looking towards the future, residents in Germany expect that stress from summer heat at their place of work – both within buildings and outdoors – will increase, thus affecting their productivity either severely or very severely (cf. Indicator IG-I-1, p. 264).

Summer heat, combined with extended drought periods, was also one of the main reasons why the Rhine was subject to an unusually long phase of low-water levels in late summer and autumn 2018. Consequently, this led to draught restrictions having to be imposed on inland shipping. As a result, goods transport on the Rhine was for a long time possible only to a limited extent, thus declining compared to 2017 by 11.1 % (cf. Indicator VE-I-2, p. 249). 2018 witnessed the beginning of a prolonged drought period which impacted companies active in various industries. Apart from goods transport, these impacts also included a reduced availability of coolant and production water as well as restrictions on the discharge of waste water and heated coolant water.

Future climate risks – outcomes of KWRA

In respect of the action field 'Trade and industry' the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7) identified high risks with regard to three climate change impacts. As expected, there is a high risk of impacts on goods transport via inland shipping lanes by the middle of the 21st century. This also applies to a high risk regarding impacts on the supply of raw materials to companies and the supply of intermediate products from abroad such as coffee, cacao or cotton. However, as far as the last-named climate change impact is concerned, a low degree of certainty has to be taken into account. Moreover, a high risk of productivity losses is expected to affect employees by the end of this century. In the run-up to the middle of this century the relevant risk – according to a three-tier assessment grid (low – medium – high) – is assessed as medium.

As far as other relevant climate impacts on trade and industry are concerned, the risks expected to arise by the middle of this century are also categorised as medium. This refers to adverse effects on the international goods transport and the release of hazardous substances. Furthermore, a medium climate risk is estimated to arise with respect to international sales markets, adverse effects on land-based goods transport and increased demand for the supply of water by the middle of this century. However, these estimates are subject to low certainty; the same applies with regard to the medium risk estimated for adverse effects on production processes estimated to occur by the end of this century.

Where do we have gaps in data and knowledge?

It should be noted that companies in the field of trade and industry can be affected by climate change impacts – and any ensuing requirements for adaptation – in very different and highly specific ways. Both factors depend, among other aspects, on the size of the enterprises concerned, their location, the type of products and services offered, and it also matters to what extent they are integrated in regional, national or international production and supply chains. Economic data available in official statistical records in respect of climate change impacts do not permit interpretation, primarily as they are influenced by multifaceted factors. Apart from official statistics, there are only few sources reporting in a synoptic way on the basis of quantitative data in respect of trade and industry. These sources define the companies considered in different ways, for example regarding size or branch of industry; it follows that also the frames of reference used as the basis for indicators tend to differ. Consequently, the significance and comparability of any data available are limited overall.

Currently, there is a complete lack of any data-based representation of weather- and weather-pattern related physical damage to buildings, premises or infrastructures owned by companies. Unfortunately, it is not possible to illustrate this scenario in a similar way to the action field 'Building sector' – regarding the extent to which companies have been affected by weather and weather-related events as far as the development of insured damage is concerned – because businesses tend to insure specific risks according to their particular requirements rather than signing up to any standardised insurance products. So far there seem to be no representative surveys available regarding weather or weather-pattern related physical damage that might provide an alternative source of information.

Another potential source of relevant information might be a continuous collection of data on the impacts of heat on the efficiency of employees. The Länder's health reports provide a starting point for this as they present data collected on four occasions in the period from 1998 to 2018. A sub-indicator contained in these health reports covers the environmental conditions at the workplace on the basis of a survey conducted by the Federal Institute for Vocational Education and Training (BIBB) and the Federal Institute for Occupational Safety and Health (BAuA). This includes the parameter concerning heat. However, these data cannot be used unless they are subjected to some fine tuning. There is no data collection available illustrating any heat-related absences from the workplace or heat-related accidents.

Neither is there a data source available for an illustration of economic impacts of low-water levels on production and supply chains. So far some information on this subject has been collected in the course of studies, but it is few and far between.[174] In order to obtain reliable data for a description of this scenario, it would be necessary to develop a continuous and regular collection of data. This is true likewise for any impacts of meteorological events on the international flow of goods and, generally speaking, for the security of supply in terms of raw materials and intermediate products or distribution channels used by companies.

Moreover, there are crucial data gaps regarding evidence of actual adaptation activities and measures taken by companies, for example, in respect of hazard prevention or emergency provisions for safeguarding production processes or for the protection of industrial and processing plant. In accordance with new sustainability reporting obligations on the basis of the Corporate Sustainability Reporting Directive (CSRD) – comprehensively supplemented in 2022 – and the EU Taxonomy Regulation, companies will in future have to declare their climate-related risks and measures; this involves, among other things, carrying out systematic climate risk and vulnerability analyses of their taxonomy-compliant economic activities. This promises to bring about a much improved data scenario in the future.

Generally speaking, the indication of climate change impacts and entrepreneurial responses for the purpose of adaptation are confronted with difficulties owing to the fact that there are always several influencing factors interacting in complex ways. For example, apart from climate change, businesses are facing many other strategic challenges. Apart from an increasing shortage of skilled employees in a growing number of sectors, this also includes the aftermath of the Covid-19 pandemic and the energy-price crisis resulting from the war in the Ukraine. These crises have demonstrated convincingly to what extent companies are affected in their business activities when national and international production chains and the flow of goods stop functioning smoothly.

What's being done – some examples

As far as companies in the field of trade and industry are concerned, it is a vital prerequisite for executives to hone their awareness of climate-related risks that might threaten their company's economic activities. If physical climate risks are ignored or if companies do not adequately recognise any direct and indirect consequences of extreme weather events and associated impacts as well as any gradual changes in climatic conditions, it is most likely that preventive measures will either fail or prove to be inadequate. However, the potential consequences of inadequate provision can also go beyond individual companies when they affect production and supply chains as a whole (cf. Indicator IG-R-1, p. 266).

There is no doubt that physical climate risks exist for Germany's export-oriented national economy in respect of climate impacts not only inland but also abroad. Given the great importance of export trade, international sales markets and international production and supply chains, the global dimension of climate risk is no less relevant. An assessment of the exposure to climate change of Germany's foreign trade shows that roughly one third of the country's 35 most important international trade partners outside the EU are located in countries faced with a particular climate risk. The volume of foreign trade with those countries and its proportion of all imports and exports has increased since 2008 (cf. Indicator IG-R-2, p. 268). Owing to the globally increasing impacts of climate change, it is possible that the number of foreign trade partners facing a particular climate risk may rise too. Overall it is to be expected that strategies aiming at an appropriate handling of cross-border climate risks will gain in importance. Such strategies might benefit from including a more detailed differentiation of trade relations or risk-mitigating measures in specific countries particularly exposed to the hazards of climate change.

To the same extent as individual companies may be affected by various potential climate change impacts, there may also be differences in the requirements they face in order to adapt to changing climatic circumstances. At least in parts, any existing regulations will dictate the relevant framework or prompt the implementation of measures. This applies, for example, in respect of the impacts of heat on employees. For employees who work in buildings, the relevant workplace regulations stipulate various requirements to be met in order to maintain employees' good health and their efficiency while outdoor air temperatures are high. For outdoor work the industrial safety legislation stipulates appropriate measures. Adaptation measures also play a role with regard to standardisation. For example, DIN and ISO standards to be observed by companies constitute important working requirements in respect of the implementation of measures for adaptation to climatic conditions[175].

A provident use of resources such as water – which is potentially becoming scarce – is also of benefit to businesses. In the processing industry water efficiency, in other words the value added per unit of water, has already been increasing since 1991, and water procurement has decreased (cf. Indicator IG-R-3, p. 270). This is to be seen as positive in the context of climate adaptation as water-saving companies are generally better equipped to withstand the impacts of heat and drought. In cognisance of the fact that this industry is among the sectors using large volumes of water, the National Water Strategy contains objectives and measures intended for trade and industry. These include minimum standards stipulating an efficient utilisation of water, examining opportunities for the increased use of process water, rain- or grey water and for the advanced development and harmonisation of water abstraction remuneration.[176]

In order to support companies, the UBA has been providing since 2022 – with reference to EU taxonomy regulations – recommendations for establishing a legally compliant climate risk and vulnerability assessment to serve as an essential foundation for the systematic climate risk management in companies[177]. Building upon this, a brochure is available which provides useful information enabling a company to integrate climate risk management in its organisational structure.[178]

Furthermore, many Länder provide information materials on the adaptation to climate change for companies; in addition, many Länder organise company networks on the subject of adaptation to climate change. These networks provide support to companies if they have questions regarding the analysis of issues arising in-house or in respect of appropriate precautionary measures and associated finance.

Climate changes relevant to the action field

State

Photo: © Sergei Malkov / stock.adobe.com

Hot days, soil humidity

Germany is experiencing an increase in the frequency of hot and dry years. Prior to 2014 there were no years in which the annual mean temperature exceeded 10 °C. With regard to the period since 2018, the annual mean temperature – only for 2021 – was still below this value. In 2018 and 2022 the highest value so far was reached amounting to 10.5 °C in both years. In parallel with increasing mean temperatures, the frequency of hot days on which the temperature rises to 30 °C and above is also increasing. Nationwide Germany now has on average roughly 10 hot days per annum compared to 3 hot days in the middle of the 20th century (cf. figure 5, p. 23). When high temperatures occur in tandem with negligible precipitation in summer as for instance in 2018, 2019 and 2022, this can entail intensive and also prolonged dry phases.

Impacts of climate change

Impact

Photo: © Sebastian / stock.adobe.com

WW-I-10: Water temperature of watercourses

As air temperature rises, the temperature of watercourses rises too, especially when water levels are low owing to drought. In all regions where fish occur – except for the grayling region. The temperature of watercourses increased significantly in past decades. Extremely high water body temperatures and associated lack of oxygen as in 2018 have massive ecological impacts. In order to protect watercourses, any water use in trade and industry for production or cooling purposes is subject to an appropriate licence. This licence stipulates at what temperature, quality and volume water can be fed back into the water bodies after utilisation. This occurred, for example, in the hot summers of 2003, 2006, 2018 and latterly 2022, when owing to prolonged heat and drought, restrictions were imposed on thermal discharge into various water bodies. Some companies, for example those active in the chemical industry, had to curtail their production thus enabling them to continue meeting the discharge conditions laid down in their licence.

Adaptations – activities and results

IG-R-3: Water procurement in the processing industry

In particular regarding water-intensive industries such as the chemical, metal or paper industries, the reduction of water demand is an important measure in order to increase resilience and to reduce dependence on water resources. In order to use as little water as possible in terms of raw or processing material, and in order to use the abstracted water as efficiently as possible, companies might for instance consider – within the framework of their environmental management – embracing an in-house water management system, using water in a circulatory system, employing water-saving technologies or using other substances such as emulsions in lieu of water. Overall, water procurement in the processing industry decreased significantly since 1991, although this decrease has slowed down since 2001. As far as government support is concerned, the saving of water in trade and industry can be strengthened by incentives and minimum standards, for example by stipulating a minimum standard for efficient industrial water use as defined according to the current state of the art.

Response

Photo: © Ratchapon / stock.adobe.com

Impacts of high temperatures on efficiency

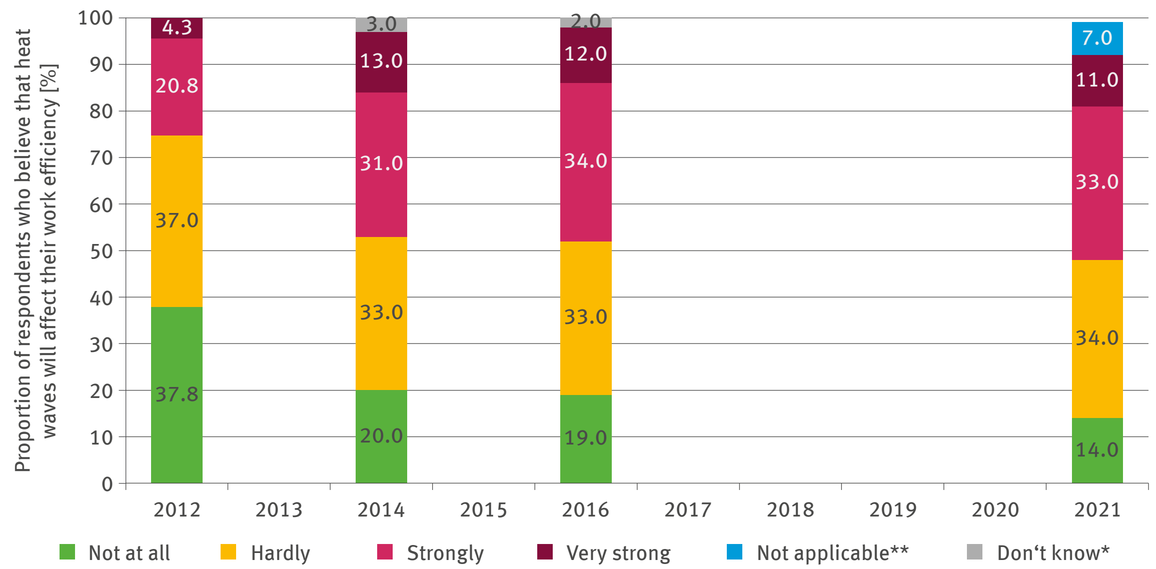
Rising temperatures and increasing absolute air humidity impact strongly on the health and efficiency of workers. The effects arising are not limited to increased morbidity: diminished concentration is an effect that can make them more prone to making mistakes or having accidents thus also affecting efficiency.[179] Extreme heatwaves entail additional health risks: When external temperatures rise beyond the humanly tolerable setpoint temperature of 37 °C, the body can only retain its core temperature – thus remaining in a healthy state – by means of perspiration. High air humidity and any necessary work clothing can restrict the evaporation of sweat thus also restricting the body's ability to control its temperature. This can result in severe dehydration, heat exhaustion, sunstroke or heat collapse. Likewise, an increase in body temperature to a life-threatening extent beyond 40 C is conceivable under adverse conditions which can lead to a life-threatening heat stroke.[180]

In respect of indoor workplaces many studies showed a significant link between efficiency and the so-called thermal comfort zone. If room temperatures depart from this optimum either downwards or upwards, efficiency will decrease. The climate of a room is termed thermally comfortable when a human being perceives air temperature, air humidity, air circulation and heat radiation in their immediate environment as optimal and they do not wish for the air in the room either to be warmer, colder, drier or more humid. For the summer months, temperatures between 23 °C and 26 °C are considered comfortable for employees in light and sedentary occupations. Measures to provide heat protection in summer (for instance shading or air conditioning by means of energy-efficient regenerative cooling technologies in indoor work spaces can help to keep temperatures within this range and to maintain a climate-friendly condition.

In Germany there are approximately 2 to 3 million people who work predominantly or at least some of the time outdoors. They are exposed to the prevailing weather conditions and weather patterns all year round. Increased stress from heat exposure, natural UV radiation and other climatic changes clearly affect these people more directly than people who work indoors. These outdoor activities

IG-I-1: Heat-related decrease in efficiency

Global warming may in future increase exposure to summer heat at the workplace, both indoors and outdoors. More than 40 % of respondents to the environmental awareness study expect that heat will in future either strongly or very strongly affect their efficiency at the workplace. The industrial safety legislation requires that measures be taken in order to safeguard an indoor climate in work spaces that is beneficial to health.



* since 2014
** since 2021

Data source: BMUB/BMUV & UBA (study ‚Umweltbewusstsein in Deutschland', for 2021: additional survey in the framework of the study ‚Umweltbewusstsein in Deutschland 2020')

contribute approximately 10 to 15 % of value added to the national economy – primarily in the sectors of agriculture, forestry, construction and in some segments of the industrial and services sectors.

A comparison of the findings from the studies entitled 'Environmental awareness in Germany' covering the period from 2012 to 2021 shows that since 2014 a consistently high proportion of more than 40 % of respondents expect that their efficiency at their workplace will be strongly or very strongly affected by rising heat stress in future. In 2021 this proportion amounted to 44 %.[181] In 2012 just a quarter of respondents expected such heat-related impacts on their efficiency at their workplace.

An employee's thermal comfort influences their working capacity thus exerting a direct influence on a company's productivity and thus ultimately on the productivity of the entire national economy. Studies have inferred that times of high heat stress in Central Europe are the consequence, among other factors, of reduced concentration and resulting mistakes as well as greater frequency and severity of accidents at work causing associated productivity losses up to 12 % and that the extent of expected losses are at least in part due to the intensity of heat stress.[182] On the basis of these assumptions, it was estimated that the impacts on labour productivity in 2018 and 2019 were due to summer heatwaves. Given the number of hot days recorded and with due consideration of differing possibilities for adaptation in different industries, the direct damage attributable to heat-related production losses in those two years was estimated to total 5 billion Euros. In addition, the estimate also included indirect damage, for example, caused by missing, delayed or poor-quality preliminary work in a value of 3.5 to 5.3 billion Euros thus resulting in overall damage for the two years in the range of 8.5 to 10.3 billion Euros.[183] However, these estimates are subject to considerable uncertainties. In fact, some studies suggest, for instance in the construction sector, that productivity might even rise, as climate change increases the length of periods available in the course of a year.[184] In sum, there is no clear picture emerging with regard to climate change impacts on productivity and economic efficiency.

The relevant workplace regulations stipulate various requirements to be met in order to maintain employees' good health and thus their efficiency while working indoors even while external air temperatures might be in excess of 26 °C. Whenever the indoor air temperature in work spaces exceeds a threshold of 26 °C or 30 °C, it is essential, if not mandatory, to take appropriate measures. Companies can, for example, ensure that suitable sunshading is installed and is used to best advantage, that the premises are

Summer heat can entail distinct losses in labour productivity. (Photo: © Andrey Popov / stock.adobe.com)

adequately aired in the early mornings, interior heat loads are reduced, working hours are shifted and refreshing drinks are made available. It may also be appropriate to relax any existing dress codes. In this case, priority should be given to taking technical measures such as using fans, as well as organisational measures such as breaks in cooler rooms rather than taking person-related measures. At temperatures in excess of 35 °C, the work space is no longer suitable, unless measures are taken with regard to work in typically hot environments.[185]

Similarly, for working outdoors, industrial safety legislation also requires that measures be taken to protect employees from adverse impacts on their health caused by heat. For example, on building sites employers can give instruction for shading or ventilation units to be installed in order to provide adequate working conditions. Above all, employers can take organisational measures by adapting working hours to the prevailing weather patterns, by arranging for sufficiently long breaks, making sure there is an adequate supply of refreshing drinks available, and ensuring that employees, as part of their training, are made aware of potential hazards and any appropriate countermeasures they can take for their own protection.

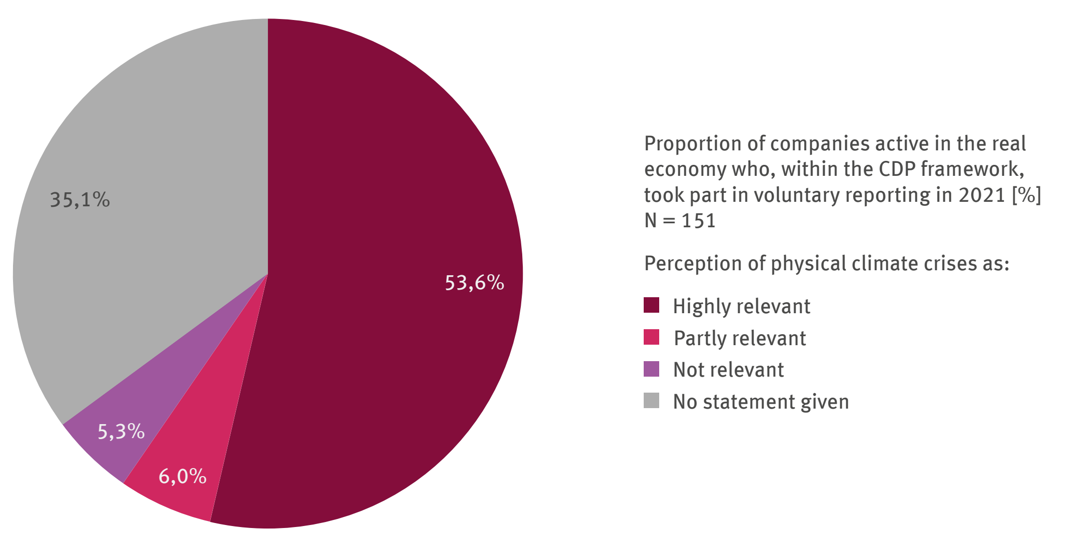
Companies' perceptions of climate-related risks

Climate change, with all its associated consequences, entails substantial damage to the national economy and confronts some companies with major challenges. Owing to climate change, their business activities are exposed to a variety of risks. Temporary or transition-related risks arise for companies from the pressure for action resulting from climate-related changes in terms of political and legal framework conditions, new technological challenges and increasing social expectations. If they fail to assess the changed market environment correctly, if they don't respond fast enough or if they lack flexibility to engage in co-designing the transition to sustainable management, this can inflict considerable commercial losses on them. Other relevant risks include physical risks that can result from extreme weather and weather-pattern events or creeping environmental changes. Potential impacts include for instance productivity losses, damage to buildings, changes in demand or adverse effects on supply chains (cf. Indicator IG-R-2, p. 268, VE-I-1 and VE-I-2, pp. 248 and 249).

Not just the world of politics and society, but also the world of finance and the capital markets – which provide companies with equity capital or borrowed capital – are keen on being able to assess the stability of companies. For this purpose, it is increasingly relevant to companies to be aware of any climate-related risks and to implement preventative measures (cf. Indicator FiW-R-1, p. 294). The CDP (formerly Carbon Disclosure Project) began 20 years ago to set up a database with information on companies' climate-related burdens. The information is supplied by companies on a voluntary basis. While initially the focus was on reporting climate-damaging greenhouse gas emissions, by now other environmental impacts are added to the database including information from companies active in the water industry and in the forestry sector. For the sub-database on climate (abbreviated to CDP-Klima) companies are asked to supply, on an annual basis, statements on greenhouse gas emissions, physical and transitory climate risks and on organisational arrangements for precautionary measures. In 2021 151 companies also provided statements – within the framework of their voluntary participation in CDP – on how they rated

IG-R-1: Perception of the relevance of physical climate risks in trade and industry

A company's inadequate awareness of physical climate risks suggests that the necessary preventative measures are not taking place. Of 151 companies which voluntarily submitted a report to CDP, a good half of those rated the relevance of physical climate risk as high. If stricter requirements are stipulated for reporting the statements made will in future gain in validity.



Data source: database CDP Klima
(analysis of data records from the demo version by Bosch & Partner GmbH)

the physical climate risks to their business activities. This included 23 companies that are part of the DAX-40 group as well as other larger and medium-sized enterprises. More than half of them rated the physical climate risk as highly relevant, compared to just 5 % that reckoned they were not relevant. The higher the proportion of companies rating physical climate risks as relevant, the higher is presumably the probability that those companies will make efforts to mitigate the material physical risks.

Nevertheless, the 2021 CDP findings should not be considered representative of German companies in general. On one hand, it is only a minor number of companies that takes part in reporting. On the other, it can be assumed that the outcomes of the survey overestimate the general perception of physical risks, because the companies that submit voluntary reports to CDP presumably engage more strongly with the issues concerned than those who do not participate in CDP. Moreover, there are presumably variations from sector to sector, that are not taken into account in this context. For example, companies that generate or process agricultural raw materials are likely to be exposed more strongly to physical climate risks than for instance software businesses. There are other studies, however, which have worked with larger data pools and still arrived at basically similar findings.[186] According to these findings, physical risks are not categorically overlooked, but most companies examining climate-related risks perceive the greater risks to be involved in the transition to a CO_2-poor or CO_2 neutral economy.

In view of the economic risks that can arise from inadequate risk awareness and lack of appropriate preventative measures, the Federal government is very keen on making every effort in continuing to raise companies' awareness of these risks. Clear regulations pertaining to companies' obligations for reporting and the submission of declarations can make a useful contribution to these endeavours. Since the middle of the 2010s, the 'Financial Stability Board' (FSB) has been working for the G20. The FSB has set up the Task Force on Climate-related Financial Disclosures (TCFD) which is composed of experts from the real and financial economies. In 2017, the TCFD submitted recommendations to make the reporting mandatory in future – including issues such as governance; in other words, regarding competencies among board members and individuals at the highest executive level – in respect of climate-related matters and risk management.[187] The TCFD recommendations were adopted at EU level. Consequently, the 'Corporate Social Responsibility' directive (CSR Directive) – in existence since 2014 – was comprehensively revised and enhanced in 2022 under the title of 'Corporate Sustainability Reporting

The awareness of physical climate risks enables companies to take precautionary countermeasures.
(Photo: © CinemaF / stock.adobe.com

Directive – CSRD'. This process resulted in distinctly expanded non-financial reporting obligations imposed on companies and on the circle of individuals with reporting responsibilities. Reporting obligations come into force starting with the beginning of the 2025 business year and are applicable to all major companies with at least 250 employees, and – starting with the beginning of the 2026 business year – also to small and medium enterprises (SMEs) listed on the stock exchange.

The CSR Directive or rather the new CSRD is closely bound up with the EU Taxonomy Regulation which has been in force since 2020. Consequently, companies active in the real economy will have to state – as they are obliged to report under the CSR Directive or rather the future CSRD – in their non-financial declarations, which proportions of their turnover, their investment expenditure and certain operating expenses are related to their taxonomy-compliant economic activities. Associated with this is also the requirement to carry out a systematic climate risk and vulnerability analysis relating to these economic activities.

It is to be expected that in future, as a result of the extended reporting obligations, in future risk awareness and prevention in respect of climate risks will be improved across the entire company. Furthermore, the disclosure regulations might help to improve data availability thus making it possible to further develop the indicator described in this context.

Climate risks to Germany's foreign trade

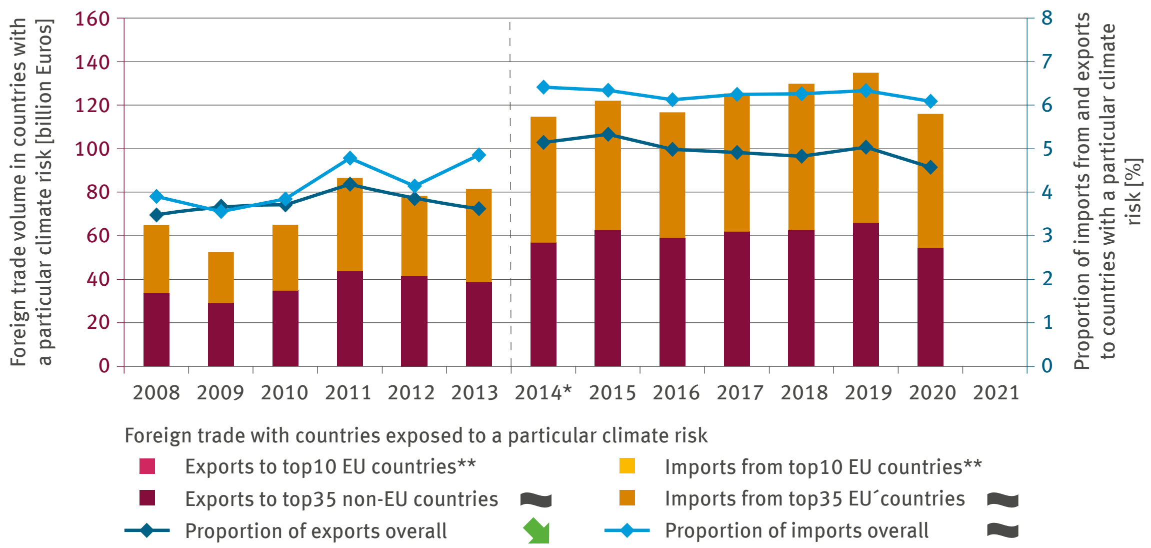
Germany's economy is strongly intertwined with the economy of other countries. In 2021 companies based in Germany exported goods and services totalling a value of 1,379 billion Euros, while imports amounted to 1,204 billion Euros. Roughly 30 % of the Gross Domestic Product is due to demand from abroad, while roughly one quarter of the working population in Germany is active in export-related occupations. In other words, Germany has on one hand opened up international markets for her products at a major scale. while on the other, the country obtains, also at a major scale, raw materials, intermediate and end products from other countries. The strong export focus has for decades been a successful model for the German economy. Apart from geopolitical risks – such as armed conflicts or international legal conflicts – the impacts of global climate change therefore entail particular risks for the German economy.

Climate change is a global phenomenon. Extreme weather events and associated impacts have been occurring worldwide more frequently and with greater intensity. In the same way as gradual climatic changes, they affect all countries, regardless of political borders. As far as the globalised economy with its far-reaching worldwide interrelations is concerned, this can bring about both direct impacts, for instance at sites close to home, but also indirect impacts, for instance when supply chains or sales channels are affected or entire sales markets are permanently weakened. This applies all the more, the more closely trade relations are intertwined and especially when trade partners are countries which are exposed to a particular climate risk. In respect of Germany, scenario-based analyses have shown via the world trade that climate change impacts arising outside Europe have a greater impact on Germany's national economy than climate change impacts within Europe. Furthermore it came to light that imports are more exposed to risks than exports.[188]

The indicator examines the question – which actual trade volume and which percentual proportions of exports from and imports to Germany regarding the trade with partner countries are exposed to a particular climate risk. The assessment of the climate risk prevailing in individual countries is based on the ND-GAIN Index which

IG-R-2: Exposure of Germany's foreign trade to global climate change

By contrast, roughly a third of the 35 most important trade partners outside the EU are among the countries exposed to a particular climate risk. The proportion of exports to countries with a particular climate risk compared to exports overall declined significantly since 2015. For the other time series, it has not been possible to identify a trend. Among the 10 most important foreign trade partners in Europe there are no countries exposed to a particular climate risk.



* Change in the assessment method used for ND-GAIN Index
** To date there have been no countries with a particular climate risk among the top10 trade partners in the EU. They are therefore not illustrated in the chart.

Data source: StBA (Aus- und Einfuhr (Außenhandel)), University of Notre Dame (ND-GAIN-Index) is calculated by the Global Adaptation Initiative at the University of Notre Dame (USA). The index is determined based on indicators, and it encompasses the vulnerability of countries to climate change and other global challenges as well as their preparedness to confront those challenges in terms of investments and by increasing the countries' resilience vis-à-vis those challenges. A particular climate risk has been attributed to those countries which are not among the first-named 75 countries covered by the ND-GAIN Index. European countries have comparatively strong opportunities at their command enabling them to deal with climate change. Consequently, there is usually no particular risk attributed to EU countries. In due consideration of the relevance of the countries involved in trading with Germany, the data on exports and imports as contained in the StBA foreign trade statistics are incorporated in the indicator. Taken into consideration are the 10 most important trade partners within the EU who have a proportion of Germany's foreign trade volume with EU states amounting to roughly 84 % as well as the 35 most important trade partners outside the EU with a proportion of Germany's foreign trade volume with non-EU states amounting to approximately 96 %. Exports and Imports are each dealt with separately and with reference to individual years. On the basis of this aggregate information it is possible to see in what way – with reference to the most important trade partners – the exposure of Germany's exports and imports to climate change is developing.

The findings show that none of the 10 most important trade partners within the EU have a low ND-GAIN index. By contrast, roughly a third of the most important trade partners outside the EU are among the countries with a particular climate risk, such as India or the Republic of South Africa. Overall, there are more countries supplying Germany with goods than countries importing goods from Germany. Owing to a methodological change that involved a sub-indicator of the ND-GAIN Index from 2014 onwards, there are limitations to the assessment of the chronological development of the indicator. The change resulted in a higher risk assessment of three major foreign trade partners of Germany: Brazil, Mexico and Indonesia. Consequently, a higher climate risk was attributed to a major part of the foreign trade. This is the reason for the discontinuity in the time series covering 2014. With regard to the short period since 2014 it is possible to see that the proportion of exports in respect of countries exposed to a particular climate risk to exports overall decreased significantly. As far as the other time series are concerned, it has not been possible to discern a trend for the period in question. The decrease in the period from 2019 to 2022 can be attributed to a decline in the foreign trade volume in the course of the Covid-19 pandemic.

Climate risks can affect both global supply chains and value added chains. (Photo: © m.mphoto / stock.adobe.com)

Another point to be borne in mind regarding the interpretation of the indicator is the fact that the indicator covers a purely theoretical, potential exposure to climate change impacts. The indicator does not make a statement regarding the extent to which imports to or exports from countries exposed to a particular climate risk have actually been or still are affected by climate change impacts. Neither does the indicator permit to assess whether imports from or exports to particularly vulnerable regions within the countries concerned are indeed emanating from those regions or are to be supplied to these regions. The indicator considers the countries in question in their entirety, regardless of climate risks that might differ from region to region. Furthermore, even imports from and exports to countries not currently considered to be exposed to increased climate risk, may become affected by climate change impacts, either on location or on the supply channels used for the products in question.

That notwithstanding, an increasing volume of potentially affected goods flows can be seen as an indication of a greater need to focus specifically on cross-border risks of climate change and to plan appropriate measures – for example, greater differentiation of trade relations at the company level[189] or – at the political level – financial aid for risk-mitigating measures to countries that are particularly at risk from climate change and are relevant to Germany's foreign trade[190]. However, there are also export opportunities for Germany if it can supply goods to countries particularly exposed to climate change if these goods can be used there for adaptation to climate change.

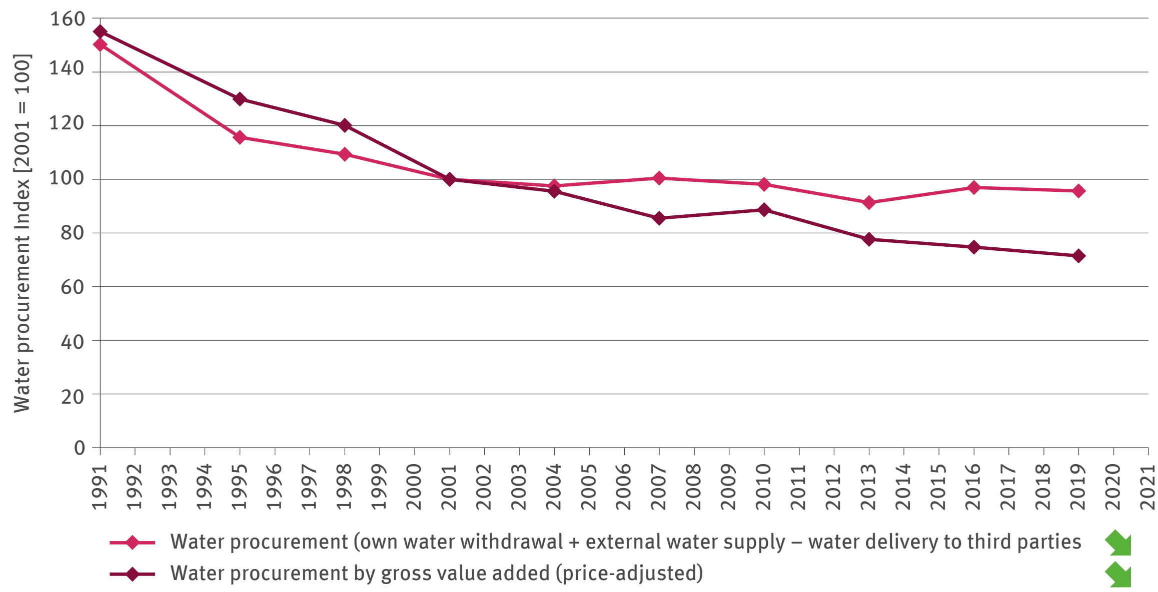
Economical use of water supports adaptation to climate change

Any thermal discharge from industrial and commercial enterprises is subject to the same legal regulations as energy plants. Therefore, industrial and commercial enterprises might encounter situations where they have to decrease their thermal discharge thus reducing their productive output in order to comply with the discharge conditions laid down in their licence. This risk often perceived as an abstract concept actually arose, for example, in the hot summers of 2003, 2006 and 2018, when owing to prolonged heat and drought, restrictions were imposed on thermal discharge into various water bodies. In the summers of 2020 and 2022 production activities did not have to be reduced. However, for the river Rhine warning level 1 was declared owing to high water temperatures.

The changing climatic conditions may lead to such dry and hot phases occurring more frequently in future, becoming more intensive and more prolonged. As shown by the hot and dry summers of recent years, the heat can also cause the temperatures in watercourses to rise in summer months (cf. Indicator WW-I-10, p. 88) and discharge volumes decrease (cf. Indicator WW-I-3, p. 74). Apart from challenges caused by low water levels (cf. Indicators WW-I-6, p. 80 and VE-I-2, p. 249) situations may arise more frequently where feeding back used and heated coolant water or the abstraction of water for cooling purposes would be permitted only in limited amounts. Industrial processes that are, as far as possible, independent of water resources are better equipped for the impacts of climate change than processes which require a lot of water. In order to use as little water as possible in terms of raw or processing material, and in order to use the abstracted water as efficiently as possible, companies might for instance consider embracing an in-house water management system, using water in a circulatory system, employing water-saving technologies or using other substances such as emulsions in lieu of water.

IG-R-3: Water procurement in the processing industry

Water-saving enterprises are better equipped to cope with the impacts of climate change. In the processing industry, water procurement decreased significantly since 1991. However, this decrease was less significant from 2001 onwards. If one relates the water procurement to the gross value added, a stronger, equally significant decrease becomes apparent. This means that more value is generated with the same amount of water – in other words, water is used more efficiently.



Data source: StBA (Nichtöffentliche Wasserversorgung und Abwasserentsorgung; Volkswirtschaftliche Gesamtrechnungen)

An important starting point for the processing industry in this context is, above all, the economical use of coolant water in production processes and regarding in-house energy production. Currently, coolant water use accounts for roughly three quarters of the entire water use in this sector. Besides, the abstraction of water for refrigeration purposes and the discharge of used coolant water are subject to temperature-related regulations, which may lead to restrictions being imposed on production during hot summer months. The abstraction of water for production-specific or personnel-related purposes, however, is less dependent on temperatures.

The water procurement in the processing industry is composed of a company’s own water withdrawal plus their external water supply, for instance from the public water supply or from other companies, facilities and associations, minus water delivery to third parties. After 1991, water procurement first decreased considerably. At that time, it amounted to 700 million cubic metres, still approximately 50 % more than the procurement in 2001. Ever since, the value has been fluctuating around 5,500 million cubic metres annually.

If one relates water procurement to the price-adjusted valued added, the strong decline in the years after 1991 continues also after 2001. In the processing industry the water procurement in 2019 amounted to almost 30 % below the value of 2001. This means that it was possible, even after the turn of the millennium, to attain a continuous increase in the efficiency of water use and – at an almost identical volume of water – it that it was possible to generate greater added value. At the same time, however, the figures also show that in the processing sector, despite a distinctly rising value added, it was still possible to reduce the water procurement slightly overall since 2001.

Heat and drought impose restrictions on companies regarding water abstraction from and discharge into water bodies – this can in turn restrict production outputs.
(Photo: © Ratchapon / stock.adobe.com)


Photo: © Volker Loche / stock.adobe.com

Tourism industry

On the relevance of the action field

Germany's tourism industry is a lucrative sector and plays an important role in Germany's macroeconomics. In 2019 the industry – with 2.8 million employees – generated profits amounting to just under 124 billion Euros. This equates to some 4 % of Germany's entire Gross Value Added. The proportion of employees in this industry compared to the overall number of economically active individuals in this country amounts to 6.1 %.[191] Germany offers a wide range of tourism options in all parts of the country – from health tourism to activity holidays, nature tourism, river-based types of tourism, city and cultural vacations as well as business trips. The structure of the tourism sector is characterised by small and medium-sized businesses. It comprises accommodation and catering businesses, travel agencies, travel organisers, companies providing tour and transport services as well as operators of tourism infrastructures or centres in the fields of sports, culture, health and wellness, and notably also business trips, congresses and meetings. The German Länder, districts and municipalities are committed to tourism in their respective regions and are actively involved in the marketing of tourism ventures. Germany's broad spectrum of touristic offerings is much in demand both among foreign visitors and, above all, among travellers and people from our own country seeking recreation.

Supply and demand in various tourism subsectors and destinations in Germany are in various degrees subject to the weather and weather patterns. Some segments of the tourist industry such as shops and the congress business – being indoor activities – are not much influenced by external conditions whereas, a concrete demand regarding an intended vacation date relating, for instance, to winter sports or outdoor bathing, is evidently more closely bound up with suitable weather patterns. Largely independent of location and type of tourism, a tourism-related infrastructure can be exposed – for reasons of climatic conditions – to increasing physical risks from extreme weather events. As a rule, the response required from the tourism industry in Germany vis-a-vis such challenges, will have to be specifically tailored to the relevant type of tourism, with due consideration of concrete impacts from climate change on the target activity.

DAS Monitoring –what is happening due to climate change

Progressive climate change has already begun to change the meteorological conditions for tourism in Germany. As far as coastal regions at the North Sea and the Baltic Sea are concerned, conditions have been improving. In those areas – subject to strong fluctuations from year to year – the periods of time in which sea water temperatures remain comfortable enough for bathing, are becoming longer. In both of these regions, the first potential 'bathing days' occur earlier and earlier every year, while the last suitable days of this kind occur later and later, extending into autumn. Moreover, the average air temperatures in the summer-holiday months of June to September have been increasing (cf. Indicator TOU-I-1, p. 278). Snow conditions in the ski tourism areas of Germany fluctuate significantly from year to year. To date it has not been possible in an aggregated form, to determine a statistically reliable trend for ski tourism areas in terms of the number of days on which a natural depth of snow amounting to at least 30 cm is reached. The Black Forest as well as the western and central upland regions have been experiencing extended phases of snow-poor winters. In the Alps and the eastern uplands snow-poor winters have so far been occurring just sporadically (cf. Indicator TOU-I-2, p. 280).

It has so far not been possible to discern any influence of changed meteorological conditions on the market shares of wider tourism areas in respect of bed-night volumes. This observation matches the findings of a research project conducted by UBA. While it is true that current weather events can influence demand considerably both in the short term and regionally, it has so far not been possible to discern any distinct impacts from changing climate parameters on demand in tourism[192]. The Indicator TOU-I-3 (cf. page 282) shows increasing demand for bed-nights in urban areas at the expense of other wider tourism areas. The development in 2020 and 2021 was influenced primarily by the Covid-19 pandemic. In both years, the general decline in bed-night volumes affected urban areas in particular, in contrast with holiday regions, above all on coasts and in the Alps, which benefited from this development.

Future climate risks – outcomes of KWRA

According to the findings presented by the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, page 7), there is a major risk for the action field 'Tourism Industry' – expected to develop towards the end of this century – that tourism offerings will suffer restrictions owing to lack of confidence in adequate snow cover. Likewise, it is estimated that, by the end of this century, there will be high risks of damage to tourism infrastructures and operational disruptions as well as high possibilities of risks to the commercial success of tourism providers. However, both estimates are considered to be affected by low certainty. In the run-up to the middle of this century the risks relating to these climate impacts are assessed by means of a three-tier assessment grid (low – medium – high). The same applies to the risk of impacts from great heat on health tourism and the risk of shifts in demand. As far as the two last-named climate impacts are concerned, there is some certainty regarding the assessment.

Where do we have gaps in data and knowledge?

Monitoring the action field 'Tourism industry' is severely limited owing to a lack of available data. This is partly due to the fact that the discussion on climate change impacts on tourism frequently refers to specific segments of the tourism industry – for example nature tourism, health tourism, cycling tourism or the bathing tourism in inland areas. These segments are either not at all or just partially reflected in any available data collected on a regular basis, which is why they cannot be described quantitatively. There are data available which are collected on a regular basis for official tourism statistics at the level of municipalities, districts and travel areas or with regard to municipality groups dealing with the catering trade. Data on occupancy rates in accommodation facilities are particularly useful for a regionally differentiated description of touristic demand. However, an unequivocal attribution of municipalities, districts or travel areas to specific tourism segments or to one particular focal segment is not possible. Consequently, the available statistical data do not permit drawing any inferences regarding the development of individual tourism segments, let alone how these may have been influenced by climate change impacts. For the Indicators TOU-I-3 and TOU-R-1 the travel areas have been attributed to five major tourism areas[193], which allows making a (rather indistinct) connection, between the travel areas concerned and their natural area potentials. It should be borne in mind that, apart from circumstances prevailing in natural areas, the demarcation of travel areas also relates to the memberships maintained by the relevant municipalities, districts and counties in various tourist associations. The travel areas therefore encompass zones characterised by different touristic offers according to the degree in which they are affected by climate change; in Baden-Württemberg, for example, this applies to parts of the Upper Rhine Rift valley and parts of the Black Forest. Any interpretation of data on touristic demand (such as bed-nights) in respect of climate change impacts on the travel areas and wider tourism areas is therefore possible only to a rather limited extent.

Apart from bed-night tourism, day tourism is also of major economic importance. As far as climate change impacts are concerned, the latter is of particular interest, as for day trips the weather pattern is of crucial significance. However, in order to ascertain the relevant changes in demand, regional data on day tourism (for example in respect of occupancy rates of the tourism infrastructure) would be required in addition to the statistical data on accommodation. Unfortunately, such data are either not collected continuously or not accessible in one central database.

Travellers and people seeking rest and recreation take a multitude of factors into account in making their travel decisions. The climatic conditions and any relevant changes are therefore only one factor among many. When using data on tourism demand for the purpose of studying the impacts of climate change on tourism, one is basically faced with the difficulty of estimating the importance of the relevant climate parameters. According to current findings, their influence is at present considered to be of fairly minor importance.[194]

Also in respect of the tourism infrastructure, climate-change related physical damage can be of importance. However, it is not possible to illustrate this scenario in a similar way to the action field 'Building sector' in respect of the development of insured damage, because the data do not permit any sector-related attribution. Another reason is that tourism providers, just like other businesses, tend to insure specific risks according to their particular requirements, thus not signing up to any standardised insurance products. So far there seems to have been no representative survey conducted among tourism providers – regarding physical damage – that might serve as an alternative source of information.

Also with a view to the illustration of measures, there are limitations owing to the data situation. Given the increasing occurrence of drought in past years and the associated limitations ensuing also for tourism providers, the monitoring of water use involved in tourism might provide a useful starting point. However, so far there are no specific data available in this respect. Generally speaking, the implementation of several measures – often relating to specific destinations or providers – does not facilitate any quantitative illustration. This is true, for instance, in respect of measures such as the expansion of offers that are available year-round, regardless of the weather, or the strengthening of summer tourism by introducing new touristic products or by taking measures to ensure greater climate resilience of the businesses concerned. Generally speaking, adaptation measures can certainly be made part of an integrated sustainable development of tourism businesses or destinations. So far an assessment of the existing certification schemes for tourism sustainability is possible only in a very limited way with regard to evidence of any climate adaptation efforts.

What's being done – some examples

The challenges climate change entails for different tourism segments, regions and groups of players are just as wide-ranging as the opportunities for and requirements of adaptation. It is up to individual providers of tourism products and services to take precautionary measures by protecting their own real estate and infrastructures from the potential impacts of climate change. For example, buildings used for tourism purposes should conform to high standards of heat protection in summer, and any outdoor areas for the use of visitors should afford adequate shielding from the rays of the sun. Likewise, cycle paths and footpaths for the use of tourists should offer sufficient shading. Furthermore, non-technical adaptation measures also play an important role. It may well be an important adaptation task for tourism providers to introduce a targeted risk management which includes, for example, emergency measures or health-related precautionary measures for protection from heat. Moreover, climate adaptation means that tourism providers should take measures to provide adequate information and communication for guests, with the objective of informing visitors about climate risks, or to guide visitor flows by directing them to low-risk areas. Targeted marketing of touristic offerings can also be useful in supporting businesses or destinations by helping them to achieve more evenly distributed seasonal utilisation. (cf. Indicator TOU-R-1, p. 284). As a suitable basis for this, a tourism provider can create strategic diversification and expansion of their offerings. Generally speaking, the adaptation to climate change is a continuous process also in tourism, which businesses or destinations need to take into consideration when enhancing their offerings.

In order to conduct their adaptation process in a targeted manner, tourism providers – in view of numerous different challenges and opportunities in adaptation – need to be able to base their decisions on well-founded knowledge as well as supportive decision-making tools. Adaptation to climate change in tourism is supported at Federal and Länder level by working out the basic essentials. For example, the aspect of adaptation to climate change is addressed as an integral part of the key theme entitled 'Climate neutrality / Environment and nature conservation' in the dialogue process involving various players in the tourism industry, accessible on the 'National Platform – Future of Tourism'. A UBA project was carried out to explore the impacts of climate change on tourism destinations in Germany and any relevant opportunities for adaptation[195]. In order to make the findings of this research readily available and useful to executive with responsibility in the practical application of tourism, the project produced a guideline for the adaptation to climate change in destinations as well as other offers of information.[196]

Apart from funding research, the public purse also supports adaptation efforts in tourism financially by means of various funding programmes. Given the wide range of potential measures and interfaces with other action fields – for instance the safeguarding of infrastructures – there are also advanced funding programmes to be considered in addition to tourism- and adaptation-specific funding programmes. Within the framework of the UBA project mentioned above, a total of 30 relevant funding programmes at Federal and Länder level were identified in 2018; in addition, various funding tools offered by the EU were categorised as relevant in this context. As far as funding at Federal level is concerned, the funding opportunities have included for instance the programme entitled 'Measures for adaptation to the impacts of climate change', the KfW bank's environmental programme and the German Federal Environmental Foundation's environmental protection funding programme. Likewise, there are – according to the findings of the UBA project – funding programmes available from most of the Länder, which support adaptation to climate change in tourism. However, especially with a view to the adaptation to winter tourism, there are increasingly intense discussions being held debating whether funding for tourism-related investments should be restricted to vacation and leisure offerings available throughout the year.

Furthermore, there are – in numerous Länder – region-specific offers of information which support the adaptation to climate change in tourism. Besides, Länder and associations increasingly incorporate the subject of climate adaptation in their existing networks for tourism providers, in order to raise awareness of the subject and to indicate available sources of information.

Photo: © Thaut Images/ stock.adobe.com

Climate changes relevant to the action field

Annual mean of air temperature

Global climate warming is evident in Germany too, as shown by increasing mean air temperatures. The areal mean indicates that for the annual mean, air temperatures rose by 1.5 % from 1881 to 2022. In other words, global warming is clearly accelerating. In the course of the past five decades, the temperature increase amounted to 0.38 °C per decade, which is more than three times higher than the value of 0.12 °C per decade averaged over the entire period since 1881. It can be stated that since the 1960s, every decade was warmer in Germany than the decade before. Nine of the ten warmest years in Germany were recorded since the turn of the millennium. (cf. page 19).

Photo: © Holger Luck / stock.adobe.com

Impacts of climate change

TOU-I-1: Coastal bathing temperatures

The seawater temperature has also risen in the course of past decades (cf. Indicator KM-I-1, p. 100). On the North Sea and Baltic Sea coasts this has a positive effect on the duration of the potential bathing period; in other words – the time period in which the seawater temperature potentially makes a bathing holiday or bathing activities possible. Usually in June suitable temperature conditions will set in which last well into the month of October. Since the 1980s, the first potential bathing days have occurred earlier and earlier every year, while the last suitable days occur later and later, extending into autumn. Despite some considerable fluctuations from year to year, the duration of the potential bathing period on North Sea and Baltic Sea coasts has been getting significantly longer.

Foto: © Micha Trillhaase / stock.adobe.com

Adaptations – activities and results

TOU-R-1: Seasonality of bed-nights in wider tourism areas

For many tourism destinations in Germany, the development of more favourable climatic conditions may provide opportunities for the extension of touristic offerings and for increasing the demand for cross-seasonal tourism. Above all, destinations which have so far had a strong seasonal focus, are thus able to become less dependent on a core season tied to specific touristic activities and attractions. In Germany, this is true in particular for wider tourism areas on the coasts where seasonality – measured in terms of the ratio between bed-nights during months of peak demand and the month of lowest demand of a calendar year – is most distinct. In 2019 occupancy rates ranged from just under 2 million in January to more than 12 million in July. According to tourism statistics for the summer half-year (May to October) the percentage of bed-nights amounted to almost three quarters (73 %) of all bed-nights per year.

In coastal regions, as indeed in all other wider tourism areas in Germany, the seasonality of demand for overnight accommodation has decreased significantly. This indicates an increasing capacity utilisation of bed-nights throughout the year in contrast with the hitherto much lower number of bed-nights in some months of the year. Insofar as this is linked to increasing independence from individual months which are particularly in demand for vacations, this can be assessed as a favourable adaptation to climate change opening up new opportunities.

Warmer temperatures for coastal vacations

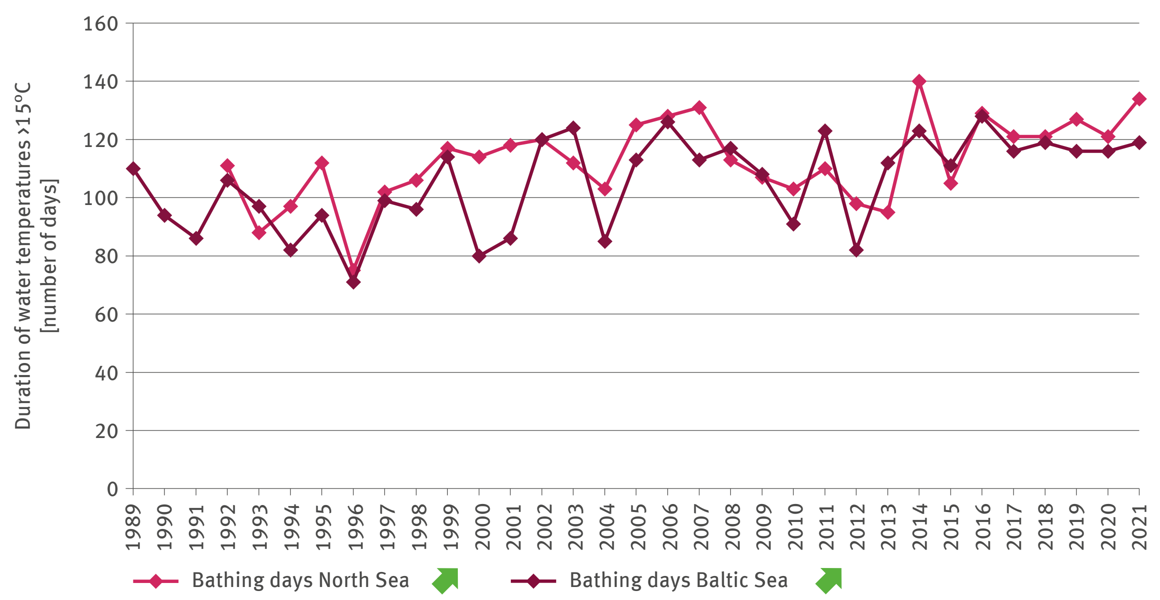
Many German people like to spend their vacations relaxing on a sunny beach. The most important holiday destination for Germans is therefore the Mediterranean region, which accounted for 38% of holiday trips in 2019 – before the Covid-19 pandemic –, as found by a FUR travel analysis[197]. In particular, Spain, Italy and Turkey are popular travel destinations among Germans. Within Germany, apart from Bavaria, the coastal Länder of Mecklenburg-Western Pomerania, Schleswig-Holstein and Lower Saxony rank most highly. The travel behaviour of Germans during the Covid-19 pandemic underlines the attractiveness of coastal tourism. As far as travels abroad are concerned, especially all travel to Spain, Italy, Turkey, Portugal, Croatia and Greece increased once pandemic-related travel restrictions were removed in 2021[198]. In Germany the market share of bed-nights in the coastal regions of the North Sea and Baltic Sea for 2020 and 2021 amounted to some 5 % more than the previous years' level (cf. Indicator TOU-I-3, p. 282).

As far as Germany is concerned, it is conceivable that beach and bathing holidays on the coast – as the typical form of summer tourism – might in general benefit from air and sea temperatures rising as a result of climate change. Owing to global warming, the bathing season might last longer, thus increasing the attractiveness of outdoor bathing locations. Evidence for a tendency towards higher sea temperatures in the coastal waters of the North Sea and Baltic Sea has already been provided in terms of measurements taken within the station network of the BSH. The annual mean temperature calculated for the entire surface of the North Sea, based on analyses conducted by BSH on a weekly basis, has increased by roughly 1 °C since the introduction of this analysis in 1968 (cf. Indicator KM-I-1, p. 100).

In order to enable an estimate – based on sea water temperatures – of the potential for bathing tourism in coastal areas, the duration of the potential bathing period is illustrated as the number of so-called bathing days on which the daily mean of the sea water temperatures of German coastal waters of the North Sea and Baltic Sea exceed a threshold value of 15 °C. There is a criterion that has to be met for the first bathing day of a season which requires that the temperature – measured after exceeding

TOU-I-1: Coastal bathing temperatures

The time period in which seawater temperatures potentially make a bathing holiday on Germany's North Sea and Baltic Sea coasts possible, is subject to major fluctuations from year to year. Usually in June suitable temperatures will set in which last into the month of October. The duration of such temperature conditions has been increasing significantly on North Sea and Baltic Sea coasts.



Data source: BSH (selected measuring stations) the threshold value – does not drop again below a daily mean value of 14 °C. The last bathing day is the last day in a year, on which the water temperature is still above 15 °C.

The indicator is based on water temperatures which are measured almost continuously at BSH measuring stations in the German Bight (North Sea) and the BSH's Kiel Lighthouse (Baltic Sea) at some distance from the coast. These measurements have the advantage that they are homogeneous and more independent of short-term influences than measurements taken right on the coast. The location of the measuring stations also played a role in selecting the threshold value for assessing the bathing temperature. The sea water temperatures taken in bathing waters at the coast tend to be higher than at measuring stations far from the coast thus signifying that upwards of this value – also due to stronger diurnal variations – the water is potentially suitable for bathing. For the purpose of comparison: In the hot year of 2018 the maximum value of the mean surface temperature of the North Sea amounted to 16.3 °C; with regard to the Baltic Sea this value amounted to 20 °C.[199] Near the coast the maximum water temperatures (daily mean) at individual stations was clearly higher: In Hörnum on the island of Sylt for instance, values of 24.5 °C and in Neustadt (Holstein) 26.0 °C were measured.

The two time series covered by the indicator have been rising since the beginning of the 1990s (North Sea) and since the end of the 1980s (Baltic Sea), indicating a significant trend. This signifies that the time period on North Sea and Baltic Sea coasts, with sea temperatures potentially suitable for bathing, is extending. In both of these coastal regions, the first potential bathing days occur earlier and earlier every year, while the last suitable days occur later and later, extending into autumn, indicating a significant trend. In parallel with the warmer water temperatures, the air temperatures are becoming more favourable too. This was indicated by developments at DWD measuring stations Norderney (North Sea) and Kiel-Holtenau (Baltic Sea) respectively: The average daily mean and highest values measured for the air temperature during the summer vacation months of June to September have been rising at both stations. The indicator shows signs that the determining climatic factors for tourism in German coastal regions are becoming more conducive to bathing. Nevertheless, higher seawater and air temperatures can also entail negative effects. For example, rising temperatures favour the occurrence of pathogens such as vibrions (cf. Indicator GE-I-7, p. 52).

Generally speaking, there are a number of other factors that influence the attractiveness of the North Sea and Baltic Sea coasts as destinations for beach and bathing tourism. These include other meteorological parameters such as sunshine duration, air quality or bio-climatic conditions interacting with air temperature, wind, radiation conditions and humidity. Besides, the occurrence of algae and jellyfish play a role. In future, conditions influencing coastal tourism can be changed by rising sea levels, more frequent and more intensive storm surges as well as coastal erosion (cf. Indicator KM-I-2, p. 102, KM-I-3, p. 104, and KM-I-4, p. 106).

On one hand, rising temperatures make the North Sea and Baltic Sea coasts more attractive for bathing holidays, while on the other, they can also make the occurrence of pathogens more likely. (Photo: © Holger Luck / stock.adobe.com)

Whether these changes will have positive or negative impacts on touristic demand or whether they will have any effect at all, will also depend on numerous other factors, such as current travel trends, demographic change or economic scenarios. So far it has not become evident that people making holiday plans consciously avoid the hot regions bordering the Mediterranean, choosing instead to visit more northerly climes. It is true that in the course of a supplementary questionnaire added to the population survey entitled 'Environmental awareness in Germany'[200] conducted in 2021, roughly two thirds of respondents stated that they were changing their leisure and holiday planning, for instance by avoiding strenuous activities in the heat or by shunning hot-temperature holiday regions, while another 10 % stated that they intended to do so in future. However, the renewed increase in demand for travel to Mediterranean countries outlined above – after the removal of travel restrictions related to Covid-19 – indicates that the desire for change has not been reflected in the actual travel plans made so far.

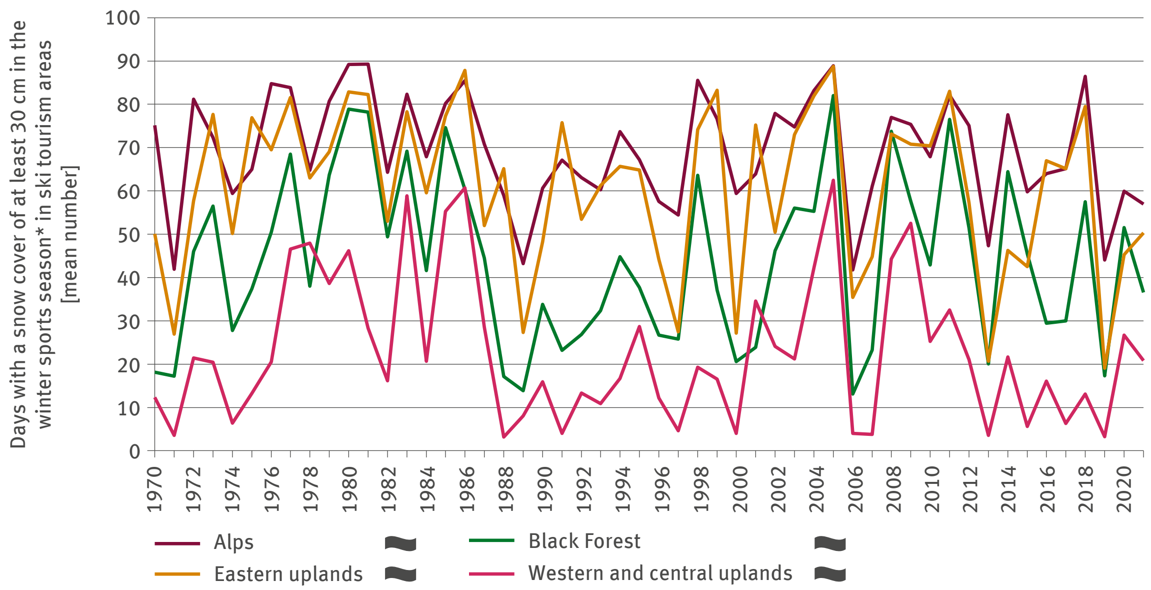
Uncertain snow conditions in the Alps and upland areas

Whether skiing or snowboarding, cross-country skiing, touring or snow hiking – snow-covered mountains, snowy forests and radiant sunshine are the ultimate ideal of many people when they think of winter holidays and winter sports. Whenever there is insufficient snow cover, the foundation for snow-related forms of tourism is undermined. Tourism destinations in high mountain ranges and uplands suffer distinct commercial losses if the snow cover is in decline, if guaranteed snow is more and more restricted to higher altitudes and if the periods of snow cover become inconsistent or if they shift. The amount of snow cover required depends above all on the specific activity and the type of terrain. Even just a few centimetres of snow cover can imbue a winter walk with a wintry atmosphere. For cross-country skiing, snow depths of 10 to 15 cm are usually sufficient. As far as alpine skiing operations are concerned, it is the specific character of a ski slope which determines what minimum depth of snow is required in order to prepare pistes, protect the soil, ensure safe skiing operations and provide the skier with a pleasant skiing experience. Generally, a snow cover of 30 cm depth is sufficient while 50 cm are considered good.[201] However, stony and rocky pistes may require a much deeper snow cover of up to 1 m depth to make them skiable.

An analysis of snow depth data recorded for the Alps and selected upland areas over the past (just under) five decades shows that the snow situation between 1970 and 2021 in all ski-tourism areas ('Alps', 'Black Forest', 'Eastern Uplands', 'Western and Central Uplands') was very changeable. A consistent natural snow cover in a winter season (15/12 to 15/03) of 91 days or, in a leap year, 92 days) is reached – with reference to the medium sea level applicable to relevant skiing areas – only in some locations of very few ski-tourism areas and that only in some years. Owing to the altitude, the overall best snow conditions prevailed in the skiing regions of the Alps, albeit with some strong fluctuations from year to year. In terms of the multi-annual average for the period from 1970 to 2021, the relevant skiing areas had 70 days per winter season, with a snow cover of at least 30 cm, calculated with the mean value weighted according to length of piste. For the eastern uplands, the multi-annual

TOU-I-2: Snow cover for winter tourism

In Germany snow conditions have been subject to strong fluctuations in the course of the past five decades. For any of the ski-tourism areas in Germany, the number of days with a natural snow cover in depths of at least 30 cm does not show any significant trend. In the Alps and the eastern uplands snow-poor winters occurred only sporadically while in the two other upland regions, there were extended phases of snow-poor winters.



*period from 15/12 to 15/3 of the subsequent year

Data source: DWD (snowcover observation) mean with a sufficient snow cover is roughly 60 days. Contrary to the Alps, the eastern uplands repeatedly have some very snow-poor years. In the Black Forest and especially in western and central uplands, including the Harz, Sauerland, Rhön, Thuringian Forest and the Fichtel Mountains, the prevailing conditions are fundamentally different. In those areas, the natural snow cover reached a multi-annual mean of only 44 days and only 23 days with a depth of snow of 30 cm. By comparison, the snow cover in the Sauerland or the Rhön upland area failed to reach those conditions in several years of the past decade.

It must be stressed that these data refer only to the natural potential of winter sports tourism in ski-tourism areas and their various regions. These findings do not permit any statements on the actual snow conditions in skiing areas. In those places the snow cover required for winter sports can be created or supplemented significantly by means of technical snowmaking. In response to phases with several consecutive snow-poor years, but also with a view to comparable activities offered by the international competition, the operators of skiing resorts have in some cases set up elaborate infrastructures for artificial snowmaking. Artificial snow is the most wide-spread measure used to extend the season or to maintain skiing operations when faced with strong fluctuations in weather patterns. On average across the Alps, it was possible in 2015 to use artificial snow in more than two thirds of the piste areas[202], in the Bavarian Alps the proportion of terrain suitable for applying artificial snow amounts to approximately one quarter[203]. In Bavaria, the entire terrain suitable for applying artificial snow increased between 2005 to 2020 by more than 500 ha to lately approximately 920 ha.

Nevertheless, applications of artificial snow are subject to physical and economic limitations. In order to produce artificial snow efficiently, a few degrees below -2 °C and a humidity below 80 % provide favourable conditions. Additives which facilitate the production of artificial snow even at higher temperatures are not certified for use in Germany. The costs involved in artificial snow generation (investment, operational and maintenance costs) are considerable anyway, and at rising temperatures or higher humidity, costs become disproportionately high. Besides, when infrastructures such as those in upland areas – owing to frequently snow-poor winters – are not continuously utilised to capacity, the profitability of such plant is seriously threatened. It is therefore obvious that – solely from an economic angle – such adaptation measures are subject to limitations of economics. Another limitation is that the application of artificial snow will affect nature and the environment owing to high

In mild, snow-poor winters, there is demand for alternative recreation and holiday offers in lieu of sports involving the pistes. (Photo: © were / stock.adobe.com)

requirements of energy and water and also in terms of the necessary construction measures – such as the installation of reservoirs and the building of access roads for the construction process or for piste levelling. This is one of the reasons why the alpine states who are members of the Alpine Convention[204] – whose objective it is to achieve sustainable development in the Alps – have agreed that the generation of artificial snow is permitted only in cold periods, on condition that the locally relevant hydrological, climatic and ecological conditions be favourable.

If winter visitors frequently have negative experiences with lack of snow in German winter tourism regions, they may in future at least to some extent change their holiday activities or holiday destinations. In the representative population survey ‘Environment awareness in Germany’[205] at least a quarter of respondents stated in 2012 that they would adapt their winter sports activities if required by the prevailing climatic conditions. While in the subsequent surveys in 2014 and 2016 the proportion was 17 % in both years, in 2021 this value had dropped to 14 %.[206] These findings as well as the consistently high number of first-time users of cable cars, chair lifts and drag lifts during the winter season clearly indicate that German holidaymakers have not yet begun to give more preference to destinations in neighbouring European states when it comes to deciding on their winter vacation.

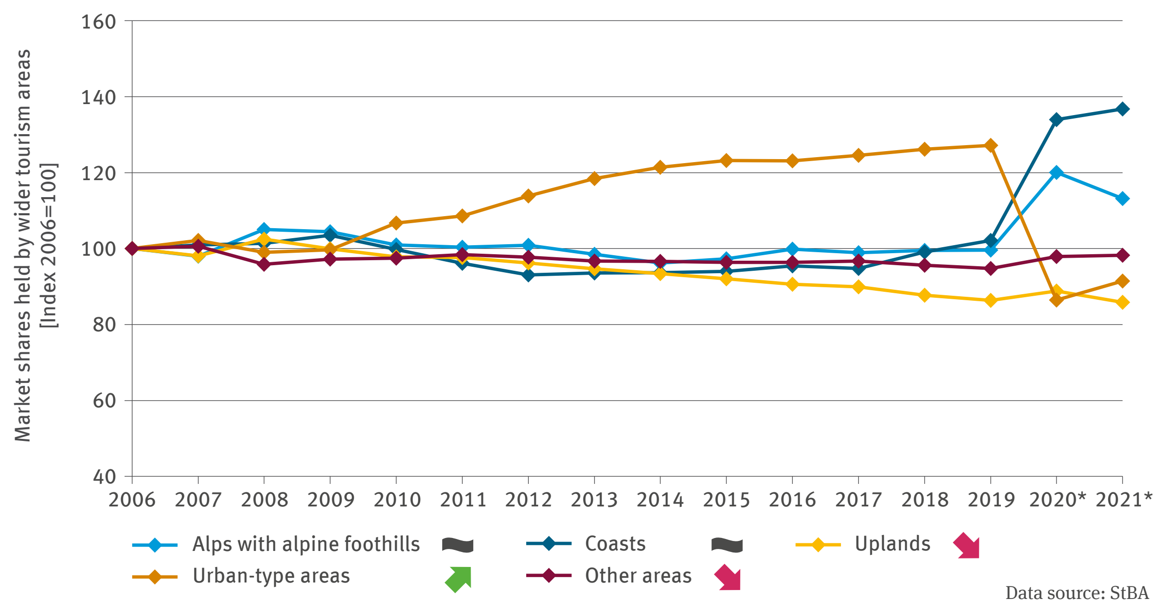
Tourism areas: no climatic influence on market shares identifiable

Apart from coastal areas by the North Sea and Baltic Sea or the Alps with alpine foothills, there are other travel destinations in Germany which have been aggregated to form three other wider tourism areas[207]: the uplands, urban-type areas and other areas (for spatial distribution cf. map on page 283). The wider tourism areas are characterised not only by different features in terms of wildlife, landscape and land use, but also by different levels of importance and intensity of tourism in their respective areas. Individual types of tourism in the wider tourism areas are – apart from landscape features – very closely bound up with certain climatic conditions such as bathing tourism on the coasts or winter tourism in the Alps and uplands. The connection is less pronounced in respect of other types of tourism such as city tourism, shopping and congress tourism or the hiking and cycling types of tourism; nevertheless, it does exist. Any changes in these conditions as a function of progressive climate change can influence the attractiveness of tourism in such wider areas either negatively or positively. Apart from climate change, this influence depends on the degree in which intensely climate-sensitive types of tourism characterise the demand, and how diverse the touristic offers are in the wider area concerned.

As far as summer tourism is concerned, rising temperatures and less precipitation can generally increase the attractiveness of tourism areas in Germany, for instance in respect of outdoor activities such as hiking, cycling or boat tours. Likewise, the bathing season – on the coasts of North Sea and Baltic Sea (cf. Indicator TOU-I-1, p. 278) and at inland water bodies from Lake Constance to the Mecklenburg Lakeland – can become much longer owing to rising water temperatures. However, higher water temperatures are also apt to affect water quality, potentially favouring the rather negatively viewed growth of algae or cyanobacteria (cf. Indicators GE-I-6, p. 50). In coastal areas, it can happen that more frequent storms and rising sea levels alter the coastlines and beaches or cause erosion thus affecting tourism activities (cf.

TOU-I-3: Market shares held by wider tourism areas

It has so far not been possible to discern any influence of climatic change on the market shares of wider tourism areas in respect of occupancy rates. Up until 2019 developments were characterised by the increasing importance of urban areas at the expense of other areas. During the Covid-19 years of 2020 and 2021, the general decline of occupancy rates affected, above all, the urban areas while the wider tourism areas on coasts and in the Alps were able to gain market share.



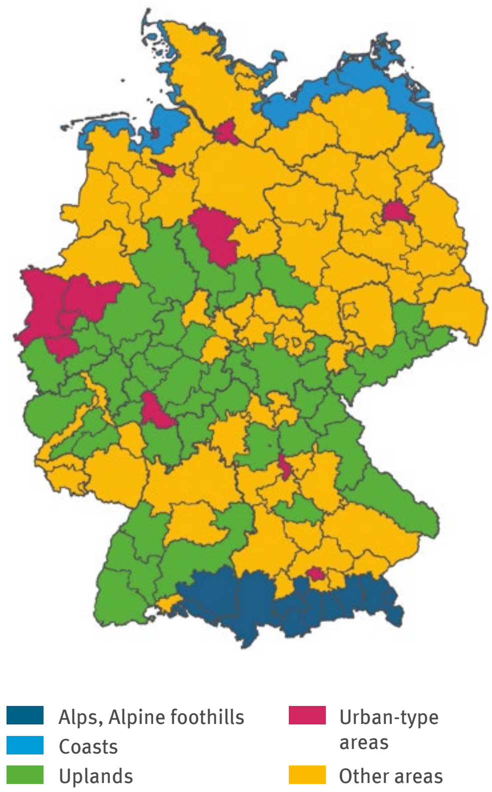
*The years 2020 and 2021 of the Covid-19 pandemic were not included in the trend analysis.

Data source: StBA (monthly survey in tourism)

Indicator KM-I-4, p. 106), while in urban-type areas, summer heatwaves can equally affect the demand for city vacations. Winter tourism areas in the Alps and uplands are apt to lose some of their attractiveness during the winter season as snow cover and the certainty of snow diminish which means the areas concerned can no longer provide a wintry landscape aesthetic or the usual winter sports activities (cf. Indicator TOU-I-2, p. 280). On the plus side, autumns become longer and warmer thus increasing the potential for the short-break types of holidays in Germany.[208] In addition to impacts from changing average weather conditions and weather patterns, climate change can also entail the occurrence of more frequent and more intensive extreme weather events affecting Germany's travel areas. For example, in recent years tourism offers and destinations in various parts of Germany were affected not only by storms, heavy rain and flooding but also by heatwaves, forest fires and water shortages.

Any changes in the attractiveness of wider tourism areas – owing to gradual or acute climate change impacts – can in turn affect market shares. Against this background, the indicator for wider tourism areas entitled 'Alps with alpine foothills', 'Coasts', 'Uplands', 'Urban-type areas' as well as 'Other areas' illustrates the development of market share in terms of occupancy rates in accommodation businesses nationwide. The indicator thus provides an easily comparable overview of the development of travel demand in the areas concerned.

The development of market shares in the period from 2006 to 2019 is characterised – with a strong overall increase in Germany from roughly 350 to 500 million bed-nights – by a significantly rising market share in urban areas at the expense of other areas, in particular the uplands and other areas. In 2020 and 2021, this development was disrupted – to various degrees within Germany – by travel restrictions and travel warnings issued by the German Foreign Office during the Covid-19 pandemic. These restrictions entailed that Germany's population overall undertook distinctly less holiday travel and if they travelled at all, they only visited domestic destinations. Moreover, the number of bed-nights from foreign visitors – amounting to some 90 million in 2019 – decreased to 32 million visitors in 2020.[209]. Overall in Germany, the demand dropped to roughly 300 million bed-nights, in other words it fell distinctly below the level recorded in 2006. This decline generally affected all wider tourism areas, but in particular the urban-type areas where – owing to travel restrictions – there were hardly any international visitors, while trade fairs and other events just could not be held. In this field, bed-nights declined by almost 60 %. The decline was lowest in the wider coastal tourism areas amounting to -20 %.



Data source: Technical data: StBA (Gemeindeverzeichnis)
Geodata: Geobasis-DE/BKG 2021

Wider tourism areas in Germany

The travel areas in Germany have been aggregated in five wider tourism areas. The 'Alps, alpine foothills', 'Coasts', as well as 'Urban areas' are characterised by highly specific features, whereas the 'Uplands' and 'Other areas' are heterogeneous and extensive.

Evidently, the destinations on North Sea and Baltic Sea coasts benefited from the widespread German predilection for beach vacations.

The development described above makes it clear that the indicator generally illustrates shifts in the popularity of wider tourism areas in Germany – such as the long-lasting trend favouring city vacations or the changes arising during the Covid-19 pandemic. However, the indicator so far does not reflect any recognisable influence of climatic changes on the market shares of wider tourism areas in terms of occupancy rates.

More independent of the peak season

There are various general opportunities available to tourism destinations to take precautions against the impacts of climate change, to prepare for coping with them and for adapting to climate change. According to a UBA proposal adopted in 2021, such possibilities and opportunities range from technical measures to measures for crisis prevention and management as well as product adaptation and management and how to guide or direct visitor flows.[210]

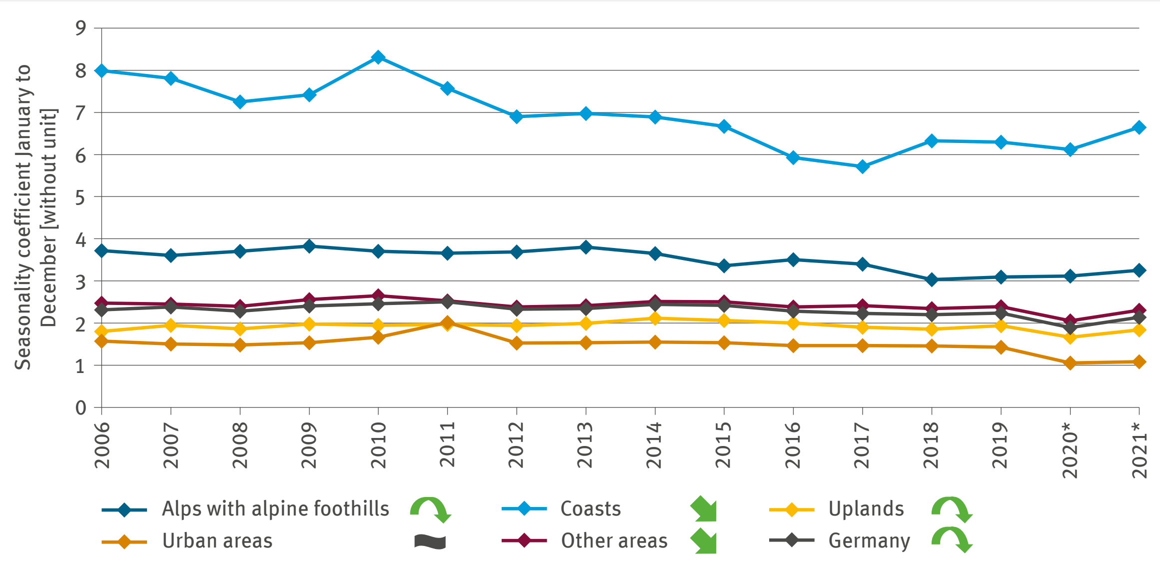
At the basic level, the adaptation to climate change includes the enhancement of a destination's strategy for diversifying their offerings. A diverse and cross-seasonal portfolio of offerings which is not subject to weather conditions or weather patterns will make destinations less dependent on individual tourism activities or attractions. This will put them in a better position to compensate for any temporary phases of lower utilisation or even operational disruptions owing to the impacts of any changing climatic conditions. Rising temperatures and less precipitation from spring until autumn as well as increasing thermal comfort provide destinations with opportunities for instance to extend their offers to the off-season or to benefit from an extended peak season.

Stabilising the seasonal utilisation of tourism infrastructures at a level compatible with the environment and comfortable for both the population and employees, provides one of the building blocks for the sustainable development of tourism destinations. It can help to avoid overburdening the environment at the same time as contributing to reliable job offers for employees.

Such deliberations form the background to the indicator on the seasonality of the wider tourism areas aggregated as 'Alps with alpine foothills', 'Coasts', 'Uplands', 'Urban-type areas' and 'Other areas'. The seasonality coefficient illustrated shows the relationship of the number of bed-nights for the month with the highest number of bed-nights compared to the month with the lowest number of bed-nights in the course of a calendar year. In this context, a high indicator value signifies high seasonality, in other words, a major difference between the month of highest demand and the month of lowest

TOU-R-1: Seasonality of bed-nights in wider tourism areas

In all wider tourism areas with the exception of urban-type areas, the seasonality of demand – judging by the number of bed-nights – has significantly decreased. This indicates a more balanced seasonal utilisation. For the destination this can indicate a useful development towards climate adaptation.



*For 2020 and 2021 the seasonality coefficient was calculated on the basis of the 2019 minimum of bed-nights, in order to allow for the prevailing Corona-related restrictions. Neither of these two years were taken into consideration for the trend analysis.

Data source: StBA (monthly survey in turism) demand. This means that wider tourism areas characterised by high seasonality are particularly dependent on the demand in individual months, and on a few specific touristic offers. In other words, they are exposed to a specific risk of reduced demand whenever the climatic or climate-related conditions for the touristic core season deteriorate. By strengthening, for example those offers which are independent of the weather, or by encouraging the demand in weaker months in a targeted way, it will be possible to mitigate this risk.

Among the wider tourism areas in Germany, the coastal regions are most strongly affected by seasonality. In 2019, prior to the Covid-19 pandemic, bed-night figures in this area ranged from just under 2 million in January to more than 12 million in July. According to the tourism statistics for the summer half-year (May to October) the proportion of bed-nights amounted to three quarters (73 %) of all bed-nights in that year. Likewise, in the wider tourism area of the 'Alps with alpine foothills', the summer half-year is very important in terms of overnight stays – roughly two thirds (65 %) of bed-nights take place during that period. However, owing to winter tourism, the occupancy rate beyond the summer months is higher compared to the coastal regions. The seasonality in this area is therefore not quite so pronounced. Here too just under 2 million overnight guests accounted for bed-nights in the demand-poorest months of 2019, while in the strongest month, demand reached just under 6 million bed-nights. Moreover, the significance of the winter season for alpine tourism manifests itself more strongly in pronounced day tourism and associated high added value. especially in skiing resorts.

The other wider tourism areas, in other words the upland regions, urban areas and all other regions clearly enjoy more regular demand for overnight accommodation throughout the year. Especially tourism in urban areas is highly independent of the seasons. The regions mentioned benefit from the fact that the offers available in those areas, such as cultural and city holidays, events tourism and business trips, health and educational holidays are less dependent on the weather or weather patterns. It is true, that here too there are peaks in demand for summer vacations, but these are less pronounced than in coastal regions or the Alps. When interpreting the figures, it must be borne in mind that the categorisation of wider tourism areas differs regarding the degree of differentiation: The 'Alps with alpine foothills' and the 'Coasts' are very tightly demarcated and thus tailored to specific tourism offers; whereas, by contrast, the 'Uplands' and, above all, the 'Other areas' have been aggregated much more generously – encompassing, for instance, the condensed metropolitan area of Stuttgart, rural Eastern Friesland, the Rhine valley, the Lüneburg Heath or Mecklenburg's 'Switzerland' and its Lakeland. In these more broadly demarcated wider tourism areas, differences in demand among different travel areas balance each other out more easily owing to the more diverse product range offered. Furthermore it should be borne in mind that the demand – and its seasonal distribution – is influenced by numerous general factors, such as the dates of school holidays and the economic development including factors like inflation or demographic change.

In highly seasonal travel areas, diverse and cross-seasonal offers can provide greater independence from the core season. (Photo: © Micha Trillhaase / stock.adobe.com)

Overall, the seasonality of bed-nights has decreased significantly in the course of recent years, and this applies to all tourism areas with the exception of urban-type areas. This meant, up to and including 2019, that the nationwide increasing bed-night figures increased slightly less in the demand-strong months than in demand-weaker months. As long as the demand for tourism observes ecologically and socially acceptable limits, such a development can actually make a contribution to the adaptation to climate change in the destinations.

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Financial services industry

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

Banks, savings banks and insurance companies are important players in the transformation process towards a CO_2-neutral and climate-resilient economy. These organisations play a key role in the implementation of the European 'Green Deal' which is striving to achieve the transition to a climate-neutral, resource-efficient and competitive economy by 2050. It is beholden to credit institutions to provide sufficient liquidity for essential investments – for both climate protection and for climate-related damage. Underwriters have an important part to play in terms of the collective assumption and sharing of risks. The implementation of the Green Deal requires an absolutely fundamental transformation process which can succeed only provided it is based on a stable financial system. This must be based on well-functioning risk management which is resilient in both commercial and climatic terms.

DAS Monitoring –what is happening due to climate change

Apart from being important players in respect of climate protection and climate adaptation, financial services providers are equally vulnerable to the impacts of climate change in respect of their own operations. In terms of risks, insurance companies and credit institutions are closely linked to their clientele; this is to say – both private individuals and companies. In other words, physical climate risks – the impacts of extreme weather events and weather patterns as well as the creeping progress of climatic changes facing their clientele – can easily turn into commercial risks confronting financial institutions. For quite some time, the insurance companies have been scrutinising the potential impacts of climate change. By contrast, negative impacts of climate change on the credit history and liquidity of borrowers or any potential losses in the value of assets, have so far been considered less of a risk by credit institutions. This is true, in particular, for regional credit institutions which are active almost exclusively within Germany. The general commercial risks encountered by insurance companies are quite specific in line with the different insurance products concerned, and the risks involved affect the profitability of insurance products. For example, liability insurance or household insurance products are typically more profitable whereas homeowners' comprehensive insurance regularly incurs underwriting losses. The profitability is calculated on the basis of the combined ratio. If this ratio amounts to more than 100 %, the insurance company incurs a loss regarding the relevant policy transaction. Over the past 20 years, extreme weather events have repeatedly entailed underwriting losses in respect of homeowners' combined insurance (cf. Indicator FiW-I-1, p. 292). In terms of insured damage, 2021 has been the most costly year so far – to the tune of 11 billion Euros – as a result of the flood disaster with focus Ahrtal.

Future climate risks – outcomes of KWRA

The financial services industry in general is covered as a cross-sectional action field in the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, page 7) This is why climate impacts have not been described, and no climate impact assessments were carried out either. In the DAS action fields a special focus has been placed on the insurance sector and the banking sector owing to their relevance to increasing the adaptation capacity.

Where do we have gaps in data and knowledge?

Contrary to the indicator set for the DAS 'Financial services industry' action field contained in the previous 2019 DAS Monitoring Report, the current issue has been amended to include an additional Response Indicator (FiW-R-2). Nevertheless, it has not been possible so far to include any quantitative indicators, especially with regard to those themes which play an important role in the banking sector: There are no representative data available to describe either the extent to which banking businesses are affected by climate change impacts or the relevant risk management by banks: Germany's banks have only just begun to address the subject of climate change in a systematic manner. However, regulators and politicians with relevant remits have been scrutinising the climate-related impacts on the industry ever more closely.

At the European level, the current issue was amended substantially by including a revised version of 'Corporate Sustainability Reporting Directive – CSRD' published in 2022 and the European taxonomy regulation which came into force in 2020, thus distinctly amending the non-financial reporting system. As a result, the resilience to climate change and the objective of climate protection have become a distinct focus of corporate reporting. Furthermore, there are regulations imminent on the part of the European Banking Authority (EBA) and Germany's Federal Financial Supervisory Authority (BaFin) which will oblige the system-relevant banks to submit a differentiated declaration of the amounts of credit exposed to physical climate risks. The data contained in such reports will provide greater transparency in future. Given the fact that – at least some of – the data will be in the public domain, this opens up new possibilities for illustrating, by means of DAS Monitoring Indicators, how climate risks are addressed in the financial services industry. Against this background, the indicator on the awareness of physical climate risks among financial services providers (FiW-R-2, p. 296) published for the first time ever in the 2023 Monitoring Report, is to be understood as a proxy indicator. This proxy indicator is based on a small dataset – covering a few financial services providers who voluntarily submit reports within the framework of the CDP – and is primarily intended to embed the important issues of climate change management in the core principles of financial services management in respect of DAS Monitoring.

The amendments mentioned which were added to the European and German reporting obligations, apply not just to the banking sector but also to insurance companies. In the insurance sector too, there are still some deficits remaining with regard to the systematic assessment of climate risks as well as risk management. Given that climate risks have, in part, a very direct effect on the profitability of certain insurance products, insurance companies are in general more proactive in addressing climate change impacts facing the insurance market. Since 2012, the GDV has been publishing their annual natural hazard report as a damage 'chronicle' of German insurers. Reinsurers too, such as the Munich Re, have for some time had their eye on the impacts of climate change. On the basis of GDV data, it is possible to generate indicators on insurance products already established in the market – such as the extended insurance for buildings against natural hazards (eEV) which has been available since the 1990s; that is to say, indicators on damage data (cf. Indicators BAU-I-5, p. 226, and FiW-I-1, p. 292). As far as insurance products are concerned which are not yet firmly established in the market and which have as yet low insurance density, such damage data are not yet sufficiently representative.

Apart from the eEV mentioned above, work is ongoing regarding further insurance products intended to provide insurance for climate risks in the future, especially in the field of agriculture. Although the GDV supports the discussion on the development of climate risk insurance and is in the process of enhancing product design, the association does not have an overview of the question as to whether and how its member organisations will ultimately implement those developments in the form of marketable products. Owing to keen competition prevailing in the insurance market, the member organisations are being very discrete about publishing their individual strategies and product developments. It is therefore not possible to illustrate the market development in terms of indicators.

What's being done – some examples

Insurance companies, credit institutions and other players in the finance sector face various challenges in connection with climate change. The credit institutions have to ensure when checking for credit eligibility that climate protection and adaptation are taken into account and that after granting credit there is adequate liquidity available to provide claims settlement after cases of climate-related damage and for any reconstruction work required. Underwriters have an important part to play in terms of the collective assumption and sharing of risks.

It is evident from scientific analyses that banks are still addressing the issues of risk management and climate change adaptation inadequately and in a manner that is not sufficiently systematic (cf. Indicator FiW-R-2, p. 296). Transitory risks still dominate the foreground of their awareness. These are regulatory risks due to more stringent climate protection requirements imposed on the clientele, as well as reputational risks which can be linked to banks' investments in climate-damaging projects. In general a greater damage potential is attributed to such risks than to physical climate-related risks. Especially in the case of internationally active banks which also do business in highly vulnerable countries (cf. Indicator IG-R-2, p. 268), this 'blind spot' involves a substantial risk potential. However, physical risks are also directly or indirectly relevant to regionally active banks.

The developments intended to improve transparency in the risk management practised by financial services providers (CSRD, as well as transparency of taxonomy regulation and new regulations introduced by EPA and BaFin) will in future contribute to a more intensive analysis of physical risks and – as expected – to the implementation of risk-mitigating measures. On one hand, higher transparency is important in examining whether the efficacy and stability of banks will prove resilient in crisis situations. On the other hand, transparency helps potential investors to take informed decisions. At the same time, the generally increasing awareness of climate protection and sustainability has resulted in a growing demand for sustainable capital investments.

With its products, the insurance sector basically makes an important contribution to the transfer of social risks. Climate risk policies are regarded as core strategic tools for adaptation to climate change. For example, the Sendai Framework for Disaster Risk Reduction 2015–2030 is being used to highlight the importance of insurance policies in reducing disaster risks and increasing the resilience of populations and institutions in the face of disasters. Likewise, in the 2021 EU Adaptation Strategy, closing the gap in insurance protection from climate risks is regarded as an important step towards achieving a climate-resilient EU. Currently, on average of roughly just 35 % of climate-related commercial losses are currently covered by insurance Europe-wide, while in some parts of Europe as little as 5 % or less are covered[211].

There are two essential prerequisites to be met in order to achieve a more extensive insurance cover: on one hand, the availability of attractive insurance policy offers, and on the other, the population's willingness to take up the offer of insurance products. The further development of appropriate insurance instruments is being pursued worldwide. By now, the eEV is well established in Germany; however, the insurance density is still rather patchy (cf. Indicator BAU-R-4, p. 234). As far as agriculture and forestry are concerned, there is still a lack of suitable offers in respect of climate risk insurance products. The existing offers are not much in demand owing to high costs and lack of financial support from the state. In general terms, the finance industry has great potential to expedite the innovations necessary to adapt their insurance products to market requirements. In addition, such endeavours might be supported by accompanying scientific studies[212].

Given the still insufficient risk awareness among the population (cf. Indicator FiW-R-1, p. 294), there seems to be a need for more strongly and more intensively bundled information on climate risks. In order to raise public awareness of the risks of damage to buildings and to increase the willingness to take up insurance, several Länder carried out campaigns to draw attention to damage from natural hazards in recent years. In fact, the success of these campaigns was limited – a case of more or less preaching to the converted, in other words the response came mostly from people who were already sensitised to the issues.

Likewise, tools such as the 'Hochwasser-Pass' (flood passport) developed for the purpose of raising awareness, were not followed up in terms of interested parties taking effective action. By using the internet-based information tool 'Naturgefahren-Check' (natural hazards check) offered by the GDV, individuals who rent or own a house, as well as companies, can obtain information enlightening them to what extent their building is exposed to natural hazards and what adaptation measures might be implemented. However, this offer too, is expected to appeal just to members of the public who are interested anyway. With the aim to reach a wider public by using a more strongly bundled information offer, the DWD announced in 2022 that it planned to develop – in cooperation with LAWA and the Federal Office of Civil Protection and Disaster Assistance (BBK) – a natural hazards portal which can be used in future to obtain information (in digital form) on any concrete hazards prevailing at a specific location, as a basis for taking preventative steps.

Risk transfer via customised insurance solutions is not always sufficient, as insurance policies should at best be just a part of comprehensive risk management. In the optimum case, risk transfer is accompanied by strategies for operational risk mitigation. That is why many underwriters now conduct their own individual consultations, for example with regard to flood-adapted building methods; and they make the conclusion of insurance policies partly conditional on adaptation standards in order to mitigate risks thus also keeping insurance premiums as low as possible. In general terms, however, a distinctly more intensive form of cooperation between insurance companies, the public purse, consumer protection associations and the insured is called for. Discussions are taking place, for example, regarding a deeper embedding of adaptation commitments in legal and planning principles and in respect of regulations which are apt to direct, for instance, the development of housing estates towards areas that are less subject to climate risks (cf. Indicator RO-R-6, p. 312). Other approaches might include adapting the insurance tax in such a way that insurance premiums become affordable, or by establishing state-guaranteed minimum insurance protection by creating a state-administered pool. In cases where damage arises, financial support might then be provided from this pool without burdening the tax payer or communalising the payment of damages. In this context, close cooperation with banks is equally important. For example the granting of mortgage loans might be made conditional on evidence of a natural hazard insurance policy; alternatively, such evidence might provide eligibility for an interest rebate on the loan.

State

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Climate changes relevant to the action field

Extreme events – heavy rain

It is to be expected that – owing to changed meteorological conditions – this will entail an intensification of cloud- and precipitation-forming processes. Extreme events such as heavy rainfall and persistent rain might therefore increase. Given that such events occur seldom and with high variability, trends have so far not been statistically relevant. However, there is evidence for the past 20 years that there has been a slight increase in respect of heavy-rain events. Especially in warm years, extreme convective precipitation events have occurred repeatedly (cf. page 24). Such developments influence the risk of flooding.

Impact

Photo: © Stillkost / stock.adobe.com

Impacts of climate change

FiW-I-1 Claims ratio and combined ratio in homeowners' comprehensive insurance

Physical climate risks resulting from extreme weather events and long-term changes in climatic conditions can have major impacts on the business activities of financial services providers. Underwriters, in particular, incur high demands for damages resulting from extreme meteorological events. Whether an insurance segment is profitable can be seen from the so-called combined ratio. The homeowners' comprehensive insurance, whether with or without the inclusion of damage from natural hazards, is generally regarded as a less profitable segment. Even individual regional extreme events can have adverse impacts on nationwide profitability values in this insurance segment.

Adaptations – activities and results

Response

Photo: © Christian / stock.adobe.com

BAU-R-4 Insurance density of extended natural hazard insurance for residential buildings

The inclusion of insurance cover for natural hazards (eEV) complements a home-owner's comprehensive insurance which provides cover for impairments such as storm and hailstone damage – by including floods, heavy rain, snow load and avalanches. Extensive insurance protection from such kinds of damage is an essential requirement for risk transfer to function well. The insurance density in respect of eEV has increased steadily and significantly since 2001. However, this density still remains low, so that many kinds of damage from extreme events are not covered by insurance.

FiW-R-1 Public awareness of storm and flooding risks

Despite the startling extreme events of recent years, the risk awareness among Germany's population remains low. As indicated by representative population surveys conducted within the framework of a regular study entitled 'Environmental awareness in Germany', not even a quarter of respondents expect that their house or home is at genuine risk of damage from storms or floodwater. Appropriate risk awareness is an essential prerequisite for increasing the willingness to take out an appropriate insurance policy.

Response

Photo: © Mr. Bolota / stock.adobe.com

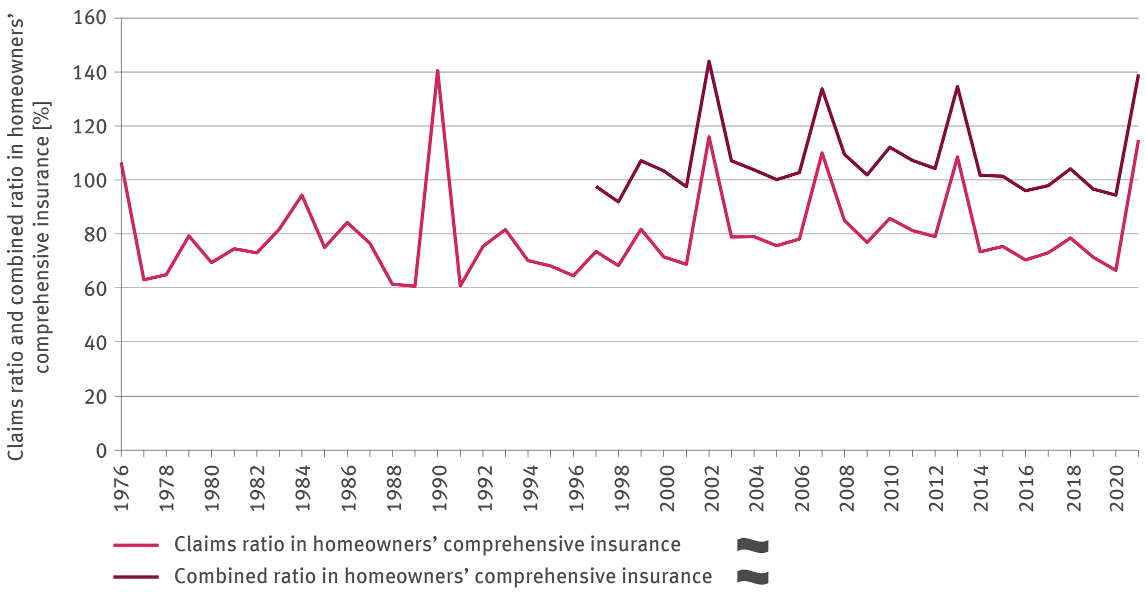
2021 – so far the most expensive year for underwriters

Increasing claims ratio figures signify increasing expectations of damages to be paid by insurance companies as the relationship of income and expenditure in the relevant insurance segment is changing. Such considerations play an important role in terms of an insurance company's balance sheet. In 2021, storms and hailstones as well as other natural hazards – especially the flood catastrophe resulting from the low-pressure system 'Bernd' in July in the Rhineland-Palatinate and North Rhine-Westphalia – caused damage to residential buildings, household effects, trade, industry and agriculture, amounting to a total of 11 billion Euros. This makes 2021 – followed in second place by 1990 with a damages total of 10.8 billion Euros owing to the severe hurricanes named Daria, Vivian and Wiebke, and in third place by 2002 with insured damage amounting to 10.3 billion Euros resulting from the August floods focused on the Elbe/Danube area (cf. Indicator WW-I-4, p. 76) – the most expensive year in terms of damages paid by underwriters in the course of the past 50 years.[213]

Whether an insurance segment is profitable is indicated by the so-called combined ratio. The storm events of recent years left their mark on the combined ratio of homeowners' insurance. Where the ratio exceeds 100 %, this signifies that this is a loss-making business for the insurance company. In the segment of homeowners' comprehensive insurance, the combined ratio is usually comparatively high. This regularly causes actuarial losses incurred by insurance companies. The data collected by insurance companies have been collated centrally for the past 25 years. Looking back at this period of time, it becomes evident that up to 2015, German insurance companies managed to make an actuarial profit only in three years (1997, 1998 and 2001) as far as the homeowners' comprehensive insurance segment is concerned. Between 2002 and 2014 the insurers of homeowners' properties accumulated an actuarial minus of more than 7 billion Euros. For a long time the competition on price in the field of homeowners' comprehensive insurance was very keen, which made insurance companies hesitant to adapt the calculation of the premiums charged by them. Since the end of the price war over homeowners'

FiW-I-1: Claims ratio and combined ratio in homeowners' comprehensive insurance

In general, homeowners' comprehensive insurance is a less profitable business for insurance companies. After price responses to increasing amounts of damage, the years of 2016, 2017, 2019 and 2020 returned to actuarial profits: The combined ratio in homeowners' comprehensive insurance undercut the 100 % level. The 2021 flood catastrophe in the Ahr and Erft valleys entailed a new damage record and disrupted this development.



Data source: GDV (branch statistics)

insurance and the resulting increase in premiums, the combined ratio for 2016 and 2017 as well as 2019 and 2020 reverted to below 100%. Consequently, in those years it was possible again to achieve an actuarial profit in the field of homeowners' comprehensive insurance. However, the severe damage year of 2021 disrupted this positive development very suddenly. So far it has not been possible to identify a statistically significant trend in respect of the combined ratio.

Looking at the time series for the claims ratio – which does not include the costs of administration and contract conclusion, thus not permitting any immediate statements on the profitability of the insurance business – the picture is quite similar. There is no discernible trend in this respect either.

If insurance companies want to avoid charging their insured clients further premium increases, they will probably have to demand more personal provision by the insured themselves. This means that homeowners will have to become proactive themselves by proving that, thanks to architectural measures, they have been able to achieve better protection of their buildings from the impacts of natural hazards. Furthermore, the systematic embedding of the adaptation to climate change in the building regulations law – down to the decree of building bans in exposed areas – is required in order to reduce the risks involved (cf. Indicator RO-R-6, p. 312). An expansion of insurance protection – especially with regard to natural hazards insurance – in order to achieve greater insurance density (cf. Indicator BAU-R-4, p. 234) is likely to help spreading the risk more widely. After all, it can be assumed that not all regions of Germany will be affected in equal measure by individual natural hazard events.

The insurance industry currently works on the premise that it will remain possible to provide insurance in Germany for damage caused by natural hazards despite being faced by climate change, and therefore advocates risk-based market solutions. However, nobody can predict with certainty, in what way the damage scenario might evolve in future. This is why insurance companies campaign for an instrument which strives for active state support in cases of disastrous cumulative damage, thus creating a buffer to absorb some of the extreme social losses and burdens incurred by the insured[214].

Major damage events are reflected in the balance sheet of insurance companies.(Photo: © Stillkost / stock.adobe.com)

The population's risk awareness is rising slightly

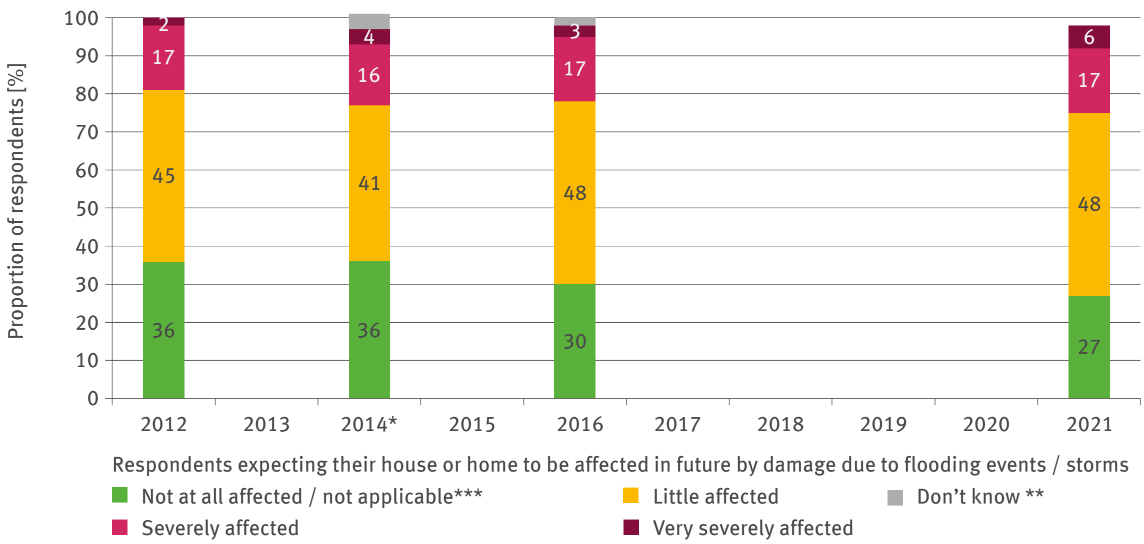
For the insurance industry, the population's and companies' appropriate risk awareness is one of the most important foundations of their business. Only if this awareness is widespread and deeply rooted and if consequently many people take out adequate insurance, will it be possible to form sufficiently large risk communities for an insurance company to facilitate affordable insurance premiums.

In what way people perceive hazards or risks, how they estimate potential impacts and what type of provident action they need to take, varies from one individual to another. Apart from hard facts – scientifically proven and measurable – which determine the extent of risk, there are numerous subjective components that can have considerable influence on the perception of risks. Such perceptions of risk can often be distorted. On one hand, they can be characterised by unrealistic optimism and the illusion to have everything under control, on the other, they can be influenced by impressions derived from current disastrous events which have triggered great concerns and can lead to an overestimate of individual risks.

This is indicated by findings from the representative population survey entitled 'Environmental awareness in Germany' – and / or supplementary questions – which is carried out at regular intervals on behalf of the UBA and the Federal Environment Ministry[215]. The respondents are asked to estimate (among other statements), to what extent they might be personally affected by the impacts of climate change. In 2012, 81 % of respondents stated that they perceived little or no risk that floodwater events or storms might damage their house or home. In the subsequent survey this estimate had changed little: In 2014, 77 % and in 2016, 78 % perceived themselves little or not at all affected. The recent survey conducted in 2021 shows clearly that risk awareness has increased further. This is true, in particular, for the very distinct increase above all in the category of respondents who now feel very much affected. The survey was conducted in September 2021, in other words, two months after the disastrous flooding in the Ahr and Erft valleys. It is justified to assume that the respondents were still affected by those recent events. It is true to say, however, that the values recorded in the course of this survey permit only

FiW-R-1: Public awareness of storm and flooding risks

Despite extreme weather events in recent years, the German population's risk awareness is still very low. Not even a quarter of citizens who responded to the survey acknowledge that their house or home is at genuine risk of damage from storms or floodwater. In 2021, the statements made by respondents were probably still influenced by the flood catastrophe that occurred in July of that year: A higher proportion acknowledged that they might be very severely affected.



* as of 2014, rounding error due to missing decimal places
** since 2014
*** since 2021

Data source: BMUB/BMUV & UBA (study entitled 'Environmental awareness in Germany', for 2021 supplementary questionnaire within the framework of the study entitled '2020 Environmental awareness in Germany') limited interpretations, as they are not linked to information on the actual exposure of respondents to the climate change impacts mentioned.

In general, it has to be assumed that Germany's population still underrates the risks involved. Above all, it is the heavy-rain events that give rise to concern. These events can – even at considerable distance from rivers and areas categorised as threatened by flooding – lead to massive inundations in cases where small streams swell up rapidly and burst their banks. If, as in July 2021, 150 litres per square metres of precipitation falls within 24 hours, the soil can no longer absorb such volumes of water (cf. Indicator WW-I-5, p. 78). Generally speaking, it is possible that localised, brief but extreme, heavy rainfall with a high damage potential can strike anywhere in Germany, thus affecting anyone in that particular locality (cf. page 25 and figure 8). The situation is similar in respect of storms, although in this case, there are still some major uncertainties regarding measurements and projections.

In addition to having very little risk awareness, many people believe themselves adequately insured – on the basis of their existing policies – for damage caused by climate change impacts . In many cases, it is still frequently overlooked – despite all information campaigns – that the customary homeowners' comprehensive insurance does not cover damage caused by heavy flooding. In fact, the density of policies for the extended natural hazard insurance is still rather patchy (cf. Indicator BAU-R-4, p. 234).

For the population to take full advantage of the possibilities of climate-impacts risk mitigation and to ensure that the necessary precautionary measures are taken, it is essential to observe two crucial factors: The population will have to take their own initiative to be fully informed about their own specific risks and in what way they might be affected. In the first place, individuals must be fully informed about options available to them in terms of ordinary everyday actions and how to go about taking these actions.

Since the mid-2020s, assistance on this has been provided by (amongst other sources) the internet-based information tool 'Naturgefahren-Check' (natural hazards check) offered by the GDV. Individuals who rent or own a house, as well as companies, can obtain information to what extent their building is exposed to natural hazards and what adaptation measures might be implemented. By entering their postcode, users can find out what kind of damage an extreme weather event has caused in their locality. On

The Ahrtal disaster in 2021 demonstrated the full extent of the population's vulnerability to climate impacts also in Germany. (Photo: © Mr. Bolota / stock.adobe.com)

entering exact address details, it has also been possible since 2022 to obtain information via the Hochwasser-Check (flood check) for any locality, thus finding out about any hazards of heavy rain and of river flooding.. This tool also offers general recommendations on appropriate action to be taken. The 'Naturgefahren-Check' (natural hazards check) is intended to heighten the awareness of people in respect of the risks involved in natural hazards and encourage them to be proactive in making their own precautionary arrangements. With the aim to achieve a more effective bundling of the information offered – by covering a broad spectrum of natural hazards – the DWD is currently cooperating with LAWA and BBK on the establishment of a natural hazard portal which will, in future, provide digital procedures for downloading actual hazards threatening a specific location, thus providing a basis for personal decisions on preventative actions. Given its solid information basis, this tool might also be effective in reaching more sectors of society.

Providers of financial services still underrate climate risks

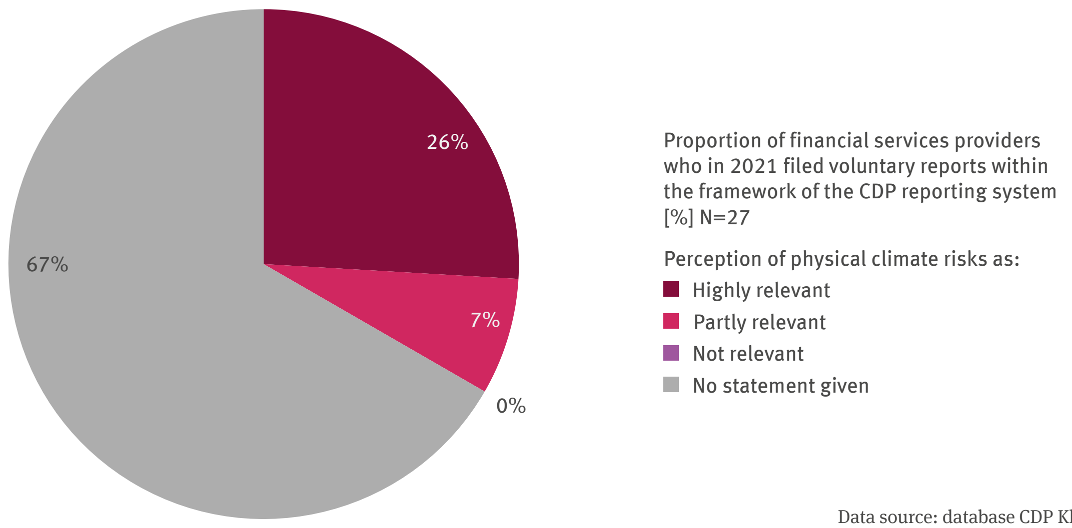
Financial services providers such as banks, savings banks and insurance companies are important players in the transformation process towards a CO_2-neutral and climate-resilient economy. Likewise, they play an essential part in implementing the European 'Green Deal'. They are tasked with facilitating the financing of investments in the implementation of sustainable company objectives regarding climate protection and climate change adaptation. Moreover, they are beholden to improve their recognition of climate-related risks in the financial system and to practise targeted management of such risks, in other words – to take appropriate financial precautions. Furthermore, greater transparency in the financial system is wanted, thus enabling potential investors to take informed decisions.

Financial services providers bear particular responsibility – by practising targeted risk management – to prevent the impacts of climate change affecting the financial markets, thus leading to destabilisation. It is possible for bankers and investors to reduce such risks by systematically taking these issues into account in all aspects of their working processes. They need to be fully aware that – as providers of capital for companies in the real economy which might suffer losses as a result of physical climate risks or even become illiquid – they are themselves vulnerable to such losses.

Since the mid 2010s, there are increasing concerns among the treasuries and central banks of G20 states that both severe climatic changes and an effective climate protection policy have the potential to inflict adverse impacts on the financial market's stability. Against this background, the FSB (Financial Stability Board) – an international body which works for the G20 – has set up the TCFD (Task Force on Climate-related Financial Disclosures) which is composed of experts from the real economy and the finance industry. This Task Force has explored which type of information is required from companies and to be submitted to players in the financial market, enabling them to carry out climate-related risk assessments for the development of recommendations underpinned by such information.

FiW-R-2: Awareness of the relevance of physical climate risks among financial services providers

Given the reality of climate change, it is enormously important for the stability of the finance system that financial services providers have a realistic perception of the climate risks associated with their business activities. Of the 27 financial services providers – voluntarily filing reports in 2021 within the framework of CDP – only a third submitted a rating of the relevance of climate risks to their activities. Presumably these risks are still being underrated by financial services providers.



Data source: database CDP Klima (analysis of data records from the demo version by Frankfurter School of Finance & Management gGmbH)

The TCFD's recommendations on improved reporting dating back to 2017[216] have been incorporated into the revised version of the European 'Corporate Social Responsibility' Directive (CSR Directive) dating back to 2014. The amended 'Corporate Sustainability Reporting Directive – CSRD' dated 2022 now distinctly includes amended non-financial reporting obligations. These amended reporting obligations are expected to make clear in future, how resilient companies are to climate change and to the outcomes of an effective climate protection policy. There is a close connection between these European Directives and the EU Taxonomy Regulation that came into force in 2020. This regulation requires participants in the finance market who offer financial products, to state in their declarations which parts of their portfolio are in conformity with the EU taxonomy regulation. Activities that support the fulfilment of the above-mentioned 'Green Deal' objectives, are considered taxonomy-conform.

There are further amendments or extensions to these reporting obligations in terms of the regulations to be launched imminently by the German and European regulatory authorities such as BaFin and EBA. In future, system-relevant banks, for instance, will have to declare the totals of credit exposed to climate risks according to pillar 3 (elevated standards for declaration purposes) of the equity regulations adopted by the Basel Committee on Banking Supervision (Basel III), differentiated by geographical attribution and sector (cf. Indicator IG-R-1, p. 266).

On the basis of these new datasets yet to be generated, it will be possible in future to make distinctly more valid statements on the risk management practised by financial services providers. Against this background, the indicator illustrated here – in respect of the financial services providers' awareness of the relevance of physical climate risks – is to be understood as a proxy indicator. It will be imperative to enhance this indicator once data availability is improved. The indicator is based on CDP data (formerly Carbon Disclosure Project). For 20 years companies active in the finance industry and the real economy have voluntarily submitted reports on greenhouse gas emissions -and other impacts from their business activities on the environment – within the CDP framework. Within the CDP-Klima database, the reporting companies state how they rate the physical risks to their business activities.

More than two thirds of the 27 financial services providers – filing reports in 2021 within the framework of CDP-Klima – did not submit a rating of the relevance of physical climate risks. The remaining companies rated these risks as relevant or even highly relevant – none of the companies denied the relevance of these risks

Financial services providers will have to assess the risks associated with their business activities in a realistic manner in order to safeguard the stability of the finance sector.
(Photo: © PaeGAG / stock.adobe.com)

directly. It is not unreasonable to assume that the high proportion of respondents who did not submit a relevance rating might be due to uncertainties in assessing these risks or that they failed to address these challenges.

Given the low number of financial services providers who filed reports, it is impossible to regard the evaluation of responses as representative. However, a survey by the Bundesbank and BaFin conducted in April 2022 among 1,300 small and medium-sized banks and savings banks in Germany produced similar outcomes. Climate risks are rated as low to moderate[217].

The apparent low rating of the relevance of climate risks implies the much greater risk that financial services providers do not take climate risks into account in any systematic way; neither do they adapt their pricing adequately. Consequently, these providers are not likely to supply companies in the real economy – whom they provide with finance – with the necessary incentives to make their own contribution to reducing the material climate risks.

Spatial, regional and urban development planning

Adaptations to climate change – Response

On the relevance of the action field

Spatial, regional and urban development planning can support adaptation to climate change in two significant ways. On one hand, these types of planning can provide targeted promotion of risk provisioning at every planning level, and they can govern land use in a way that mitigates existing or expected climate risks – for example from extreme weather events, weather patterns and their impacts. For instance, a different plans can be used to direct the development of human settlement and infrastructures towards low-risk areas, to safeguard flood plains by turning them into retention spaces, or to protect open spaces as climatic balancing areas or as components of biotope networks.

On the other hand, spatial, regional and urban development planning can help to reconcile diverging claims and requirements arising from climatic circumstances as well as reconciling such claims/requirements among themselves and with issues of landscape potential.

DAS Monitoring – what is happening due to climate change

Climate change has not affected all parts of Germany equally. The impacts of meteorological changes depend in part on regionally specific factors of influence and vulnerability. In their planning processes, the regions have to confront their individual challenges, while any expected impacts should be recognised and taken into account at the earliest possible stage and as comprehensively as possible. Spatial, regional and urban development planning are themselves neither directly exposed to nor dependent on influences of weather or weather patterns. Therefore, they are not directly affected by impacts resulting from climate change. That is why DAS Monitoring does not contain any statements on climate change impacts concerning this action field.

Future climate risks – outcomes of KWRA

In the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7), spatial, regional and urban development planning are addressed as a joint cross-sectional action field. This is why climatic impacts were not described for this action field in the KWRA; consequently, no climate impact assessment was carried out. With their planning tools, spatial, regional and urban development planning set the planning framework conditions for the implementation of adaptation processes at the relevant level. The outcomes of a KWRA survey have shown that it is important to give adaptation measures more comprehensive consideration in regional development planning processes. Among other things, this can be achieved, for instance, by explicitly strengthening the argument for climate adaptation as a crucial element in balancing considerations. In view of the climate risks presumed to be facing Germany in the future, there is a specific need for balancing any land use interests in respect of natural resources such as water and soil.

Where do we have gaps in data and knowledge?

Planning at Länder and regional level implements, either explicitly or implicitly, the adaptation to climate change in terms of spatial planning objectives and principles and also in terms of technical drawings specifying the supra-local plans regarding their respective areas of application. The contents of plans are recorded in the Regional Spatial Structure Plan Monitor (ROPLAMO) of BBSR, and these records permit the assessment of the prevailing state of climate adaptation in the process of spatial planning.

Towns and municipalities are responsible for the core task of implementing climate adaptation in a local context, with due consideration of planning regulations. The planning tools available in this context are the land use plan as a link to supra-local spatial development and the development plan for more small-scale partial areas of the plan. However, there is currently no overview available indicating to what extent the municipalities have been implementing any existing opportunities for action. According to an assessment carried out in 2020, municipal climate adaptation measures have been taken into account increasingly in these plans. However, it must be said that at both planning levels, that there is unexploited potential at both planning levels.[218] Any assessment of land use plans and urban development plans is made difficult owing to the high expenditure involved. Such evaluations would require a comprehensive qualitative analysis of a plethora of plans. With a view to DAS Monitoring, there are currently insufficient quantitative data available in order to illustrate in an indicator the consideration of climate change adaptation in the process of urban development planning. Moreover, there are data gaps also in respect of the integration of the vulnerability aspect into planning concepts, or the consideration of climate protection and adaption in environment-related spatial planning tools such as Environmental Impact Assessments.

In cases where climate change adaptation is taken into account in regional and urban development planning, it remains unclear to what extent the specifications laid down actually prove effective in practice. The current legal framework, for instance, strengthens climate adaptation where it is made a balancing requirement. However, there is no information available indicating to what extent these issues carry weight within the framework of balancing processes.

What's being done – some examples

A vital spatial planning tool to reduce climate risks and damage potentials is the stipulation of specific types of land use. One of the measures employed by regional planning is the safeguarding of areas for wildlife and landscape thus promoting the maintenance of biodiversity (cf. Indicator RO-R-1, p. 302): The biotope network ensures that animal and plant species can adapt their respective distribution area to changing climatic conditions. Moreover, the targeted designation of purpose-specific priority and restricted areas supports flood control (cf. Indicator RO-R-3, p. 306), it contributes to safeguarding the groundwater and drinking water reserves when heat and drought occur more and more frequently (cf. Indicator RO-R-2 page 304), or it serves to reduce bio-climatic stress in affected regions, especially in towns where heat is rising (cf. Indicator RO-R-4, p. 308). The recent expansion of some of the land categories in question exemplifies the increasing incorporation of these issues in current planning processes.

Apart from the targeted safeguarding of ecologically or climatically valuable land, it is crucial to curb any new take-up of land for purposes which jeopardise its potential in terms of adaptation to climate change. In particular, the focus is on restricting the sprawl of settlement and transport areas (cf. Indicator RO-R-5, p. 310). Despite the fact that the take up of land has slowed down in recent years, it is important to redouble efforts to curb its inward intensification, for instance by land recycling or supplementary densification of settled areas; at the same time, however, it is important not to neglect bio-climatic or other requirements in the adaptation to climate change. It remains a serious issue of concern that owing to the prevailing high settlement pressure, new housing developments still keep appearing in flood plains (cf. Indicator RO-R-6, p. 312). Regional and urban land use planning must carry out their control functions resolutely in order to keep safe any flood plains and areas exposed to other hazards such as geo-risks.

Both Federal and Länder governments support climate adaptation in regional planning, and in particular, sustainable urban development by means of their programmes furthering such objectives. The promotion of urban development at Federal and Länder level helps towns and municipalities to eradicate serious deficits in the field of urban development and to create residential areas worth living in. To this end, climate protection and adaptation constitute prerequisites for obtaining funding. These prerequisites apply to cross-sectional tasks that attract funding for a variety of programmes. The Federal programme entitled 'Adaptation of urban spaces to climate change' promotes the climate-adapted development of green spaces and open spaces, such as parks and park-like spaces; it also supports the desealing and greening of open spaces and transport areas. The White Paper entitled 'Weißbuch Stadtgrün' is one of the documents formulating practical measures and recommendations proposed at Federal level for the integration of urban green spaces into the general urban space.[219]

The Federal government's measures and recommendations are underpinned by the outcomes of various research projects. Part of the BBSR's remit is the Action Programme 'Demonstration Projects of Spatial Planning' (MORO), which focuses on the conflict between increasing spatial demands and the increasingly limited resource of space at the level of regional planning. Other projects are dedicated to the research of urban restructuring and the development of technologies for water-sensitive urban development. Findings from federal research on climate adaptation were summarised within the framework of 'cross-evaluation of core joint projects carried out at Federal level for adaptation to climate change with focus on urban and regional development'[220] and this summary was processed by means of producing reports and guidelines for municipalities and regions.

Given that impacts of climate change occur right across the borders of Länder, intensive and networked communication is a key to sustainable regional development. Since 2021 any such endeavours are supported by the ZKA. The Centre's tasks include rendering advice to municipalities in all phases of development and implementation of climate adaptation concepts. Furthermore, ZKA provides information on suitable fundin opopportunities.

Priority and restricted areas reserved for wildlife and landscape conservation – contribution to biotope networking

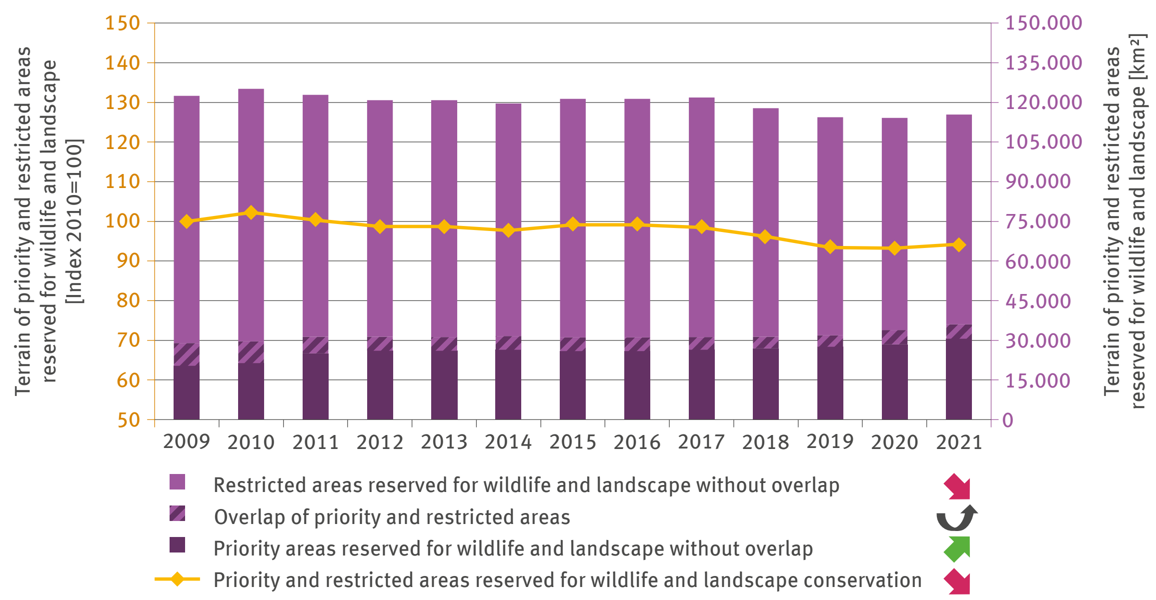
Climate change will alter the habitat conditions for animal and plant species over a large area. Higher temperatures and changing precipitation patterns as well as extreme events will affect various components of ecosystems, impacting functions such as the nutrient balance, habitat structures or the available food supply. Ultimately this means: that the boundaries of habitats of animal and plant species shift.

In these circumstances, a functioning compound system or network of biotopes is essential for the survival of specialised species which require specific locations and habitats. In a contiguous network of ecologically significant open spaces, species are able to explore and colonise new, climatically more suitable habitats of sufficient size and content. This is the only way to safeguard also the essential genetic exchange among different populations and distribution areas for the continued existence of species.

By designating priority and restricted areas reserved for wildlife and landscape, spatial planning can contribute to safeguarding the establishment of an ecological network by means of planning. This strategy enables the planning system to safeguard areas or to impose restrictions on their use, thus protecting the areas concerned from competing land use claims. In 2021 this was the case on slightly more than one third of the entire terrain of the Federal Republic of Germany: In that year, a total of circa 115,000 square kilometres were designated as priority and / or restricted areas. It must be borne in mind that the assessment combines various, partly heterogeneous designations applied in the Länder concerned. These include for instance spatial planning areas for the protection of wildlife, the protection of landscapes and landscape-related recreation as well as areas reserved for the development of an ecological network. This is why in some places, there is a degree of overlap between priority and restricted areas for wildlife and landscape, for example, when terrain is reserved as priority areas for

RO-R-1: Priority and restricted areas reserved for wildlife and landscape conservation

In 2021 Germany had approximately 115,000 square kilometres – roughly one third of its terrain – which were designated as priority or restricted areas reserved for wildlife and landscape. Länder and regional planning authorities use this approach to support the biotope network thus helping animal and plant species to adapt their specific distribution range to changing climatic conditions.



Data source: BBSR (ROPLAMO – spatial planning monitor)

species and biotope protection at the same time serving as a restricted area for the special protection of the landscape. In the time series concerned, these partial areas are included only once.

Despite temporary increases, the total of designated areas decreased between 2009 and 2021 by circa 7,000 square kilometres. This decline occurred at the expense of restricted areas and was essentially due to the fact that some designations imposed on restricted areas were revoked in the process of revisions. The number of new designations of restricted areas – predominantly imposed in other planning regions – was could only partially compensate for this decline. As in the past, more than 90 % of 114 planning regions nationwide still make use of the opportunity to designate priority or restricted areas for wildlife and landscape. Many regions make use of these categories by designating large-scale areas thus demonstrating that they attach great importance to the protection of wildlife and landscape thereby establishing and maintaining an ecological network.

However, these figures alone do not make it possible to gauge whether the ecological network actually meets its objectives and whether the landscape is indeed permeable for animal and plant species. Such an assessment would have to take into account, above all, how the designated areas are spatially distributed and how they are actually interconnected and what ecological quality they exhibit. Moreover, priority and restricted areas are not the only areas that are intended to safeguard ecological connectivity. The development and safeguarding of the biotope network is primarily an essential task in the remit of nature conservation bodies which, among other things, designate protected areas on the basis of nature conservation law; these bodies plan and implement the management of designated areas (cf. Indicator BD-R-3, p. 212). These areas are also part of the biotope network. However, they are only taken into consideration for this assessment insofar as they are also designated as priority or restricted areas in terms of spatial planning. Spatial planning tools such as regional green belts and green corridors which can benefit ecological networks are not taken into account in this context either. This is because these areas can, for instance, might also open up the potential for the allocation of tasks such as recreational use which would run counter to the objectives of the biotope network.

Apart from beneficial effects, such ecological networks unfortunately also provide opportunities for less pleasing developments. It is expected for example that as a result of climate change, undesirable species introduced by

Spatial planning areas reserved for wildlife and landscape allow, in addition to specific legislation, the safeguarding of refuge areas and networked areas for plants and animals. (Photo: © dina / stock.adobe.com)

humans will be able to widen their distribution range. Given the circumstances of climate change, it has become even more important now and for the future to address this problem by good management of ecological networks in order to prevent any developments from counteracting nature conservation objectives or at least to minimise their impacts.

Precautionary protection of drinking water and groundwater

In the past it could be taken for granted in Germany – apart from regionally limited areas of water shortage where usable groundwater was in short supply – that water would always be readily available in sufficient quantities. However, by now it has become necessary to pay much more attention to water resources in our country. This is because the groundwater recharge rate has been in decline. In fact, it was particularly low in the drought years of 2018, 2019 and 2020 (cf. Indicator WW-I-2, p. 72). However, groundwater recharge in sufficient quantities is an essential prerequisite for Germany's drinking water supply, almost three quarters of which is sourced from groundwater. Another important consideration is that changing precipitation and temperature conditions also affect the quantity and quality of any surface water used for the abstraction of drinking water (cf. Indicators WW-I-3, p. 74, WW-I-7, p. 82).

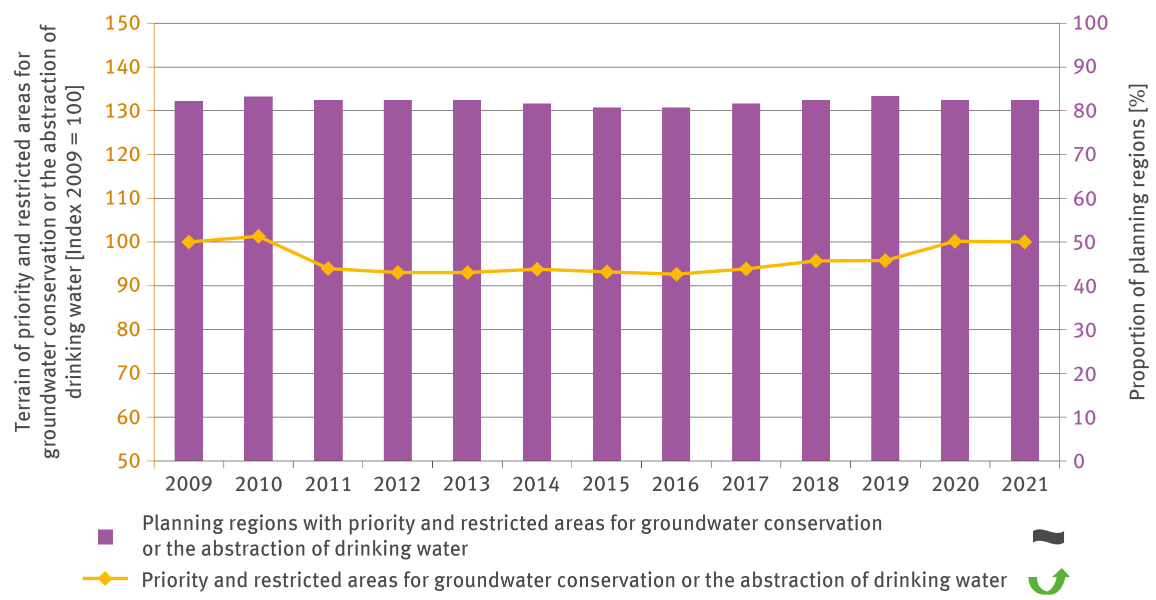
Progressive climate change means that this set of problems is likely to escalate, in particular in those regions of Germany where the climatic water regime is already less than favourable now. Increasing water scarcity and more frequent droughts may give rise to regional conflicts, especially over the use of water resources near the surface, but also over groundwater resources.

Planning at Länder and regional level can designate priority and restricted areas for the conservation of drinking water and groundwater, thus safeguarding water resources by means of planning processes, moderating between conflicting claims on land use and avoiding or mitigating conflicts. Just under 80 % of planning regions make use of this option. The high proportion of designating planning regions demonstrates that spatial planning tools are not just used in planning regions which tend to be affected by water shortages. In fact, the conservation and safeguarding of water resources is of major importance also in water-rich areas, to some extent because their water resources are in part used for provisioning water-poor areas.

To what extent various area categories are implemented for the conservation of groundwater and drinking water in individual planning regions depends above all – apart

RO-R-2: Priority and restricted areas for groundwater conservation / abstraction of drinking water

Given the rising frequency of drought years, the safeguarding of water resources by spatial planning as practised already in many planning regions, is visibly gaining in importance. New designations made it possible in recent years to make up a least for the decline in terrain experienced in the early 2010s.



Data source: BBSR (ROPLAMO – spatial planning monitor)

from variations in planning practice – on the individual spatial properties of regions, such as soil properties and geological baseline conditions, for instance whether the vegetation is near-natural and the intensity of its exploitation. In 2021 an overall terrain of more than 41,500 square kilometres in Germany was designated as priority or restricted areas for the conservation of drinking water and groundwater – the equivalent of more than 10 % of the total land area of the Federal Republic. Even though the areal expanse alone does not facilitate any direct conclusions on whether areas are designated to the appropriate spatial extent or quality, this percentage does illustrate the great importance attached to the conservation of water resources by spatial planning.

As a rule, regional plans are newly drawn up or updated every 10 to 15 years. In this process, planning regions may update the specifications contained in plans, which may entail changes in areal designations. Furthermore, plans may on these occasions also be adapted to changes in law or jurisdiction. Nationwide, the terrain designated in planning terms for the conservation of water resources initially decreased after 2010. However, beginning in 2017, this development has reversed so that the expanse of designated terrain has been increasing again. For example, the value originally recorded in 2009 was finally reached again in 2020 thanks to the new large-scale designation of priority areas reserved for groundwater and drinking water conservation incorporated in the regional plan for Saxony's planning region of Oberes Elbtal-Osterzgebirge which came into force in 2020.

It is to be expected that owing to climate change the conservation of water resources will gain even greater significance in years to come. This background was one of the reasons why the Federal Cabinet adopted the National Water Strategy in March 2023. This strategy aims to achieve sustainable use of water resources by the middle of this century, in respect of both, human beings and the environment, ensuring the conservation and restoration of a near-natural water regime, and enhancing climate-adapted water infrastructures. This includes the use of planning processes to ensure the cooperation between the water management on one hand and spatial planning on the other, in order to safeguard terrain for groundwater recharge and the abstraction of drinking water, for instance by stipulating priority areas for future water abstraction areas in regional plans.[221]

Apart from the option to stipulate the designation of priority areas for future water supplies, as for instance by safeguarding future water conservation areas, it is important also to take into account the safeguarding of

In view of climate change it has become essential to handle water resources with greater circumspection, where possible involving the use of spatial planning tools.
(Photo: © Visions-AD / stock.adobe.com)

areas for groundwater recharge. Especially the latter objective includes certain requirement regarding the nature of the actual soil cover; this is because the areas thus safeguarded must allow for good infiltration of water into the soil. So far, spatial planning has provided limited opportunities in this respect, for instance the option, rarely used so far, to designate priority areas for expanding woodland cover. The increasingly frequent occurrence of drought periods suggests that the safeguarding and promotion of groundwater recharge might become an important task for spatial planning thus needing to be expanded accordingly.

Safeguarding areas for inland flood control

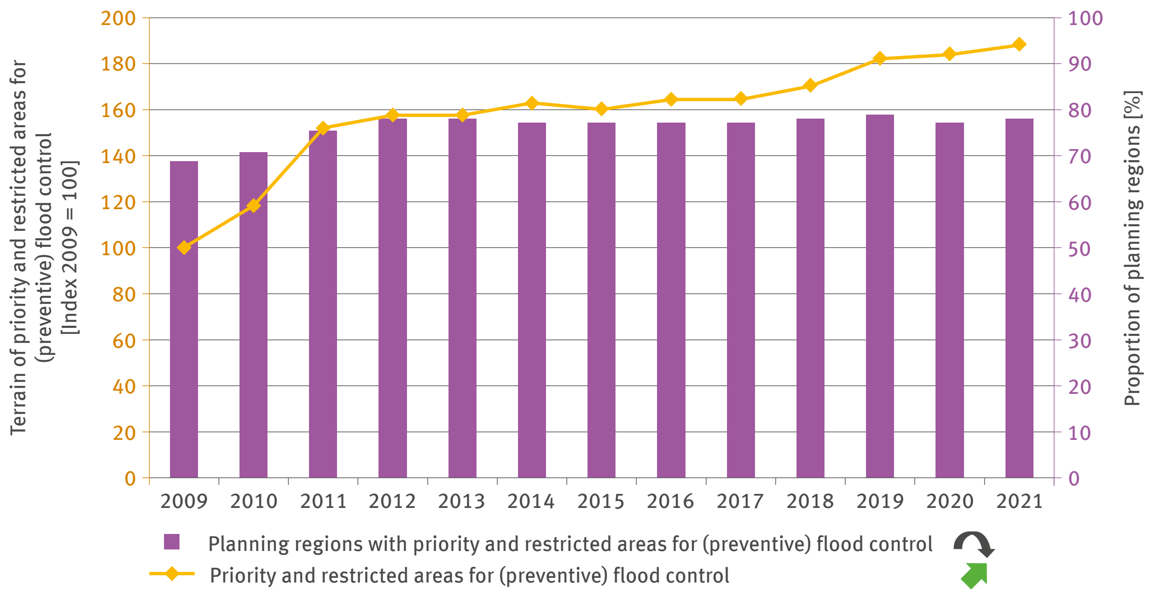
Progressive climate change is apt to change the frequency and severity of flood events and inundations, for instance when heavy rain events in summer become more frequent and more intensive, or when winter precipitation increases or falls more often as rain (cf. Indicators WW-I-4, p. 76, WW-I-5, p. 78, BAU-I-4, p. 224). In cases where soils are already saturated with water or severely desiccated, or there is a lot of precipitation in a very short time, not much of this will be able to infiltrate the soil. As a rule, this precipitation will run off the surface draining directly into water courses. Consequently, provident flood control is an important measure for the adaptation to impacts of climate change (cf. Indicators WW-R-2, p. 92, and WW-R-3, p. 93).

The designation of flood plains therefore is a key component of preventive flood control, as per mandatory regulations laid down in the Water Resources Act (WHG), to be observed nationwide. It is the remit of competent authorities to designate flood plains within areas perceived to be at risk thus ensuring that they are available for flooding in case of a so-called 100-year flood event. Furthermore, areas such as flood polders and flood channels have to be included in this designation to serve as flood relief spillways.

However, over and above any legal water-related regulations, it is the remit of spatial planning to use its own tools for contributing to preventive flood control. An essential element of the planning toolbox available for this purpose is the use of spatial planning specifications on flood control. These can be used to govern land use in a way that makes an area less vulnerable to flood risks given that such risks are expected to increase as a result of climate change. In endangered areas, it is possible – beyond the requirements of water-related legislation for floodplains – to preclude the utilisation of these areas for settlement or infrastructure purposes. Areas of importance for water retention in the landscape and for provident flood control with a view to climate change, can be safeguarded or protected by means of imposing usage restrictions.

RO-R-3: Priority and restricted areas reserved for (preventive) flood control

In the period of 2009 to 2021, the terrain of priority and restricted areas for (preventive) flood control underwent a distinct increase by approximately 6,300 square kilometres. By the end of 2021, 89 of 114 regions had incorporated relevant specifications in their regional plans.



Data source: BBSR (ROPLAMO – spatial planning monitor)

The most significant spatial planning tool for this purpose is the designation of priority areas for preventive flood control. In any such areas, flood protection takes priority over any other utilisation of space or spatial functionalities. Any types of spatial utilisation incompatible with this objective are precluded in this area. So far the practice of designating priority areas has been generally heterogeneous among planning regions. However, it is typically based on the demarcation of recognised flood plains in line with water-related legislation. In some cases, specifications are included in regional plans as memoranda, in others the designated priority areas are identical with specified flood plains, while in some other regions priority areas extend beyond the demarcation of flood plains.

As decreed in the WHG, the designation of flood plains was supposed to be finalised by the end of 2013. As was to be expected, however, numerous planning regions have had to postpone any first-time or renewed designation of priority and restricted areas reserved for preventive flood control to a later date, and in some planning regions this transition still remains to be completed. By 2021, the overall terrain designated as priority and restricted areas in planning regions employing regional planning comprised a total of approximately 13,500 square kilometres. While the number of designating planning regions remained virtually constant over the past 10 years, there has been a continued increase in the nationwide designation of terrain reserved for flood control, largely due to updates and newly drawn up regional plans. Overall, the extent of designated terrain has experienced an increased since 2009 by 6,300 square kilometres.

In the interest of the adaptation to impacts of climate change and in order to enhance risk provisioning for extreme flooding events, it seems desirable – where appropriate – to strengthen spatial planning designations for preventive flood control by going beyond the legal specification of flood plains. In past years, various modelling projects with regard to spatial planning were used to explore what possibilities exist for risk provisioning also in those areas which, strictly speaking, are already protected from floodwater by dykes. In the region of Oberes Elbtal-Osterzgebirge, for example, a new methodology was developed for designating priority and restricted areas for preventive flood protection and this methodology was implemented in their regional plan. In this process, the demarcation of priority areas for flood provisioning is based on the risk intensity (water depth and flow rate) of an extreme flood water scenario and also takes into account the existing settlement area. The increase

Spatial planning is entitled to designate retention spaces along riversides in terms of priority and restricted areas for flood control. (Photo: © Norbert G. Bildwerk / stock.adobe.com)

in designated areas reserved for priority and restricted areas for preventive flood control since 2018 is due to the fact that the regional plan in the region of Oberes-Elbtal Osterzgebirge as well as other equivalent designations in other planning regions came into force at that time.

Safeguarding terrain to ensure a good local bioclimate

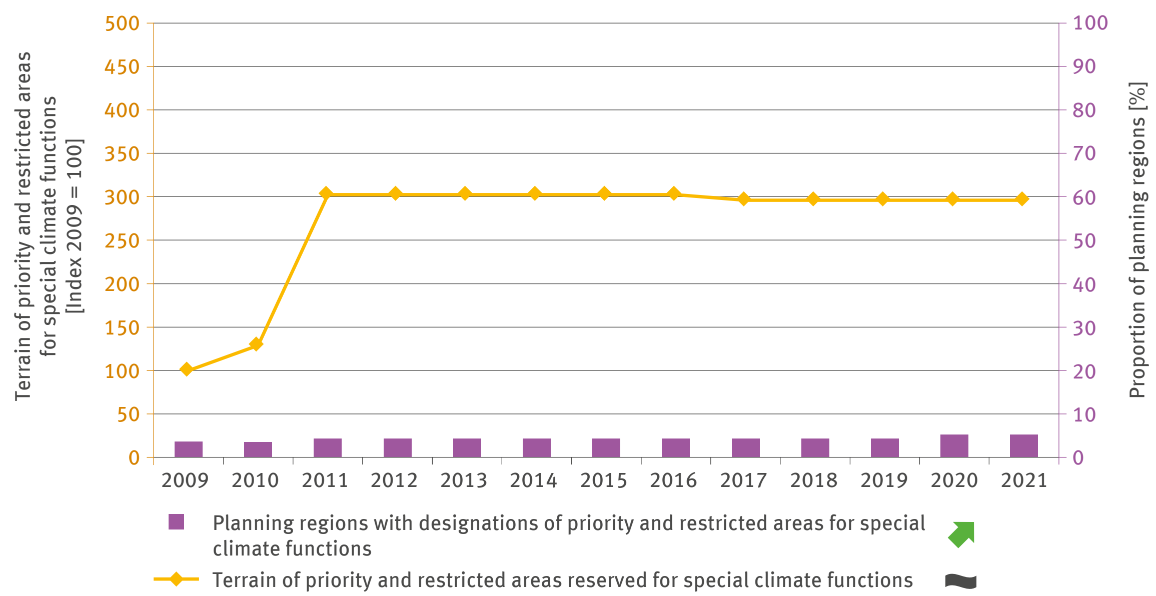
In towns and greater conurbations with high-density settlements and a high degree of sealed surfaces, it is common to measure distinctly higher average temperatures and higher peak temperatures than in their periphery – this effect is termed 'urban heat island' (cf. Indicator BAU-I-2, p. 221). The intensity of heat island effects increases with increasing population density. In larger towns with approximately 100,000 inhabitants the temperature difference between town and periphery can be up to 6 °C. Depending on natural bio-climatic conditions (such as geographical aspect, altitude etc), this effect can in summer months give rise to increased heat stress in towns compared to the periphery, and climate change may lead to a future increase in the occurrence of this phenomenon. It is a fact that particularly town spaces cool down more slowly in the evening or at night compared to the periphery; this can cause difficulties to the population, when high temperatures do not make it possible to have a good night's rest. For example, in the megacity of Cologne at the end of a clear night a difference in excess of 10 °C was recorded (cf. Indicators GE-I-1, p. 40, BAU-I-1, p. 220).

Regional planning is able to counteract this projected increase in bio-climatic stress situations by designating climatically important large-scale open areas as priority and restricted areas reserved for specific climate functions, where cool and fresh air accumulates, and by networking those priority and restricted areas with localised green spaces, thus permitting the passage of fresh air into urban spaces. In this way regional planning is able to prevent any land use which might counteract these objectives. Furthermore, planning can also be used to designate areas where – in view of local circumstances – specific action should be taken in order to reduce bio-climatic stress.

It is true to say, however, that hitherto the designation of priority and restricted areas for facilitating specific climate functions has materialised in very few regions. One reason for this is that this planning category is currently still relatively new whereas plans created at state and regional level typically remain in force for extended periods. Innovations therefore take time to establish themselves gradually as an integral part of such plans.

RO-R-4: Priority and restricted areas reserved for special climate functions

Priority and restricted areas reserved for special climate functions constitute a fairly new tool used in spatial planning. This is why this area category has so far been applied in only six planning regions nationwide.



Data source: BBSR (ROPLAMO – spatial planning monitor)

Another reason is that regional planning also uses other spatial planning tools for the protection of open spaces, such as regional green belts for safeguarding such climatically important open spaces; alternatively, regional planning uses for example a symbolic approach by illustrating bio-climatically relevant ‘air channels’ without allocating tangible tasks to specific areas. Whatever tools are used and in what way they are employed, is also dependent on the designation practice adopted in the federal state concerned. This is why there may not be an additional requirement for the designation of specific areas.

The planning regions of Hesse, Rhineland-Palatinate and Saxony – where priority and restricted areas for specific climate functions were designated previously – both of the above-mentioned objectives are thus being pursued: Reserving climatically important open spaces and identifying bioclimatically stressed areas as being in major need of action. In Hesse regional plans have to fulfil the purpose of safeguarding areas sustainably so that they can serve as climate-balancing spaces or as air channels. In the regional plans for Middle Hesse and Southern Hesse areas are specified in detail where cool and fresh air accumulates and from where such air can be channelled elsewhere, in order to safeguard and – where necessary – restore such processes in these areas. These areas are to be kept clear of development or any other measures which might inhibit the accumulation or transport of fresh and cool air. Any plans and measures which might impair the aeration of locations exposed to climatic stress or air-quality stress are to be avoided in those areas. Their implementation is permitted only in cases where evidence can be submitted proving that no substantial detrimental climatic impacts would ensue.

The second approach within the planning category as outlined above has been adopted in the regional plan for Middle Rhine-Westerwald and in the regional land use plan for Frankfurt / Rhine-Main. In this case, thermally stressed spaces and climatically vulnerable valley locations are designated as restricted areas, partly with the objective to enhance the prevailing climatic conditions as much as possible. To this end, it is intended to conserve or expand climate-balancing areas or to avoid housing development projects which would impede the free passage of fresh air.

Terrain which produces fresh and cool air for balancing the local climatic conditions is not just important in warm regions such as the Rhine-Main area.
(Photo: © A. Emson / stock.adobe.com)

Curbing land take-up benefits climate adaptation

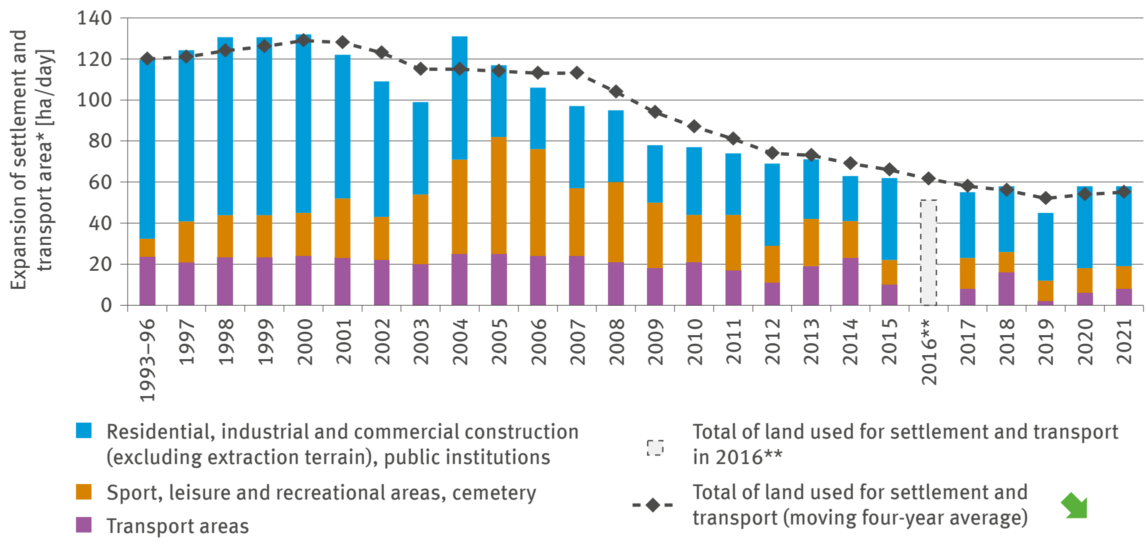
A terrain that has not been built on. is unfragmented and free from urban sprawl, is a limited and desirable resource which is much in demand and the object of competition among sectors such as agriculture, forestry, developers, transport infrastructure, nature conservation, the exploitation of raw materials and the generation of energy. The designation of priority and restricted areas is a tool used by spatial planning in order to guide the development of land use including the curbing of new land take-up, and to balance competing claims on land use. After all, it matters to conserve or further enhance ecosystem services important to humans and wildlife alike.

In connection with changing climatic conditions, these ecosystem services address the potential of unsealed surfaces to allow the infiltration of precipitation and also – especially at times of heavy rain or flood scenarios – to provide temporary water retention services. Alluvial meadows free from building developments give rivers space to expand and can take pressure off the underlying areas of river basins at times of flood (cf. Indicators BD-R-2, p. 210, and RO-R-6, p. 312). In bioclimatically stressed spaces, the passage of fresh and cool air to residential areas is paramount. On the periphery of conurbations, air is apt to cool off faster in the summer months above meadows and arable land than in residential areas. Air channels such as parts of open valleys transport the cool air to neighbouring residential areas thus mitigating any thermal stress (cf. Indicator RO-R-4, p. 308). As far as agriculture and forestry are concerned, and also in respect of the harvesting of renewable raw materials, it is above all relevant to protect fertile soil and productive land in a sustainable way for the future. Moreover, animals and plants depend on open spaces and unfragmented, networked landscape structures for their habitats. If habitat conditions change as a result of climate change, fauna and flora are in need of functioning biotope networks enabling them to adapt.[222]

Land that is free from buildings retains its potentials, or such potentials are relatively easily restored, if the change of use involves agricultural or forestry purposes, provided the type of new land use is, for example, the generation of renewable energy or multiple usage such as agri-photovoltaics or nature conservation, whereas the

RO-R-5: Increase in settlement and transport areas

In terms of the four-year average rate, the growth in settlement and transport areas slowed down for many years. Lately their growth stagnated at some 55 ha per day. Even though the recent transition to ALKIS in institutional real estate cadastres limit the information value of this figure, it can be stated with certainty that this increase in land use clearly exceeds national objectives. In other words, there is more left to do in order to protect land resources and their functionalities.



*The area survey was based on the evaluation of real estate cadastres maintained by the individual Länder. Owing to the transition to ALKIS in the cadastres, the illustration of increase in land take-up since 2004 is distorted. **The transition of the data source to ALKIS in 2016 is currently impeding the time comparison and the calculation of changes. However, the settlement and transport area continues to cover largely the same types of land use as before.

Data source: StBA (expansion of settlement and transport area), UBA (DzU) potentials would be permanently lost, if the new land use were to involve developing the terrain for settlement or transport infrastructure or if it were to involve any form of mining such as large-scale quarrying projects. The reduction of areal land take-up – with its various adverse effects – can therefore be seen as a general adaptation measure the implementation of which can be supported by means of the toolbox available to spatial planning.

At the same time, curbing any new land take-up is also one of the key sustainability objectives pursued by the Federal Government. Originally it was intended for any new land take-up for residential and traffic purposes – as laid down in the national sustainability strategy adopted in 2002 – to be reduced to 30 ha per day by 2020. The updated German Sustainability Strategy[223] now intends for the daily increase in the take-up of residential and transport terrain to be reduced to less than 30 ha by 2030. The BMUB's Integrated Environmental Programme adopted in 2016[224] even exceeds this target. With a view to the target path for the implementation of the EU's resources strategy and the climate protection plan 2050 which envisages that by 2050 the transition to a circular land use management will have been completed and any new take-up of land will have been reduced to net zero, a value of 20 ha per day has been set as an interim target for 2030.

In contrast with the powerful expansion of residential and transport areas in the early 2000s, the new take-up of land has more than halved in recent years. While the moving four-year average was then in excess of 130 ha per day, the mean of the period from 2018 to 2021 amounted to 'just' 55 ha per day. There are several reasons for this. Essential regulations were tightened up in the construction and planning law. At Federal, Länder and municipal level, efforts were redoubled in the endeavour to be more provident in the use of land resources. The weaker economic development and economic crises such as the banking crisis, combined with changes in demographics, curbed the private and commercial demand for buildings.

Above all, the sector covering residential, industrial and commercial construction (excluding extraction terrain) as well as public institutions contributed to the increase in settled areas in the period from 2018 to 2021. Latterly, this sector grew in 2021 with figures of approximately 39 ha per day, residential housing making the biggest contribution to this growth. Sport, leisure, recreational and cemetery areas contributed another 11 ha to the settled terrain; transport areas increased by just under 8 ha per day in 2021. In that respect, the main driver was the areas used for road transport.

Provident handling of land resources is to be seen as integral to climate adaptation. The fewer sealed areas there are, the better. (Photo: © ThomBal / stock.adobe.com)

The increase in land use for settlement and transport areas in terms of the four-year average in the past two years has interrupted the mostly continuous decline in new land take-up which had prevailed since 2000. Admittedly, various conversions and transitions in the performance of area surveys during recent years have limited the comparability of data. Nevertheless, the development emerging in the course of recent years makes it clear how challenging the task is to achieve the objectives set in the German Sustainability Strategy and the Integrated Environment Programme. Further endeavours are required, also with regard to the effects of a provident handling of land resources on climate change adaptation. Thanks to its toolkit consisting of informal and formal tools, spatial planning can make valuable contributions in this respect, for instance by means of circular land use concepts. Any additional efforts required to achieve provident land use will have to take account of potential impacts resulting from climate change. Among other things, it is not acceptable that an intensified settlement development in an inward direction, that is to say, by means of land recycling or retro-densification, should be allowed to make the existing bio-climatic stresses worse. In fact, building development would require the negotiation of suitable solutions and compromises in the course of in-situ structural development, so that the often competing objectives and challenges are met.

Provident climate protection in housing developments

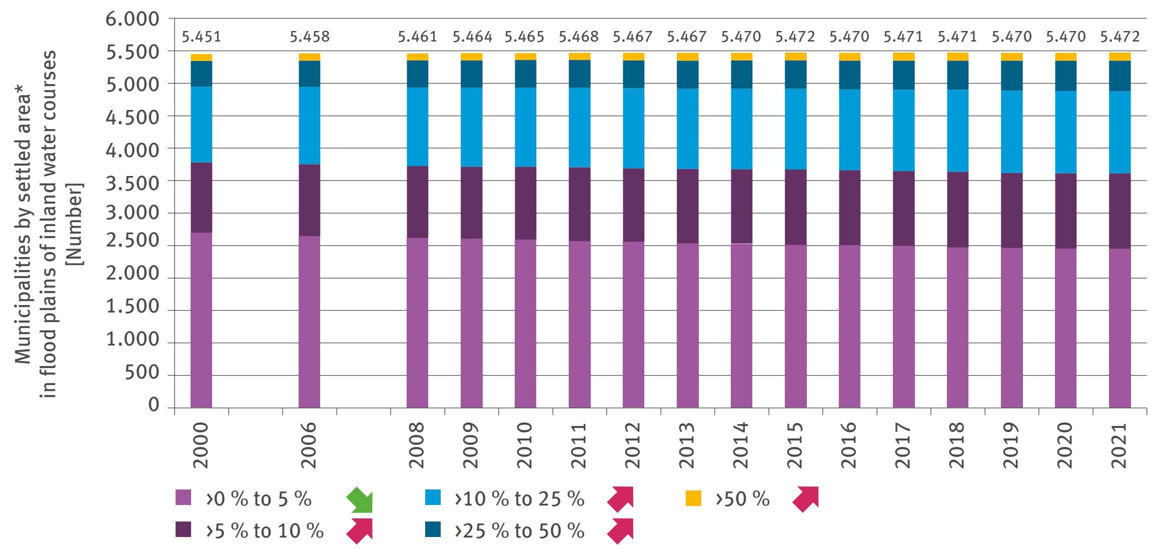
In connection with climate change, it is a particularly important and increasingly essential task of spatial planning to make appropriate provision for potential risks. On one hand, spatial planning can help to steer the development of settlements deliberately into directions where risks associated with climate change either do not exist at all or exist only to a manageable degree. Besides, spatial planning can ensure that recognisably vulnerable areas are to be kept, as far as possible, free from any settlement activity. Relevant risks to be considered in planning processes include the sudden mass movement of materials such as rock falls, landslides or sinkholes as well as – in coastal areas and on islands – storm surges. Such hazards can increase regionally as a result of climate change, if extreme weather situations and weather patterns increase in both frequency and intensity.

In conjunction with the specific legal requirements to be observed in respect of flood protection, spatial planning must take special care to consider in its planning processes any flood hazards associated with rivers and streams, making certain that preventive flood protection is implemented resolutely.[225] Progressive climate change goes hand in hand with changes in precipitation scenarios, thus increasing hazards connected with flood events: Such events can turn out to become more frequent, and the outcomes, as shown drastically in 2021, can be very serious (cf. Indicators WW-I-3, p. 74, WW-I-4, p. 76).

The course of flood events and their damage potential are considerably influenced by human activities, both in the past and nowadays. For example, in former times natural flood plains in many river valleys were eliminated by measures such as building dykes and river modification. Numerous watercourses were shortened thus increasing the flow rate of the rivers concerned. In times of flooding, the waters from many tributaries therefore now accumulate faster in a river bed; the resulting flood waves are often steeper than in the past and their travel times shorter. Consequently, there is an increased risk of damage from floodwater. Besides, valuable material assets were constructed in the shelter of dykes where the land was formerly available for rivers in terms of flood plains. If the flood protection provided proves inadequate when these

RO-R-6: Land use for settlements in officially designated flood plains

In spite of the existing flood water hazards, settlement pressure is so high that building continues even in flood plains, thus counteracting the regulation laid down in the Federal Water Act which stipulates that this be limited to exceptional cases only. The number of municipalities where more than 5 % of buildings in settlement and transport areas is located in flood plains, is even now continuously and significantly increasing.



*Settled areas: Percentage of settled area in an officially designated flood plain near an inland water course, which is characterised by built-up settlement and transport areas.

Data source: IÖR Monitor
Territory status: municipalities: 31.12.2020; officially designated flood plains (Länder): 31.12.2019 / 31.12.2014 (Brandenburg)

settlements or industrial estates are flooded, the damage caused can in some cases be considerable (cf. Indicator BAU-I-5, p. 226).

Nowadays, protection from flood events is covered by the German Water Resources Act in accordance with specifications contained in the regulations laid down in the HWRM-RL. Furthermore, as far as inland waterways are concerned, it is required in Germany in accordance with provident land use to stipulate binding specifications for flood plains on the basis of (statistically speaking) once-in-a-hundred-years flood events (HQ100); these specifications have to conform to specific protective rules. In such areas, both the allocation of urban development plans for new building locations in the outskirts, and the construction or extension of buildings, are either prohibited or permitted only in exceptional cases. Furthermore, it has been mandatory since 2018 that any flood formation areas be identified, and express permission is required for such areas where specific changes of land use such as conversion of grassland to arable land or conversion of alluvial woodland to another type of land use are proposed.

However, in the past many forms of developments such as transport areas, industrial and trade buildings as well as residential buildings had already been implemented in numerous flood plains associated with inland watercourses. For instance, according to the Monitor of the Development of Settlement and Open Spaces[226] maintained by the Leibniz Institute of Ecological Urban and Regional Development (IÖR), in about half of municipalities of Germany buildings have been erected in parts of flood plains. Looking at the development over the past approximately 20 years, it is clear to see that – while the number of those municipalities overall remained relatively constant – there were changes in the distribution of various categories in respect of the extent of terrain used for buildings: The number of municipalities with less than 5 % of settlement and transport areas in flood plains declined significantly whereas this number increased significantly in all other categories. In other words, the increase in settlement and transport areas (cf. Indicator RO-R-5, p. 310) does not refrain from targeting flood plains. On the contrary, the building activity in terms of settlement and transport areas in those municipalities shows an increase since 2000 by circa 100 square kilometres which is equivalent to growth by just under 13 %.

According to current legislation, any further expansion of building activity leading to settlement and transport areas in flood plains ought to be limited to exceptional cases. The continuous growth recorded in past years shows, however, that despite well-known flooding risks, the pressure to build in flood plains remains high. The statistics available do not allow any conclusions as to how many other hazards such as the mass movement of materials or storm surges are taken into account when land developments are contemplated. Nevertheless, it seems that efforts need to be redoubled, also in terms of spatial planning, regional and urban development planning, at least with a view to flood protection, in order to influence and exert provident control over land development.

Now as before, there are still new settled areas developing in flood plains. (Photo: © benschonewille / stock.adobe.com)

Photo: © Andreas Gruhl / stock.adobe.com

Civic protection

Impacts of climate change – Impact

Adaptations to climate change – Response

On the relevance of the action field

Flood, heat, drought, pandemics and war – these severe events and their impacts have recently shaken Germany. In this context, progressive global warming has increasingly foregrounded natural hazards. In this country, meteorological changes have been increasing the risk of crisis situations due to weather and weather patterns. The findings of the 2022 World Risk Report[227] are among the sources acknowledging these developments: According to this Report, the risk of disasters ensuing from natural hazards have increased continuously.

It is the core task of civic protection to safeguard the safety of citizens in the event of a disaster. Germany commands an effective integrated emergency relief system which has been tried, tested and proven its worth: Organisations at Federal, Länder and municipality levels as well as private emergency services cooperate closely in order to assist humans effectively in emergencies, to keep losses at a minimum, to remedy damage to the best of their abilities and to put humans on their guard in respect of impending danger situations. One of the supporting pillars of civic protection is the great number of voluntary helpers who become involved in public and private relief organisations.

Nevertheless, disaster preparedness and management are confronted by the increasing challenges of climate change. The existing structures are being updated continuously so that civic protection can fulfil its tasks faced by the portents of climate change. The challenge is to adapt the existing resources to the increasing disaster risk, to optimise coordination and organisation, and to accelerate the implementation of effective preventive measures.

DAS Monitoring – what is happening due to climate change

In many places the organisations and voluntary helpers active in the field of civic protection are signalling that the number of call-outs due to weather events and weather patterns is on the increase, although currently – in view of the heterogeneous recording of call-outs – it is not possible to provide the relevant quantitative evidence for the entire Federal Republic. In particular, extreme weather events seem to require the deployment of civic protection crews more and more frequently. The deployment situation seems to be characterised especially by flooding events. Evidence for a close correlation between individual extreme weather events and extraordinarily high peaks of strain on volunteers is documented in the form of data recorded by the Federal Agency for Technical Relief (THW) (cf. Indicator BS-I-1, p. 320). In July 2021 violent rainfall events led to massive flooding, especially in western Germany. It was in the valleys of the Ahr and Erft rivers in Rhineland-Palatinate and North Rhine-Westphalia where one of the most severe flood disasters in the history of the Federal Republic occurred. The momentous scale of the Ahr valley flood was partly due to the fact that it occurred so very suddenly. Many people affected were caught unawares by the water masses and unable to take the necessary precautions for their own protection. In that year the THW recorded call-out figures amounting to 15,500 emergency relief responders from all THW emergency relief associations – the highest ever in the history of the organisation.[228] The more frequent and more intensive weather-related and weather-pattern related extremes arising from climate change are always reflected in new peaks of strain imposed on emergency relief members of organisations actively involved in civic protection. In addition, it has to be borne in mind that the operating capacity of volunteers can suffer from impacts on their own health due to climatic changes such as increasing heat. Furthermore, individuals may be affected themselves in terms of their premises or their private sphere thus in turn restricting the operational capacity of the organisations concerned. In order to ensure the availability of sufficient capacity in cases of call-outs, it is becoming increasingly important to redouble recruitment efforts and to ensure the availability of both employees and voluntary helpers.

Future climate risks – outcomes of KWRA

Research carried out within the framework of the 2021 Climate Impact and Risk Analysis (KWRA, cf. Reading Aid, p. 7) shows that climate change is escalating the risk of dangerous events occurring; the intensity and complexity of this risk represents an increasing challenge to the actors involved in civic protection. Extreme weather events such as, in particular, heavy precipitation can become stress tests for the emergency relief responders, in view of the fact that any resulting damage can take them to the limit of their capacity to fulfil the tasks they are faced with. Moreover, the structures of civic protection themselves can be threatened by such extreme events.

Such cases where the structures of emergency services themselves are affected can involve damage to equipment and premises, blocked access roads, failure of power tools and communication channels; worse still – they can lead to absences of crew members owing to ill health.

Given that precautionary measures and emergency relief responses are in the foreground, the KWRA – contrary to its focus in other action fields – here places the main focus on the categorisation of an organisation's capacity for adaptation. Consequently, there are opportunities, especially in facilitating, coordinating and optimising cooperation among various groups of actors such as fire brigades and rescue services, municipal authorities and infrastructure managers. Guidelines on adaptation measures or recommendations on how to behave in an emergency are apt to support the population in their endeavours to make their own best possible preparations for any future disaster scenarios. Greater compatibility among detection systems used nationwide and among recorded deployment data might contribute to the development of more effective adaptation measures on the basis of an improved data scenario.

Where do we have gaps in data and knowledge?

So far it has not been possible to achieve a methodical and comprehensive assessment at a national level with regard to the extent to which disaster situations caused by extreme weather events such as flooding or storm actually bind the emergency relief responders involved in civic protection. The DAS Monitoring Indicators for call-out and exercise scenarios are restricted by the extent of available THW data. The data provided are of an illustrative nature; in other words, they do not necessarily permit any conclusions in respect of the call-out figures incurred by other organisations. In future it would be desirable to incorporate data supplied by fire brigades and emergency relief organisations. Among these are the German Red Cross, the Arbeiter-Samariter-Bund, the Deutsche Lebensrettungsgesellschaft, the Malteser Hilfsdienst and the Johanniter Unfallhilfe. However, given the decentralised organisational structure of the associations concerned which are subdivided into numerous, legally independent entities, there are currently no coordinated data sources available nationwide regarding the deployment figures of such organisations. This is also true with regard to fire brigades for which comparable inter-municipal regulations in respect of the recording of deployment figures exist only in exceptional cases. Furthermore, the majority of individuals involved have been recruited as volunteers, and there are limited time capacities available for establishing a statistically viable data collection on the basis of homogeneous criteria. A fundamentally changed data scenario is therefore unlikely to emerge in the future. Moreover, in order to provide a more detailed description of climate change impacts on civic protection and any potential requirement for measures, it would be desirable to have a documented record outlining to what extent the premises used by civic protection organisations themselves are affected by climate change impacts. To date the data required are either not available or available only from isolated surveys.

Surveys of the population's awareness of natural hazards have only recently become the focus of interest. In the context of the development of the DAS monitoring indicator system, it became possible to gain insights into the hazard and prevention awareness of the German population by means of the environmental awareness studies conducted at regular intervals. However, as the surveys only started in 2012, the time series are currently still short. The reliability of the data is therefore limited and conclusions about future developments are only possible to a limited extent, if at all. With regard to civil protection and its further development, the environmental awareness studies also only provide a limited picture: for example, it is not possible to draw direct conclusions about the actual self-help capacity of citizens from their level of information, which depends not only on the level of information but also on the actual possibilities in the respective situation.

What's being done – some examples

Given the increasing risk of weather-related and weather-pattern related disaster situations likely to entail increased strain on emergency relief responders, the organisations concerned are called upon to adapt their capacities and organisational structures to any new conditions evolving. A central building block is the recruitment of volunteers in order to secure an increasing or at least permanently stable pool of emergency relief responders. The increase in membership numbers is evidence of the intensified efforts to recruit more responders, at least as far as THW and fire brigades are concerned (cf. Indicator BS-R-4, p. 328).
There are nationwide campaigns intended to boost membership numbers in years to come, such as THW's campaign launched in 2020 translated as 'Your Time is NOW!', and

the BBK's campaign for recruiting volunteers, launched in 2021, translated as 'No matter what you can do – you can help' and the accompanying establishment and operation of a web-based platform which is named 'mit-dir-fuer-uns-alle.de'. Adverse circumstances such as the worldwide Covid-19 pandemic did not entail any marked decline in membership numbers. At the same time, the increase in major deployment events and their media coverage led to an increase in the public's interest in becoming involved in civic protection. The new membership includes more and more female recruits, as well as migrant individuals and seniors.

New social and technical developments have been opening up new avenues in respect of civic protection, too. For example, during the flood events of 2013 and 2016 and during the flood disaster in the Ahr valley in mid-2021, thanks to social networks, emergency relief was organised quickly in many of the areas affected. In the light of Standard ISO 22319:2017 'Guidelines for planning the involvement of spontaneous volunteers (SVs)'[229] the conceptual framework for a coordinated incorporation of SVs is currently being further enhanced in cooperation with the deployment organisations and the Länder in order to make even more effective use of the existing willingness of volunteers – who are less interested to commit themselves to fixed structures than in the past – to get involved in providing emergency relief.

In addition, the practice of civic protection benefits from findings made in scientific research projects. Within the framework of the KlamEx project, the BBK and other partner authorities within the strategic alliance of authorities entitled 'Adaptation to Climate Change' analysed in what way extreme precipitation shapes and influences the deployment scenario, in what way impact factors determine the extent of damage and what kind of measures can support the risk preparedness for heavy rain in terms of civic protection and urban development. In this context, the comprehensive catalogues compiled by DWD of heavy rain events in Germany were included in the sources consulted. Going back as far as 2001 these catalogues provide valuable data on heavy and persistent rain and therefore play a part in supporting the follow-up analysis of extreme precipitation events.

With the aim to prepare their members for call-outs in the best possible way, civic protection organisations carry out regular exercises. These lay the foundation for appropriate action in extreme situations and for practising targeted crisis management. The data provided by THW demonstrate that even in years with extreme events, it is possible to carry out the requisite amount of training exercises adequately, both in terms of time and participants (cf. Indicator BS-R-3, p. 326). This provides an important basis for the stability of civic protection, given that owing to climate change, it is possible that weather-related and weather-pattern related disaster events are likely to occur more frequently.

According to the findings of KWRA 2021 there are adaptation potentials especially in respect of the funding, coordination and optimisation of cooperation among the variety of organisations active in civic protection. Emergency relief organisations active throughout the Federal Republic, but also fire brigades and the THW cooperate with public authorities such as the BBK, the UBA, the DWD or the BBSR on the objective to integrate their knowledge on climate change impacts and adaptation potential in the practice of civic protection. Besides, the organisations involved also reflect their own structures in this process while optimising their internal processes.

Apart from the work done by various organisations, the population's ability to protect themselves is an important component of civic protection. The challenge is to sharpen citizens' awareness that they should implement their own preventive and protective measures and, tailored to each target group, to enlighten the population on how to behave in a disaster scenario. The BBK's nationwide information campaign translated as 'Ready in case' is one of the measures that serve this purpose. The findings of studies on environmental awareness indicate that the population's awareness and sensibility are on the increase (cf. Indicators BS-R-1, p. 322, and BS-R-2, p. 324). In 2021 the proportion of respondents who felt sufficiently well informed about relevant risks from climate change impacts reached two thirds – the highest value yet. Moreover, there were more individuals than in previous years who stated that they would take precautionary measures of their own.

A comprehensive and reliable warnings infrastructure is an important building block in the scheme of the population's self-protection. Digital warning apps such as NINA (Emergency Information and Warning App of the BBK) convey vital information to the public at times of disasters while the early warning system enables individuals in time to take the necessary precautions. The competent institutions are working continuously on improving and expanding these services. In February 2023, Cell Broadcast was taken into regular operation as a new warning system. This tool facilitates the cell-enabled broadcasting of warning messages straight to mobile phones or smartphones. Apart from digital solutions, permanently installed analogue sirens are part of Germany's warnings infrastructure. They bridge gaps in cases when mobile technologies have become temporarily unavailable or have broken down. With its funding programme for sirens, the Federal government has been supporting since 2020 the installation of new sirens and the technical updating of existing installations.

Climate changes relevant to the action field

Extreme events

In Germany heavy rain is one of the extreme weather phenomena which have a particularly strong potential of putting people's lives and infrastructures at risk. Spatial and temporal variability of heavy rain, and the fact that such events are associated with problems of measurability, make it difficult to make solid forecasts of trends. However, it is safe to predict that climate change is likely to bring about an increase in heavy-rain events and concomitant intensity. On one hand, higher temperatures warm up the air which enables it to absorb greater amounts of water vapour. On the other hand, the associated meteorological changes bring about the intensification of processes which trigger precipitation. DWD records indicate that in recent years heavy rain occurred, at least regionally, with greater frequency (cf. page 24).

Impacts of climate change

BS-I-1 Person hours due to weather-related damage events

In cases of severe natural hazards, emergency crews are mobilised by civic protection organisations, in order to rescue humans from emergency situations arising in affected areas, to secure provisioning and to avoid or remedy any damage. The organisations involved in civic protection and their volunteers are facing ever-increasing peaks of strain resulting from rising numbers of weather-related and weather-pattern related call-outs. Apart from violent storms the deployment situation seems to be characterised especially by flood events due to heavy rain. The most recent severe flooding scenario that kept volunteers on their toes took place in July 2021 in the Ahr valley.

Adaptations – activities and results

BS-R-4 Active emergency relief responders in civic protection

In order to meet the increasing demand for disaster relief responders and to reduce the strain imposed on volunteers – resulting from frequent call-outs owing to climate change – the organisations involved in civic protection have been stepping up their recruitment measures. And this has been rewarded with success: In 2021 there were 50,000 more individuals active in fire brigades and THW than just five years before. It is also true to say that adverse working conditions and particular challenges during the worldwide Covid-19 pandemic did not entail a marked decline in membership numbers.

BS-R-2 Precautions taken among the population

The population's own precautionary measures play a crucial role in supporting the emergency relief responders. A person who has taken precautionary measures requires less assistance and can sometimes take the pressure off emergency relief responders by providing assistance themselves. The organisations concerned can provide information on the risks involved and give advice on how to behave in an emergency; they can also make suggestions for effective precautionary measures. In the 2021 environmental awareness survey more than two thirds of respondents stated that they would take what they consider as sufficient precautionary measures of their own. This is the highest value since the launching of these surveys in 2012.

Extreme events entail unprecedented deployment peaks

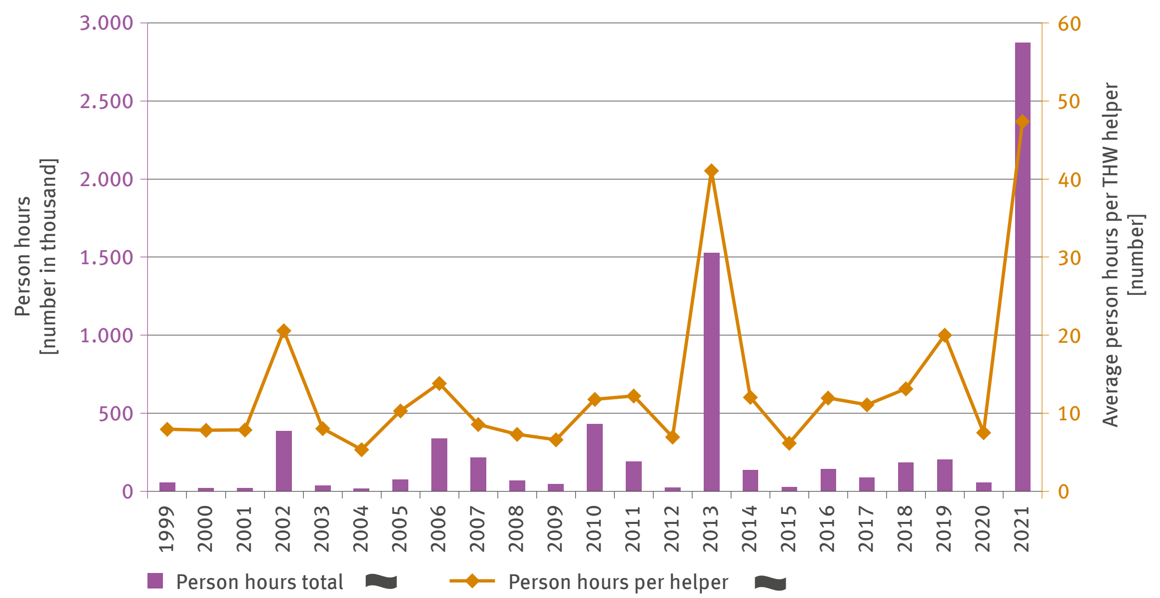
In the course of the past two decades, Germany has experienced a number of meteorological extreme events. As a result of climate change, such events have been occurring more frequently and with greater intensity. Extreme weather events sometimes entail massive call-out stresses imposed on emergency relief responders involved in civic protection. After all, part of the essential remit is to provide technical assistance whenever extreme weather-related and weather-pattern related events cause emergency or disaster situations. For example, emergency relief responders are able to secure dykes by means of sandbags or install mobile flood protection walls in order to prevent flooding; they evacuate residents and they prevent the flooding of industrial or sewage treatment plants. After severe storms or hurricanes the emergency relief responders remove windthrows from roads and rails making them passable again. Even after a relatively brief and localised heavy-rain event, emergency relief responders are often busy for hours pumping out flooded cellars and pumping living accommodation dry.

In many places the organisations active in the field of civic protection are signalling already now that the number of weather-related call-outs for which technical assistance is required is on the increase. There are detailed quantitative and comparable data available on the number, duration and causes of call-outs carried out by THW. Although so far no significant trends have been identified regarding long-term increased strains on emergency relief responders, the figures for recent years demonstrate the way in which individual extreme events – and above all the 'floods of the century' in various river basins – have characterised the deployment situation.

In the early summer of 2013, entire sweeps of country in Central Europe were inundated owing to rainfalls lasting for days on end. In Germany, a total of nine Länder were affected, especially in the east and south-east, in the river valleys of the Danube, Elbe and Saale. Severe flooding entailed the greatest deployment of fire brigades Germany had ever before experienced. The THW itself rates the year 2013 as unprecedented in terms of the call-out pressure on volunteers: The total number of person hours in that year amounted to 1.5 million.

BS-I-1: Person hours due to weather-related damage events

In years dominated by hurricanes, heavy rain or extreme flood events, there is a distinct increase in the emergency relief workload to be dealt with by THW volunteers. The time series examined is strongly characterised by severe individual events. The impacts made in 2021 by the 'Bernd' low-pressure system and the associated flood disaster which struck western Germany in particular, culminated in the highest call-out peak ever. So far, no significant trend has been identified.



Data source: THW (helper statistics)

In July 2021 one of the most severe flood disasters experienced in Germany's history triggered the greatest ever call-out effort since the foundation of the THW. Parts of the Ahr valley in Rhineland-Palatinate were impacted particularly violently. The overwhelming volumes of water took many people by surprise. There were numerous fatalities and thousands of casualties. For months on end a great number of emergency relief responders from all over Germany, including some 15,500 THW responders, gave assistance in the areas affected.[230] The extent of the disaster meant that volunteers across the entire range of skills and capabilities were required: In the first few days the focus was concentrated primarily on rescue and pump operations. As water levels receded, the physically demanding workload shifted increasingly to clearance and infrastructure operations. As a result of massive destruction, it was necessary to restore the electricity and water supply in many locations. Besides, utmost priority was given to the (provisional) restoration of impassable or destroyed highways and bridges in order to safeguard the supply of relief goods to the population. Overall, the THW's emergency relief responders worked just under 3 million person hours in that year.

Extreme flooding and hurricanes entail peaks of strain incurred by emergency relief responders involved in civic protection. (Photo: © medienweber / stock.adobe.com)

The high number of call-out figures incurred in 2002, 2006 and 2010 were also mostly due to flooding events. The above-average call-out figures for 2007 were predominantly due to the hurricane Cyril in January. In May and June 2016, the impacts of heavy rain kept emergency relief responders on their toes nationwide. From the end of May until the beginning of July some 10,000 THW emergency relief responders were in action day and night. Events in the town of Simbach-am-Inn gave rise to the THW's biggest drinking water emergency relief operation in Germany hitherto. In the course of a fortnight the THW supplied the population with a total of 5.6 million litres of water. Another focal point was the restoration of road bridges and supply infrastructures which had been destroyed by streams and rivers turning into raging torrents.

The steadily high demand for emergency relief services continuing work week after week is a particularly great challenge for THW as the organisation relies predominantly on voluntary helpers for their emergency relief operations. For some volunteers this involves release from their place of work, sometimes for weeks on end – a tricky situation given the current labour market. This results in a high turnover of emergency relief responders, which requires increased coordination and entails organisational problems.

Basically it has to be borne in mind that the THW's call-out figures provide only limited clues as to the other organisations involved in civic protection because the THW operates only on demand. Besides, the figures are also dependent on the type of events occurring, because in specific call-outs, it is above all the THW with their specific material equipment which will be geared up for the task.

The KlamEx project of the strategic alliance of authorities entitled 'Adaptation to climate change' explored in 2019 to 2021, to what extent call-out figures recorded by fire brigades are suitable for an inter-municipal analysis of the call-out strain incurred as a result of extreme weather events. A survey regarding the documentation of tempest-related call-outs, in which 10 Länder participated was conducted within this framework. The responses showed that a great number of input systems were used and that there were differences in the categorisation of the deployment cause or in the interpretation of the term 'Einsatz'. For this reason there are limitations to any comparison of call-out figures from one municipality to another. This is in contrast to deployment data from Länder in which homogeneous regulations existed for the collection of call-out figures within their area of responsibility. The introduction of a nationwide homogeneous regulation is not foreseeable for the near future.

Notwithstanding the lack of a homogeneous data basis, it has to be assumed that in respect of years with distinct extreme events high deployment workloads accrue both in fire brigades and in private emergency relief organisations owing to weather-related and weather-pattern related events and that such call-outs are associated with complex difficulties on account of the voluntary nature of the organisational structures concerned.

Openness to information and knowledge is increasing

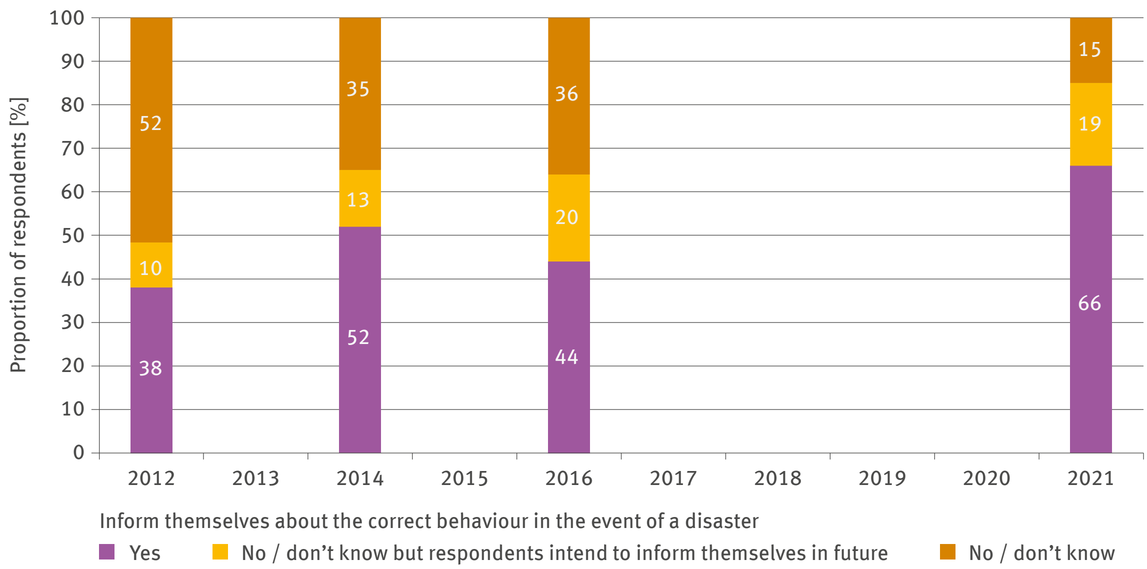
The population's ability to protect themselves is an important component of civic protection. The term self-protection encompasses the total of individual measures taken by the population, the authorities and / or businesses in terms of the prevention, precautionary measures and self-help required for coping with events. By behaving appropriately in emergencies, citizens can protect their own safety and that of their fellow human beings at the same time as helping to improve overall safety.

In case of an accident or emergency situation, emergency relief responders need time to reach their target location and provide the necessary assistance. In case of an accident, this might typically just take minutes whereas in weather-related or weather-pattern related extreme events it can take considerably longer for rescue teams to arrive in sufficient numbers enabling them to assist everyone concerned. This was lately demonstrated by the severe flood disaster in the Ahr valley in July 2021 when roads and bridges were carried away by masses of water thus barring volunteers from direct access to flood victims. It can also happen that the geographical extent of the emergency location is particularly widespread making it difficult to reach all individuals in need of assistance as fast as necessary. In order to protect life and limb and also to protect material assets, it is therefore of particular importance for citizens to be able to help themselves in the first instance until the fire brigade, rescue services or disaster relief services arrive to provide assistance in a more organised way in events such as severe tempests, extraordinarily heavy falls of snow, flash floods or large-scale flooding.

To this end, it is vital that appropriate assistance can be provided by individuals who are well acquainted with the potential impacts of damaging events before these actually occur. It therefore matters that as many people as possible are familiarised with the potential risks and that they are well informed on how to behave in emergency situations. In recent years, technical progress in the processing and dissemination of geographic information has produced numerous new sources available to citizens to inform themselves on hazards that might exist either locally or regionally. For example, the internet provides information on flooding hazards, some of which is specifically focused on

BS-R-1: Information on how to act in a disaster situation

In 2021, 66 % of respondents to the environmental awareness survey stated that they had informed themselves on the appropriate behaviour in a disaster situation, while another 19 % stated that they intended to do so in future. 15 % of respondents do not see any point in informing themselves. This is so far the lowest figure recorded in these surveys. The survey outcomes indicate that there is an increasing awareness and sensibility among the population.



Data source: BMUB/BMUV & UBA (study ‚Umweltbewusstsein in Deutschland', for 2021: additional survey in the framework of the study ‚Umweltbewusstsein in Deutschland 2020')

individual land parcels; it also provides information on Geo Risks such as mass movements, landslides or risks of storm damage. The GDV offers its 'Naturgefahren-Check' (natural hazards check) on the internet which provides online estimates for individual addresses on natural hazards such as flooding, storm and hailstorm, lightning and overvoltage.

On the basis of their awareness of hazards which might exist regarding the area where they live or work, citizens can obtain information on how to behave in emergency situations. On one hand, it is important for instance to develop and maintain general skills for instance in First Aid courses. On the other, specific information material is made available by authorities. At Federal government level, the BBK provides information on how to behave in a disaster, for example by means of leaflets and through its website. The website includes offerings such as a new interactive programme entitled '360° Notfalltraining' (emergency relief training' which is intended to facilitate – especially for younger target groups – access to subjects like precautionary measures, self-protection and how to behave in emergencies.[231] The information campaign launched in 2021 entitled 'Für alle Fälle' (translated as 'Ready in case') includes the use of tv spots to address a variety of target groups in the population. Besides, citizens can subscribe to the Federal government's warning app NINA to receive warnings in respect of civic protection or storm warnings issued by the DWD which also provides flood information via its transnational Flutwasserportal (Flood Portal) for both individually selectable locations and for their own specific location (cf. Indicator HUE-2, p. 334). In addition, there are information services provided by individual Länder and in some cases by competent municipal authorities.

As part of a national representative survey entitled 'Environmental Awareness in Germany' which is conducted regularly on behalf of the UBA and the Federal Environment Ministry[232], respondents have been asked since 2012 whether they inform themselves on how to behave in a disaster scenario. For the first time in 2021 the data were collected within the framework of a special survey on environmental awareness which will in future be conducted only every four years. While in 2012 the figure was still 38 % of all respondents who obtained relevant information, this value had already risen to 52 % in 2014, and amounted to 44 % in 2016. In 2021 the proportion rose to 66 %. Also the proportion of respondents who intend to obtain information in future has increased from 10 % in 2012 to 19 % in 2021.

Although these figures do not reveal the degree of intensity in which the respondents looked into the range of hazards and possible behavioural responses (cf. Indicator BS-R-2, p. 324), they do indicate that by now 85 % of respondents recognise the need for and the usefulness of such information. The increase over the past ten years indicates that the population's awareness is growing and the same seems true in respect of their willingness to be better informed in order to take appropriate precautions thus being ready for action in case of a disaster. It is safe to assume that the extreme events of recent years and the greater presence of climate change topics in the media have made a relevant contribution to this state of raised awareness. No doubt, the impacts of the 2021 floods in the Ahr valley have induced people to inform themselves well on the impacts of climate change and the best way to behave in the case of an extreme event. The flood disaster occurred only a few months before the last survey was conducted in 2021.

Regular attendance of First Aid courses or emergency exercises at the workplace strengthen the level personal preparedness. (Photo: © Pixel-Shot / stock.adobe.com)

It should be borne in mind when interpreting these figures that not all citizens are exposed equally to all weather-related natural hazards. For example, storm surges or flooding occur along coastlines or along water courses whereas other areas are not or distinctly less frequently and less severely affected by such events. On the other hand, it is a fact that the population has become extremely mobile. Besides, it has been proved that hazards such as heat or heavy rain can happen anywhere in Germany and that these events can occur in disastrous proportions. Given this background, it is desirable that the entire population be in full possession of the knowledge what the basic rules are on how to behave in emergency situations.

Still gaps in personal preparedness for emergencies

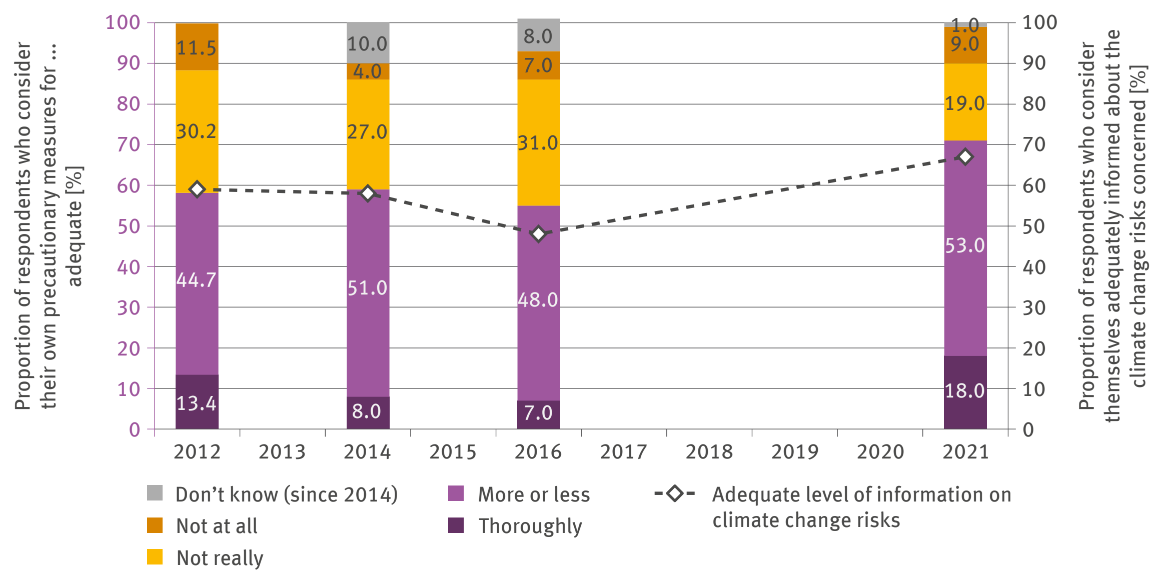
In order to ensure self-protection, it is not just important to be able to help oneself and others quickly and efficiently in an emergency. Citizens can also take various appropriate measures in their own personal environment to protect themselves from the impacts of weather-related and weather-pattern related situations such as periods of hot weather, storms or heavy rain thus preventing worse outcomes. To this end it is essential that citizens are confident that they are adequately informed about the risks associated with climate change impacts (cf. Indicator BS-R-1, p. 322). Some of the behavioural responses adapted to extreme weather are more or less part of automatic everyday routines. In that context it is, for example, sensible to avoid physical exertions such as sports in extreme heat, to wear the right clothing for certain temperatures whether at home or at work, to drink plenty of fluids on hot days and to avoid unnecessary long car journeys when weather patterns point towards risky conditions.

While such measures still appear obvious to most, the same cannot be said of precautions required for emergency situations. In Germany, the supply of basic goods and services such as groceries, water, electricity and telecommunications is known to function very well. As a rule, citizens can trust in the reliable functioning of fundamental logistics and infrastructures. But here is the other side of the coin: Given that negative experiences regarding supply and provisioning are rare in Germany, the population is in general less well prepared for exceptional circumstances. Emergency reserves of water, groceries, candles or batteries – held routinely only a few decades ago – are nowadays held only by comparatively few households. However, just by stocking some of these largely basic supplies, citizens can play their part in ensuring that extreme situations do not entail any disastrous outcomes for themselves. It is conceivable that the current situation in respect of the war in Ukraine might induce a change in people's perceptions prompting them to think again and increasing the population's willingness to take adequate precautions for themselves.

Apart from the general precaution to stock some emergency rations, it is also of key importance to take

BS-R-2: Precautions taken among the population

By 2016 the proportion of respondents who consider themselves adequately informed about the climate change risks concerned, had decreased. The survey conducted in 2021 shows an increase in the corresponding proportion to more than two thirds. The perception of individuals to have taken adequate precautionary measures for self-protection was common to more than half of respondents in all surveys.



Data source: BMUB/BMUV & UBA (study ‚Umweltbewusstsein in Deutschland', for 2021: additional survey in the framework of the study ‚Umweltbewusstsein in Deutschland 2020')

structural precautions for the protection of one's premises from extreme weather events. For example, house owners can protect their own four walls from weather-related and weather-pattern related risks by, in some cases, simple construction measures such as fitting non-return flaps. In this context, the BBK informs house owners not only by means of relevant information leaflets but also by making videos available on a dedicated YouTube channel (https://m.youtube.com/@BBKBund) in order to reach as wide a range of the population as possible. Likewise, the population is informed in alternative ways of the importance of self-protection, for instance by means of an information campaign broadcast on tv, translated as 'Ready in case' (cf. Indicator BS-R-1, p. 322).

A major role in operational aspects of civic protection is played by citizens' skills and abilities to protect and help themselves by taking various precautionary measures. A person that has taken precautionary measures and is in a position to help themselves and – where possible – others, requires less assistance and is potentially able to take the pressure off emergency relief responders.

In comparison to the outcomes of environmental awareness studies conducted in 2012, 2014 and 2016 as well as the survey conducted in 2021, it becomes clear that the proportion of respondents who inform themselves adequately on impacts of climate change relevant to them personally, was at first declining up to 2016 by 11 %. Compared to a value of still 59 % in 2012, this value had dropped to just 48 % by 2016. However, over a period from 2016 up to the survey conducted in 2021, the corresponding proportion has been rising: Latterly, 67 % – equating two thirds of respondents – stated that they had acquired a sufficient extent of information on the risks associated with climate change. Examining the question whether respondents are taking adequate precautionary measures for themselves, all surveys show that a little more than half of the participants are confident that the measures they are taking are adequate. By 2021 the proportion had risen to 71 %.

For the first time in autumn 2021 the survey on themes related to the 'Adaptation to climate change' as part of the environmental awareness study was conducted within the framework of a special survey on environmental awareness which will in future be conducted only every four years. At that time, the severe flood disaster – which had occurred only a few months before in North Rhine-Westphalia and Rhineland-Palatinate – still had a strong presence in the media. It is conceivable that the events in the Ahr valley contributed to raising the population's level of information on the risks of climate change to an even higher level. Given the high number of losses and severe damage caused by the flood, it is also possible that the disaster played a role in prompting the population to check their own precautionary measures and, where necessary, to implement or augment those measures.

Apart from drinking water and groceries – medication, batteries and many other things required in everyday life – should be part of a person's emergency provisions.
(Photo: © Imagenatural / stock.adobe.com)

On the other hand, the outcomes of the 2021 survey indicate that some 30 % of respondents consider their information level and their own precautionary measures as inadequate. When interpreting the outcomes, the following limitations should be borne in mind: the statements are based on a subjective understanding of risk information and taking precautions, which makes it impossible to estimate whether respondents who in their own opinion are taking adequate precautions, are in fact largely unaware of any potential gaps in their own preparedness for emergency situations.

Exercises – basis for appropriate action in an emergency

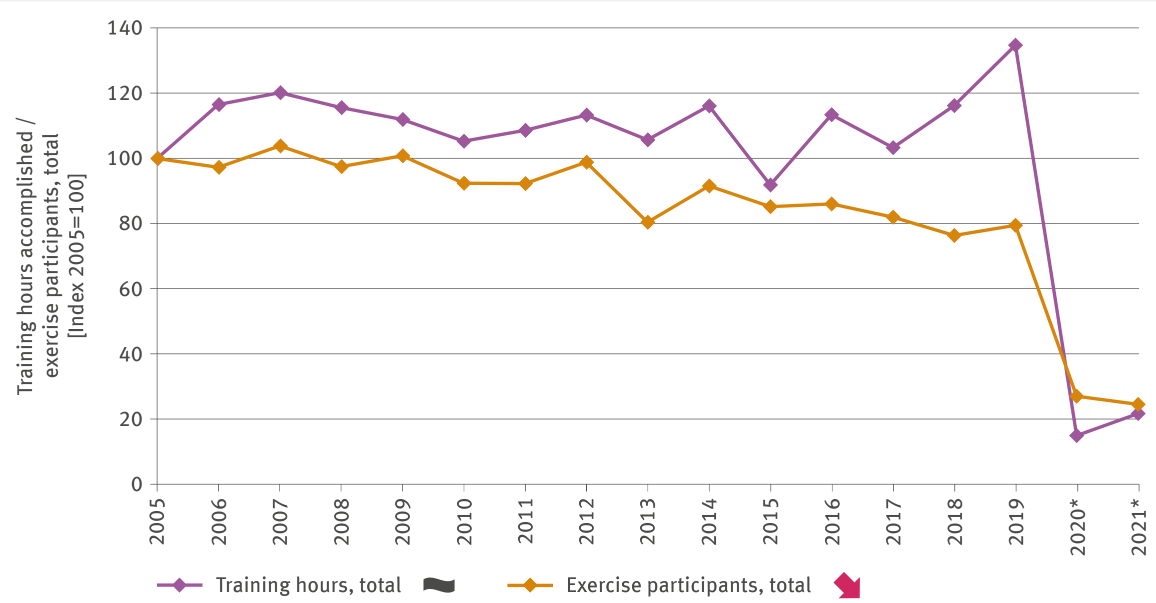
By means of regular training exercises the emergency relief responders are supported in safeguarding the foundation for appropriate action in extreme situations; this is the basis of targeted crisis management. Regular training enables emergency relief responders to act appropriately, both in respect of organising and coordinating relief operations and also in providing immediate assistance on location. There is no specific reference to climate-related aspects required for these exercises as far as preparing for the impacts of climate change is concerned, because any relevant potential events arising will not differ fundamentally from the way they are occurring now. Coping with heavy rainfall and storms but also flooding events or periods of hot weather is part of the core remit of civic protection. New challenges may arise, above all, from increases in frequency and intensity of such events in future and increasingly they could also arise from a potential overlap as and when they occur.

Basically, training exercises for civic protection can be carried out in two different ways: either as a full-scale exercise scenario or as a (simulated) command post exercise. The purpose of the latter is, in particular, to contribute to checking the communication structures and to prepare the authorities responsible for disaster relief services for a real emergency. This is because after training or real-time emergencies it has often emerged that there is room for improvement in civic protection, especially in terms of inter-organisational communication and coordination. For this reason, training exercises in civic protection are usually structured in a way as to involve units from various regions and – where appropriate – with different types of specialisation including for instance their material equipment, thus allowing them to train jointly.

In this process, the frequency of, and participation in, exercises are subject to various influencing factors. This can mean on occasion that an exercise is slightly reduced in scale without affecting the efficacy of emergency relief responders. For example, in years with increased frequency of emergency call-outs, the number of participants and training hours attended may be diminished because volunteers lack the time to participate or they need to be

BS-R-3: Exercise volume

As a rule, the THW is able to carry out the necessary amount of training exercises adequately, both in terms of time and participants, even in years when extreme events have to be dealt with. The severe flood events of 2013 and 2021 did not affect the training hours attended any more than just negligibly. During the Covid-19 pandemic, the THW focused on maintaining its operating capacity. In 2020 and 2021 exercises were possible only with severe limitations.



*The trend analysis was carried out to the exclusion of the years 2020 and 2021.

Data source: THW (training statistics)

allowed the necessary time to rest. Any lack of knowledge of response routines taught in training exercises owing to non-attendance will in such cases be offset by experience gained in the process of real-time call-outs.

Increasingly, one obstacle to participation in exercises is a lack of willingness on the part of employers to release the THW's or other relief organisations' voluntary helpers from their paid employment for the purpose of participating in training exercises. In years with high call-out figures, this can be one of the reasons why non-participation in training exercises is permitted, thus making it unnecessary for volunteers to request yet more release from their paid occupation. A case in point occurred in 2013 for instance, in terms of a decline in training hours attended, when in May and June of that year the emergency relief responders faced particularly demanding challenges as a result of severe flooding caused by violent and persistent rain, especially in the east and south-east of Germany. With the exception of both 2020 and 2021, the amount of training hours attended was lowest in 2015, amounting to a total of slightly more than 308,000 hours. This was caused by greater involvement of THW emergency relief responders in the coordination and implementation of finding accommodation for refugees arriving in Germany.

The years 2020 and 2021 are characterised by a massive decline both in training hours attended and in exercise participants. This development is primarily a consequence of the Covid-19 pandemic: At that time the THW's focus was on maintaining its operating capacity. Furthermore, the implementation of measures required in accordance with pertinent obligations in the fight against the pandemic made it necessary to reduce the exercise volume to a minimum. In 2021 when exercises became possible again to a limited extent, major exercises involving numerous participants continued to be curbed in order to reduce the amount of contact situations. Consequently, fewer than 5,000 emergency relief responders took part in THW exercises in 2021.

In mid-July 2021, the devastating flood disaster in western Germany was an additional factor affecting the exercise volume. However, even in cases of such major damage scenarios the THW is expected to reduce its exercise activities only slightly. For example, the number of training hours attended in the highly challenging year of 2013 with lots of call-outs, was no lower than in 2010 when distinctly fewer deployment hours accrued (cf. Indicator BS-I-1, p. 320). Consequently, it can be stated that even in 2021 – despite the intensive deployment of THW emergency relief responders in the Ahr valley – the Covid-19 pandemic remained the determining factor in the development of the exercise -volume.

Exercises create routines for real-time call-outs – for practical assistance on location as well as for organisation and coordination. (Photo: © filmbildfabrik / stock.adobe.com)

If you exclude the two years of 2020 and 2021 which were both characterised by the Covid-19 pandemic, the trend analysis for the development of training hours attended does not indicate a significant trend. After a slightly declining and subsequently fluctuating number of training hours between 2007 and 2017, the training hours attended started to rise again during the three years prior to the outbreak of the pandemic. In 2019 this number reached its maximum value so far. The total of 450,000 hours equates just under 40% more training hours attended than in 2005. By contrast, the number of exercise participants, in terms of statistics, had already declined significantly prior to the outbreak of the pandemic. The development from 2015 to 2019 demonstrates that the actual participants attended more frequently and / or longer. During the years of 2005 to 2012 an average of approximately 19,500 full-time and volunteer relief responders took part in THW's training exercises. In the period from 2013 to 2019 on average only approximately 16,500 volunteers took part in the exercises.

There are indeed other organisations which take on tasks in connection with civic protection; they too participate in training exercises thus preparing themselves for coping with the challenges of weather-related and weather-pattern related extreme events. However, the THW's figures do not permit any conclusions regarding the training regimes of other organisations

More active participants again in civic protection

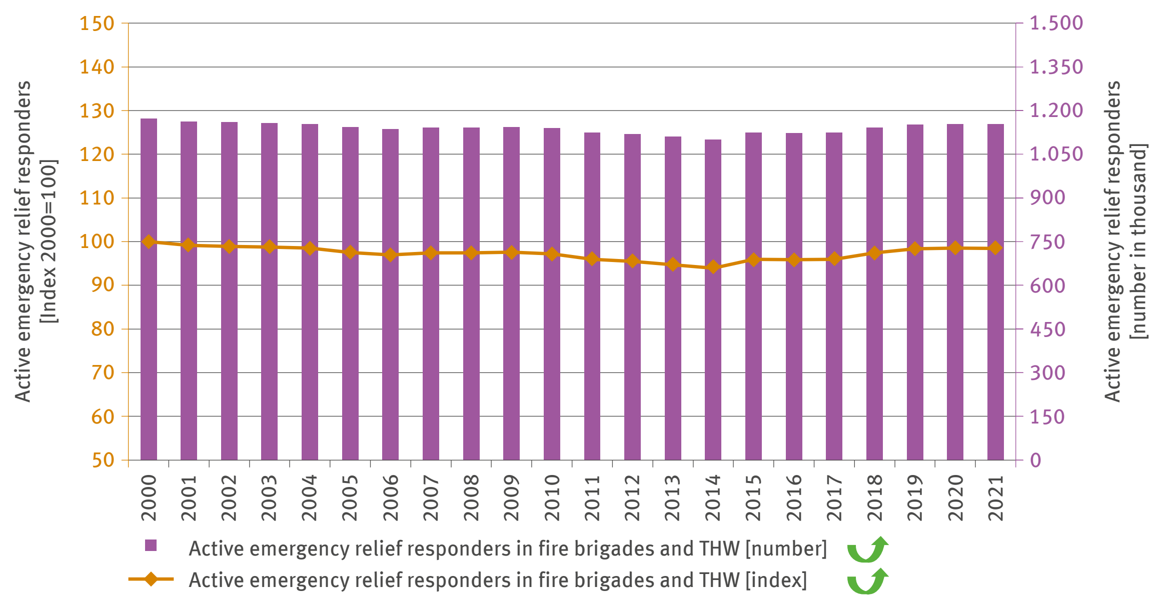
As far as civic protection in Germany is concerned, volunteers are our core strength: Around 1.7 million voluntary helpers get involved in various emergency relief organisations. Around 98 % of THW members are working on a voluntary basis. Around 94 % of active members of fire brigades in Germany are organised in volunteer fire brigades. Consequently, those responsible for civic protection have emphasised time and again that without the willingness of members of the public to become voluntary helpers in the relevant organisations, the capacity of units to carry out their tasks will be seriously jeopardized.

Also with regard to climate change, the minimum requirement for the further development of civic protection is a stable resource of full-time and voluntary emergency relief responders. This is not just because the expected changes of climatic framework conditions are may require more frequent and more extensive operations resulting in greater stress levels, but also because the availability of responders may be restricted if they are themselves affected by the disaster, for instance by damage to private premises or due to health problems resulting from heatwaves.

Looking at the development of the past two decades, it is clear that up until 2014 there has been a significant decline in the number of active members of fire brigades and of the THW. During that period, their number decreased by approximately 70,000 from 1.17 million to 1.1 million active members. Subsequently, the development was reversed: Up until 2020 the number of active members of fire brigades and THW increased again. In other words, currently there are more than 1.15 million active members. Another decline did not occur until the last year of the current timeline. From 2020 until 2021 the membership numbers of fire brigades and THW declined by just under 600 individuals. As a result of the worldwide Covid-19 pandemic the organisations involved in civic protection themselves suffered limited service capacity. The aggravated working conditions imposed a severe test of endurance on emergency responders. Nevertheless, the reduction in numbers of active voluntary emergency relief responders remained manageable. There are also lateral entrants among the new recruits joining in 2020: the very adversity of the pandemic prompted them to become active in assisting others.

BS-R-4: Active emergency relief responders in civic protection

The number of emergency relief responders declined between 2000 and 2014, above all owing to a decline in the number of members of fire brigades. Since then the commitment has grown again. In 2021 there were in total some 1.15 million more individuals active in fire brigades and THW – 50,000 more than just five years before. Adverse circumstances such as the worldwide Covid-19 pandemic did not lead to a marked decline in membership numbers.



Data source: THW (helper statistics), DFV (fire brigade statistics)

Given that the membership numbers of fire brigades are four times as high as those of the THW, they play a much stronger role in characterising the progress of the time series. The declining trend up to the mid-2010s is due primarily to a negative development in volunteer fire brigades. While professional fire brigades as well as factory or company fire crews were able to boast increasing or at least stable membership figures, volunteer fire brigades had approximately 70,000 fewer volunteers than just 15 years previously. One of the factors that led to a tailing-off in the recruitment of volunteers was the suspension of compulsory military service starting in 2011. This affected in particular the age group of 20 to 25 year olds.

For the TWH, the mean of the years 2000 to 2014 amounted to some 41,000 active volunteers. In 2015 the number increased to 66,000 and remained at that level in 2016 and 2017. Up to 2021, the number of active THW volunteers rose to just under 79,000. In order to safeguard a viable number of emergency relief responders, the THW requires around 5,200 new helpers annually. It has not proved possible to reach this target figure in the past few years. The THW gained on average approximately 4,000 new members per year, while additional demand exists above all in local associations in rural regions. Up until 2011, the THW managed to recruit annually around 2,500 individuals owing to the suspension of compulsory military service.

In recent years it was possible to increase the proportion of female volunteers in organisations which are predominantly technically oriented: In 2000 the proportion of female members of fire brigades amounted to 5.7 %, while by 2021 the proportion of female members had risen to 10.5 %. As a result, there are nowadays 44,000 more women active in fire brigades than in 2000. Especially among youth fire brigades many female volunteers become actively involved. In the period from 2000 to 2021 the proportion of females rose from 22 % to more than 28 %. In the THW the number of female volunteers has increased steadily since 1999 by almost 8,000. Compared to a proportion of scarcely 4 % in 1999, this value amounted to approximately 12 % in 2021.

The demographic change is reflected in the many years of declining membership numbers up to the mid-2010s, but also in the number of voluntary helpers rising only gradually. Changes in the age pyramid have led to shrinkages in the pool of potential emergency responders to the same extent as the increasing concentration of people living in towns and cities. Recruitment bottlenecks can occur especially in sparsely populated rural areas with a comparatively older population despite their greater willingness to make a commitment to civic engagement compared to inhabitants of towns and cities. In this respect, various studies take a very critical view of the future, raising the question in what way the existing structures are to be taken forward in order to ensure their reliable functioning in the future. In order to ensure that the number of voluntary helpers will continue to rise in future, the organisations active in the field of civic protection intend to make greater efforts, for instance, to involve people with a migration background or even senior citizens as helpers in accordance with their level of individual capacity. There are campaigns at Federal level in support of these endeavours, such as the BBK's campaign launched in 2021 for recruiting volunteers translated as 'No matter what you can do – you can help' and the accompanying establishment and operation of a web-based platform which is named 'mit-dir-fuer-uns-alle.de'.

Most emergency relief responders provide their assistance voluntarily for the sake of civic protection.
(Photo: © VRD / stock.adobe.com)

Furthermore, social and technical developments also open up new avenues. For example, during the flood events in 2013, 2016 and during the devastating flood disaster in the Ahr valley in mid-2021, emergency relief was organised fast and unbureaucratically via social networks in many of the areas affected. This seems to indicate that it might be possible for civic protection to become even more effective in utilising the existing willingness of individuals to get involved and provide assistance, even if the way this is done relies less on fixed structures than in former times. Work is ongoing with the objective to develop appropriate concepts for a structured integration, coordination and training of spontaneous volunteers: this work is taking place in BBK's close cooperation with the emergency relief organisations and the Länder.

Photo: © metamorworks / stock.adobe.com

Cross-sectional activities carried out at Federal level

Adaptations to climate change – Response

Widespread doubts about manageability of climate impacts

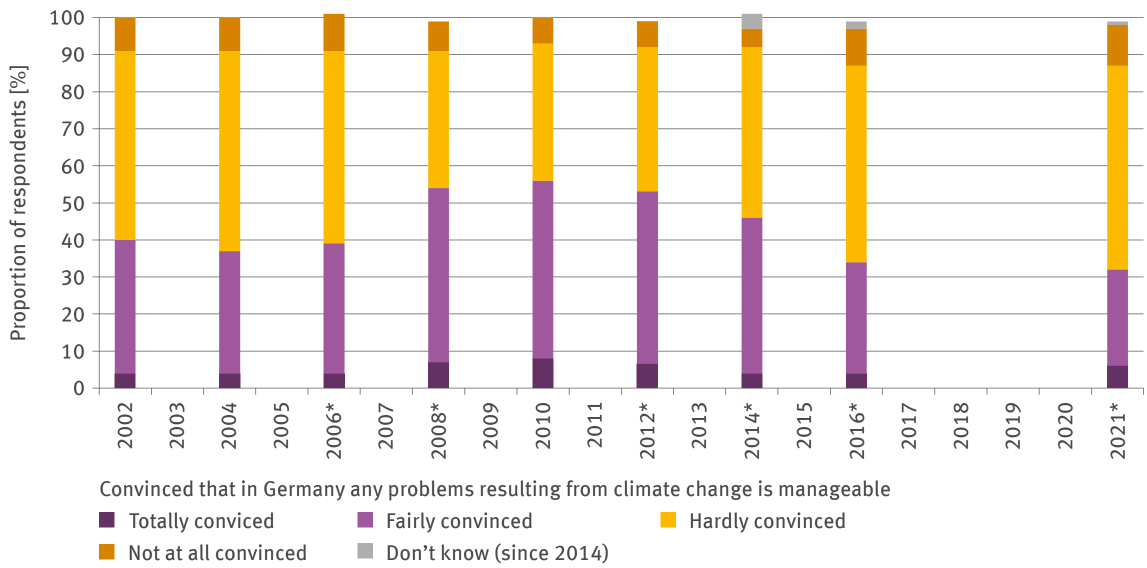
The availability of and access to fairly robust projections of future climate change and associated impacts are essential prerequisites for adequate political, administrative, operational and private decision-making and appropriate actions.

Federal government considers it one of its key responsibilities to ensure adequate information is easily accessible, with convincing illustrations of the challenges concerned while highlighting the decision-making assistance available. To this end, Federal government created the German Climate Preparedness Portal. By visiting the website www.klivoportal.de, authorities, companies and civilians can home in on approved support offerings which provide advice on adapting to climate change, as well as support on implementation matters. In 2021 the BMUV initiated the Centre for Climate Adaptation (ZKA) which provides an additional weblink entitled www.zentrum-klimaanpassung.de, offering opportunities for obtaining advice, for continued professional development and for the networking of stakeholders and decision-makers in municipalities as well as bodies responsible for social services. Whether and to what extent the information provided is ultimately taken on board by relevant members of the public, motivating them to take rational and targeted action, is largely dependent on how they view the issues concerned. To achieve widespread and enduring acceptance of the concept and implementation of adaptation measures in Germany nationwide, depends on a broad consensus among the German public recognising that climate change is a serious challenge that requires taking the necessary adaptation measures. Consequently, to know the public's perception, their appraisal of climate change and its impacts on society is an important foundation for the Federal government for shaping its information policy accordingly and targeting its funding activities in a meaningful way.

The social assessment of climate change and adaptation is the result of many factors, some of which interact in complex ways. Crucial influencing factors include the occurrence of (extreme) events and the appraisal of personal risks. Typically, climate protection and adaptation enter the public consciousness especially at times when extreme weather events and their impacts affect many people in

HUE-1: Manageability of climate change impacts

Since 2010 the proportion of citizens stating as a result of a representative public survey that the impacts of climate change are manageable in Germany has been declining. In 2021, 66 % of respondents were little or not at all convinced.



* Rounding error due to missing decimal places

Data source: BMUB/BMUV & UBA (study ‚Umweltbewusstsein in Deutschland', for 2021: additional survey in the framework of the study ‚Umweltbewusstsein in Deutschland 2020')

their own country and when they become aware of the heavy damage they have caused. Intensive reporting in the media tends to kindle the public's awareness regarding events closely bound up with climate change. But the more the public turn their attention to other subjects, the more the perceived importance of climate protection and adaptation tends to wane. Other crucial influencing factors – apart from the current weather-related and weather-pattern related situation – are the public's confidence in the government's agency to take appropriate action, an individual's understanding of causes, consequences and possibilities of action, as well as an individual's own scope for action based on their private and professional circumstances.

The representative population survey entitled 'Environmental Awareness in Germany' is conducted regularly on behalf of the UBA.[233] The survey contains several questions which permit drawing conclusions regarding respondents' opinions and appraisals in respect of climate-change impacts on Germany. Since 2002 the questionnaire has been integral to a catalogue of questions posed in an environmental awareness study and, among other things, this questionnaire asks respondents to what extent they are convinced that Germany is capable of managing the problems arising from climate change. The outcomes of this question are illustrated in the indicator presented here.

As far as past years are concerned, the time series regarding the individual response options do not yet indicate a significant trend. However, it can be stated that up until 2006 the majority of respondents were little or not at all convinced that it would be possible to manage the climate change impacts. During the period from 2008 to 2012 the majority ratio has shifted and the appraisals turned out more optimistic than before. For example, in 2010 no less than 56.0% of respondents were either fairly or even fully convinced that climate change impacts would be manageable in Germany. Since then scepticism has risen again, and since 2014 more than half of respondents were again little or not at all convinced that in Germany the problems resulting from climate change are manageable. As far as the surveys conducted in 2016 and 2021 are concerned, roughly two thirds of respondents had shared this appraisal. As possible reasons for this, the 2016 Environmental Awareness Study stated that respondents may have become more aware of the complexity of the issues or that they were experiencing the impacts of climate change with greater intensity in their own everyday lives.[234] Both studies showed that climate change was perceived more as a threat than before; in 2021 as many as 80% of respondents perceived climate change impacts as a threat to livelihoods in Germany. Accordingly, more than 90% of respondents considered adaptation measures to be required urgently.

There is a lot of scepticism among the population regarding the manageability of climate change impacts in Germany. (Photo: © yanlev / stock.adobe.com)

Although there was no explicit question regarding a respondent's personal willingness to adapt to climate change, this question can be seen as part of the socio-economic transformation which was, in fact, the focus of the Environmental Awareness Study conducted in 2020. Generally, it was noted that respondents were largely in agreement with regard to climate- and environment-related protection measures, and respondents also declared their willingness to behave in harmony with the environment. At the same time it was noted, however, that respondents felt uncertain and overwhelmed when it came to their own ability to participate actively in the transformation process. For citizens to become actively involved in the transformation process, they will need supporting offers, better and clearer framework conditions, more communication and positive incentives.[235] To date, these routes do not seem to have been taken sufficiently, and such deficits seem to affect how respondents view the manageability of climate change impacts.

In a qualitative preliminary study conducted in the run-up to the 2020 Environmental Awareness Study, another factor was identified which may also affect the appraisal in a negative way: In fact, part of the respondents rated the response in politics and society as being much too hesitant and not adequate to the problem.[236] To prevent damage to the public's confidence in the state's agency, it is necessary to use the political and social discourse as a vehicle to arrive at concrete and viable solutions and measures.

Warning and informing – an important task at Federal level

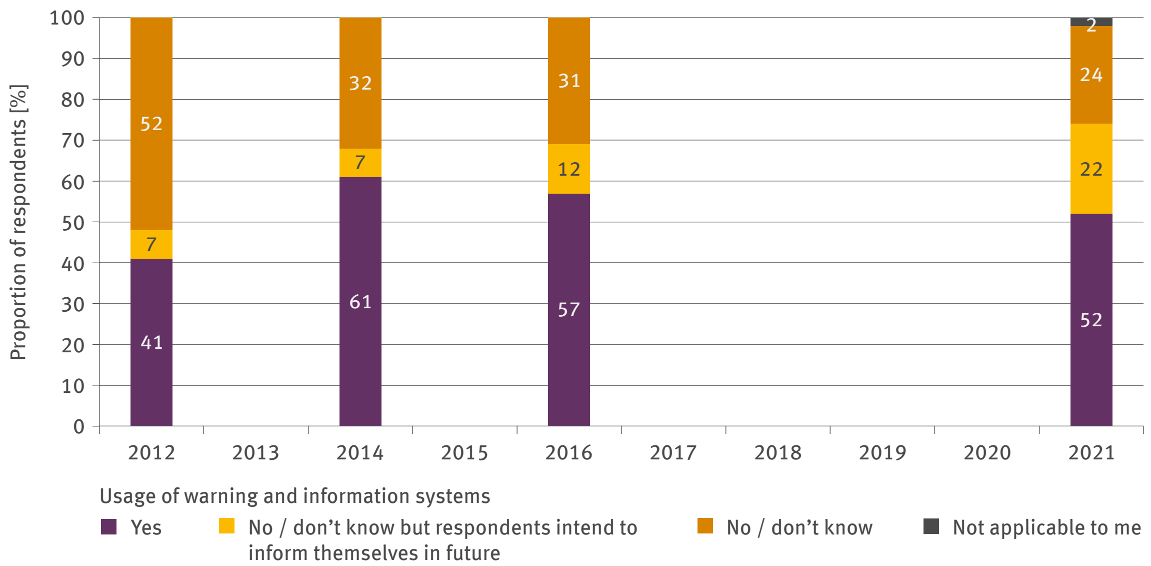
Warning and information services are used at Federal level as a key tool to deal with climate change, to inform the public on basic dangers and risks and to warn them about imminent critical events and to recommend precautionary measures. It is in the interest of Federal government that the population make intensive use of these services and that they be disseminated more and more widely.

There are various warning and information systems available at Federal level regarding the risks or stress situations which might become more critical as climate change progresses. The DWD offers online access to their official weather warnings, for example in cases of frost and icy roads or storm, heavy rain and thunderstorm, UV rays and heat (for heat warnings cf. Indicator GE-R-1, p. 58). These types of information are also available on the DWD-WarnWetter-App. The warnings are issued according to defined criteria in several stages and they refer to defined warning areas. Users can access such warnings, differentiated by levels, down to the municipal level. Furthermore, interested parties or groups at risk can obtain health-related danger- or warning-indices either online or via the fee-based GesundheitsWetter-App (health-weather-app). Apart from information on thermal stresses or – in cases such as meteoropathy (atmosphere-related syndrome) – on other stressful weather scenarios, the app also provides information and warnings on UV-related stress and on pollen-related stress (cf. Indicator GE-R-3, p. 60). Besides, citizens can subscribe to the Federal government's warning app NINA offered by the BBK to receive warnings in respect of civic protection, weather and tempest warnings issued by the DWD. It also provides flood information via its Länder-comprehensive Flood Portal for both individually selectable locations and for their own location (cf. Indicator BS-R-1, p. 322). The warning app NINA is part of Germany's warnings media mix which also includes warnings broadcast by radio and by cell broadcasting as well as warnings on billboards in towns and cities.

Associated with climate change citizens may also experience increasing health risks caused by UV radiation and ozone. As far as UV radiation is concerned, the BfS in cooperation with the UBA and DWD, generates the latest

HUE-2: Usage of warning and information services

In 2021 more than half of respondents to the Environment Awareness Study stated that they were using warning and information services from the Federal or Länder governments. However, this proportion was distinctly below the statistics recorded for the two previous surveys. Nevertheless: The proportion of those respondents who were not yet making use of these services but intended to do so in future, was much higher than recorded for the previous surveys.



Data source: BMUB/BMUV & UBA (study ‚Umweltbewusstsein in Deutschland', for 2021: additional survey in the framework of the study ‚Umweltbewusstsein in Deutschland 2020')

information – emanating from the nationwide solar UV Monitoring Messnetz (measuring network) – on UV radiation stress as well as forecasts which are published both online and via the DWD warning apps mentioned above (cf. Indicators GE-I-8, p. 54, and GE-I-9, p. 56).

Weather conditions comprising intensive solar irradiation stimulate the formation of ground-level ozone which – owing to complex photo-chemical processes – consists mostly of nitrogen oxides and volatile organic compounds (cf. Indicator GE-I-9, p. 56). Germany-wide forecasts regarding exposure to ground-level ozone are provided via the UBA's internet offerings.

Particularly keen attention is paid – at times when water-levels become extremely high – to the flood warning or information services which have been operated for many years by the Federal Waterways and Shipping Administration with remit to publish current water level data for federal waterways. The same can be said of the Hochwasserportal (floodwater portal) operated jointly by the Länder entitled www.hochwasserzentralen.de. This portal issues data on flood warnings on a daily basis for any water bodies that are part of their respective remit. A smaller target audience subscribes to the Sturmflutwarndienst (storm surge warning service) operated by BSH, which communicates water levels as indicated at gauges on the North Sea and Baltic Sea coasts.

Other extant warning and information services focusing on events which can be associated with climate change are of particular interest to specific professional groups, companies or administrations. These include the Länder's phytosanitary services which forecast the occurrence of pest organisms and recommend integrated pest control measures. Likewise, information services which forecast low water levels are available.

The representative population survey entitled 'Environmental awareness in Germany' conducted regularly[237] has – since 2012 – also contained questions regarding the usage of warning and information services. The survey refers to examples such as the pollen information service, the heat warning services and the flood warning or information services. In the 2012 survey, 41 % of all respondents stated that they make use of warning and information services. In 2014, the outcome of the subsequent survey indicated a sharp increase in usage to 61 %. However, in two subsequent surveys conducted in 2016 and 2021, the proportion of respondents who make use of the warning and information services was in decline, ultimately amounting to just 52 %. By contrast, the proportion of respondents who by that time had not made use of such services but intended to do so in future, had moved in the opposite direction. While in 2012 and 2014, their proportion had still amounted to just 7 %, by 2021 this proportion increased to 22 %. Both developments may have been a side effect of the Covid-19 pandemic. In that context, many citizens had made use of additional apps which provided them with warnings and behavioural advice. It is conceivable that other warning apps were used less at that time or they may have been deleted (temporarily).

Warning and information services are important building blocks for personal preparedness; at the same time they help to raise awareness. (Photo: © keBu.Medien / stock.adobe.com)

Basically, the almost population-wide distribution and use of smartphones has been a massive boon to the accessibility of warning services. Warnings and information on all relevant risks and stresses have now become accessible to nearly all interested parties, either online or via apps. In addition, it is possible to receive new relevant alerts on mobile phones via cell broadcasting or via the push-button function of apps.

Information on warning and information services relating to climate change impacts and precautionary measures for the prevention of damage arising from climate change are offered in a bundled form by the German Climate Preparedness Portal available at www.klivoportal.de.

More money for research into climate impacts and adaptation

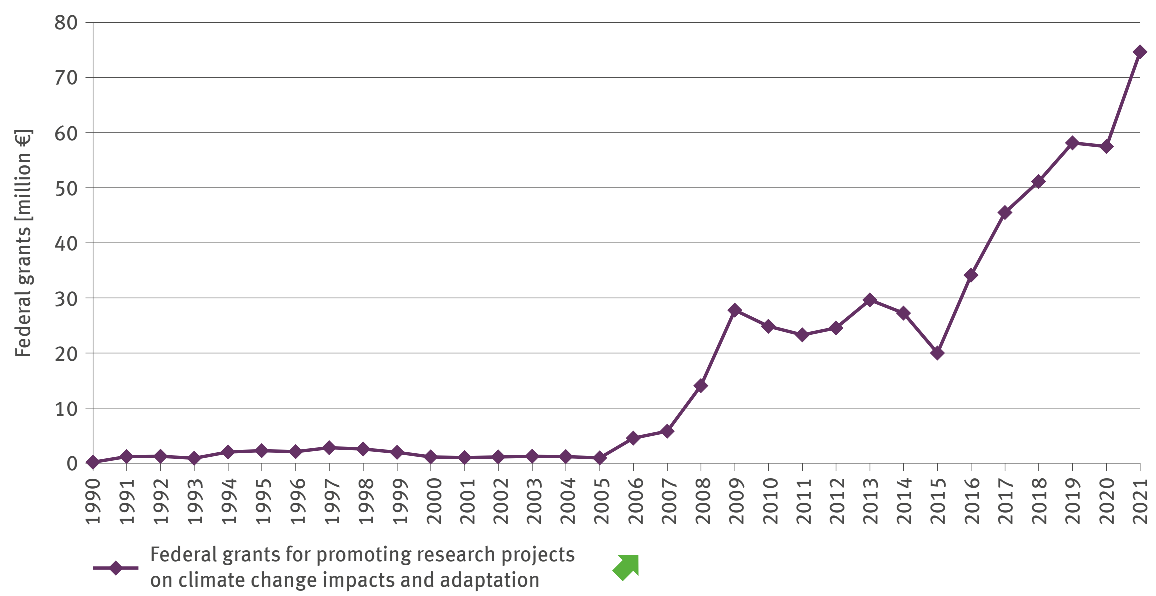
When making decisions that have long-term effects, it is essential to consider and take adequate account of the future climate and any potential climate change impacts. Any planning and projects of the public sector have to be resilient to the impacts of future climate changes. This applies to infrastructure projects such as the expansion of extant or the construction of new roads and railway lines, or the enhancement of inland waterways, flood protection measures or the construction of new power lines in response to the energy turnaround, and also with regard to public buildings or, last not least, the allocation of development areas at the municipal level. Likewise, companies are keen for their long-term investments into buildings or production facilities to be climate-resilient, and they want to make location decisions in a way that they are sustainable in the long run. Notably, private individuals also want to be able to make the right decisions, for instance in choosing their living location or regarding the purchase or construction of real estate.

An essential basis for decision-making is, on one hand, a well-informed vision of the future which allows them to make a fairly reliable appraisal of future climatic changes and of existing vulnerabilities as well as the potential impacts of climate change. On the other, strategic, technical and also practical solutions also need to be robust and flexible enough to cope with the wide range of potential climatic changes. It is therefore an important aspiration at Federal level to spare no effort in providing the necessary knowledge base required for adaptation processes or measures and to pursue a methodical funding approach to relevant research activities.

Many Federal funding activities for research into climate change and adaptation are bundled under the umbrella of the BMBF strategy entitled 'Research for Sustainability' (FONA) within the action field 'Improving adaptability and risk preparedness' financed by the BMBF. Currently the focus is on these themes: 'Researching climate-change related extreme events in Germany', 'Understanding and preventing climate change impacts on health' and 'Making towns and regions more resilient'. Besides, there are other programmes sponsored by Federal departments which study adaptation issues and are involved in piloting adaptation measures. A major focal point in the BMUV's departmental

HUE-3: Federal grants for promoting research projects on climate change impacts and adaptation

Several Federal departments promote research on the theme of climate change impacts and adaptation by means of grants for time-limited projects. There has been a distinct increase in the volume of such grants since 2006. However, the figures reflect only part of the research grants provided at Federal level. By the same token, any contract research commissioned by Federal ministries is not included.



Data source: BMBF (Förderkatalog – own analysis) research plan is the 'Adaptation to climate change impacts'; furthermore, a strategic key theme is dedicated to 'Climate adaptation and resilience in urban areas'. In the focal point 'Resilient transport and data systems & traffic safety' administered by the BMDV, the strategic framework of their departmental research (RFR) addresses the themes of 'Adaptation of transport systems to the impacts of climate change' and 'Reliability and resilience of transport infrastructure'. Other themes deal with the protection of critical infrastructures and the enhancement of alert messaging systems. An important element of the BMDV's departmental research is the BMDV's Experts Network launched in 2016, which has seven members from departmental research institutes and competent authorities working in fields such as adaptation to climate change, environmental protection and reliable transport infrastructure.

Apart from in-house research by competent authorities and departmental research institutions, there are many examples – as in the case of the BMUV's departmental research plan – of time-limited research and development projects that are allocated by means of a competitive award system (commissioned research). In addition, Federal government – within the framework of funding and specialised programmes – provides funding by way of earmarked grants for the promotion of projects. Likewise, major joint projects in the field of climate change impacts and risks as well as adaptation are also promoted in this way. As far as BMBF is concerned, relevant measures in this context include 'RegIKlim – Regional information on climate-related action', 'The economics of climate change', 'Climate resilience from actions in town and region', 'Urban climate in flux', and since end-2021, the emergency measure entitled 'Climate adaptation, flooding and resilience' (KAHR) by way of scientific support for restoration processes after the flood disaster in Rhineland-Palatinate and North Rhine-Westphalia. In respect of joint projects, the participation of partners from a variety of scientific disciplines and various regions was rated very highly, in the expectation that this might lead to the development of holistic solutions while supporting efforts made in transferring scientific findings into practical applications. Within the framework of the BMBF measure entitled 'Climate, environment and health' emerging researchers employ innovative approaches and methods in order to explore and curb the development of health risks ensuing from climate change.

To date there has been no cross-departmental compilation of all promotional activities relating to the adaptation to climate change; neither has there been an overview published of the funding disbursed for those purposes. Only the grants contributed by BMBF, BMUV and BMEL as well as the BMWK are listed centrally in the promotions catalogue published by BMBF; consequently, these are the only ones permitting an assessment in respect of the themes of climate change impacts and adaptation. From 2006 onwards, projects based on these focal points have been receiving grants at a major financial scale. In those days the BMBF created the promotional focal point 'klimazwei – Research for Climate Protection and Protection from Climate Impacts' endowed with a funding volume of some 35 million Euros to cover the period 2006–2009. Since then, the funds dispersed for grant-based funding of research and development on climate-change impacts and adaptation have been increasing considerably indicating a significant trend. The bulk of these funds went to measures provided by the BMBF, while smaller amounts relevant to these measures were awarded by the BMUV, BMWK and the other departments mentioned above.

As before, many questions relating to climate change impacts and adaptation remain unanswered, and therefore research grants are much needed.
(Photo: © Mckyartstudio / stock.adobe.com)

However, the funding catalogue does not cover any commissioned research. The figures therefore reflect only part of the funding provided for research and development relating to the adaptation to climate change. Any relevant activities such as those conducted by the BMG whose planned activities are outlined within the framework plan for departmental research, or any relevant parts of the BMUV's departmental research plan are currently not reflected in the indicator. Likewise, any measures which indirectly impact on adaptation are not covered by the time series. Consequently, the data do not permit any evaluative statements in respect of quantity or quality of Federal grants.

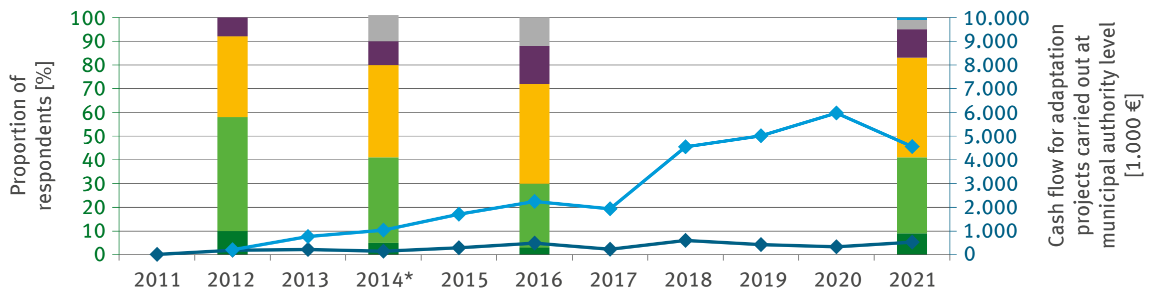
Municipalities receive funding for adaptation purposes

Municipalities are key players in the adaptation to climate change, as many climate change impacts materialise at the local level. Accordingly, measures have to be developed and implemented in cooperation with municipalities. Some of these are, for example, measures in connection with urban greening and housing developments as well as the adaptation of urban infrastructure or precautionary measures in the construction sector or preventative measures for health protection (such as the preparation of heat action plans). It is true to say that the adaptation to climate change as a municipal task is a relatively new but increasingly recognised action field in Germany. Federal government therefore attaches great importance to supporting municipalities in the adaptation process: The information and advisory service offered by the ZKA launched by the BMUV in 2021 is aimed specifically at persons in authority and stakeholders in municipalities. In addition, there is substantial financial assistance available. It is currently not possible to present a general overview of the way in which Federal government provides assistance to municipalities in these respects. This is because different departments provide assistance in different ways. However, the award of funding within the framework of the DAS funding programme partially reflects the Federal government's commitment in this regard.

In the period from 2011 to 2019 funding was disbursed within the framework of the NKI and the Municipal Directive for the preparation of municipal adaptation concepts in the form of 'Climate Protection Sub-Concepts for Adaptation Purposes'. These concepts are used by municipalities as strategic planning and decision-making tools; they identify the demand for adaptation, make statements on the participation of relevant stakeholders and indicate options for action at a local level. Between 2011 and 2021 a total of 44 towns, districts and regions were awarded funds totalling just short of 3.5 million Euros for the preparation and implementation of adaptation concepts. By comparison, the proportion of funds disbursed for adaptation – awarded by 2021 within the framework of the Municipal Directive – was very low, amounting to less than 0.5 %. One reason for this is that the NKI cannot be used for taking any investment-related – and thus expensive – adaptation measures. Since the beginning of 2019, NKI funding opportunities have again been restricted solely to

HUE-4: Adaptation to climate change at the municipal level

Federal government supports municipalities, towns and districts, for example via the National Climate Protection Initiative and the DAS programme in developing concepts and implementing measures ensuring good adaptation. The outflow of funds awarded by those programmes has increased. The proportion of survey respondents giving a favourable answer to the question whether their municipal authorities were sufficiently engaged in adaptation, lately increased again.



Extent to which precautionary measures are taken at municipal authority level ...
- Declined to answer***
- Don't know**
- Not at all adequate
- Not really adequate
- Fairly adequate
- Totally adequate

Cash outflows for ...
- Municipal adaptation concepts and their implementation – NKI
- Lighthouse projects and adaptation concepts at municipal authority level – DAS programme

Data source: BMUB/BMUV & UBA (study ‚Umweltbewusstsein in Deutschland', for 2021: additional survey in the framework of the study ‚Umweltbewusstsein in Deutschland 2020'), ZUG (Statistik über geförderte Projekte)

* Rounding error due to missing decimal places | ** since 2014 | *** since2021

activities relating to climate protection. The funds dedicated for use by 2025 are reserved solely for the completion of projects already under way.

Since 2012, adaptation measures are also supported within the framework of the DAS programme entitled 'Promotion of Measures for Adaptation to Climate Change Impacts' operated by the Federal Environment Ministry. Until 2021, the programme created incentives for small and medium-sized enterprises, including municipal companies, to draw up adaptation concepts, it supported the implementation of municipal lighthouse projects as well as inter-municipal or regional alliances in establishing cooperation, drawing up concepts for adapting to climate change and implementing them on a pilot basis. The first-named funding priority with focus on these enterprises was taken up to a very limited extent. This is why the indicator illustrates only the outflow of funds to flagship projects and adaptation concepts. In the period 2012 to 2021, the Federal government awarded funds totalling just short of 28 million Euros for these projects. A new Funding Directive was last issued in July 2021. The new round of funding within the framework of the DAS programme is focused on the establishment of sustainable adaptation management in municipalities and on innovative model projects for the adaptation to climate change. The establishment of a sustainable adaption management in towns and municipalities was aided by funding from December 2021 until end of January 2022. By doing so, targeted incentives were created for local authorities to strategically think climate adaptation and manage it themselves. The requisite overall concepts were devised by local climate adaptation managers whose employment was funded by the BMUV. These sustainable adaptation concepts provide the foundation for concrete activities within a given municipality. As of 2022 municipalities can apply for funding to support innovative model projects. This is particularly aimed at local projects – which can serve as good examples for other municipalities – that are designed to provide protection from damage by extreme weather events such as heavy rain or heatwaves. In complement to the DAS programme, the Federal government supports municipalities by means of the emergency programme entitled Climate Adaptation. Valid until 2026, a budget of 60 million Euros as well as specialist advice have been made available. The programme was created in response to the flood disasters of summer 2021 as well as recurring heatwaves and droughts.

EU structural funding represents another opportunity to obtain funding for municipal adaptation projects. In the case of operational implementation measures in promotional programmes, the management of climate change impacts is often just a secondary objective which – although influencing the design of the measures concerned – is not usually

Municipalities are important players in climate change adaptation.(Photo: © Igor Syrbu / stock.adobe.com)

a distinct item of calculation which can be extricated from the overall funding. The European LIFE programme includes the sub-programme 'Climate Change Mitigation and Adaptation', as part of which large-scale strategic projects are funded, in which municipalities may also be involved.

In addition, there are specific funding programmes available at Länder level which support climate change adaptation at the municipal level. These include for example KLIMOPASS in Baden-Württemberg, Klima Invest in Thuringia, the 'Kommunales Qualitätsmanagement- und Zertifizierungsverfahren zur Klimafolgenanpassung' in North Rhine-Westphalia or the 'Förderung von Vorhaben zur strategischen Neuausrichtung des Wassermengenmanagements und klimafolgenorientierten Ausbaus von Infrastrukturen der Wasserversorgung und –nutzung' in Lower Saxony.

In the representative survey entitled 'Environmental awareness in Germany'[238] citizens have been asked since 2012 to state whether the town or municipality in which they live has addressed the adaptation issue sufficiently and whether, in their opinion, the authorities are taking adequate precautionary measures. While in the 2012 survey, 58 % of respondents answered this favourably, by 2014 this proportion had diminished to 41 %, a distinctly lower percentage, and by 2016, the proportion had dwindled to only 30 %. In 2021 this value increased again to the 2014 level. However, as before, the population obviously still perceives notable deficits. Statistically speaking, the increasing efforts made in municipalities are possibly offset by increases in public awareness.

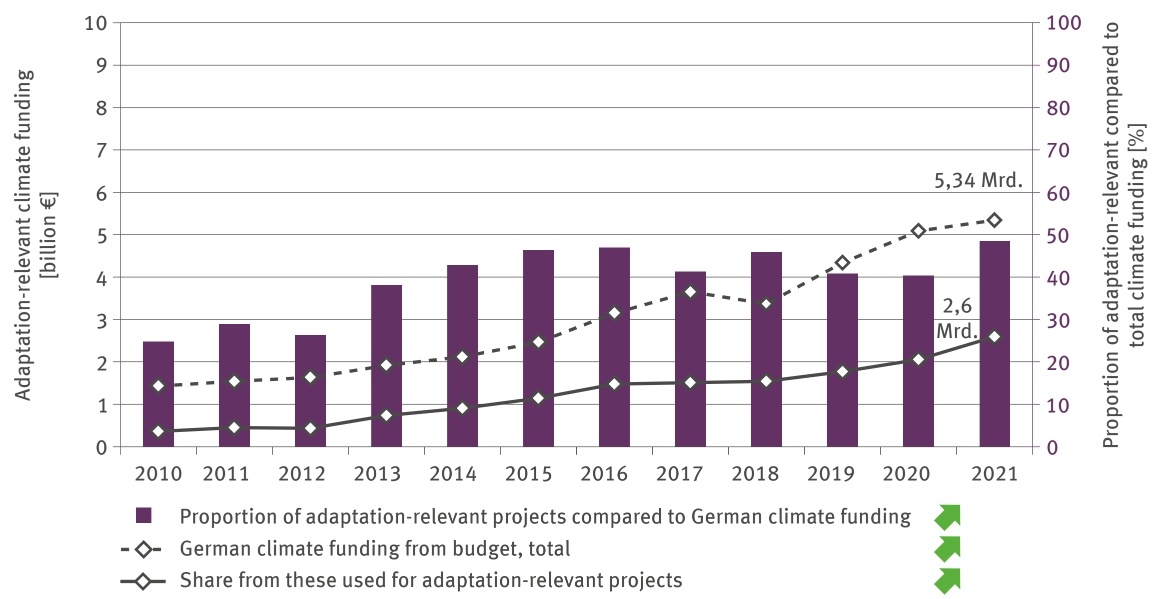
Climate change adaptation is a global challenge

In view of the global dimension of climate change and associated impacts, Germany has for years campaigned for wide-ranging international cooperation on adaptation efforts. This includes cooperation at the international level and the bilateral and regional levels, in order to make people, living spaces, ecosystems and economies more resilient to climate change impacts thus avoiding damage and loss. As far as the wider international environment is concerned, German activities take their cue from international processes and cooperations including the IPCC. In particular, emerging economies and threshold countries are affected by those impacts as they often lack the resources and capacities to protect themselves from extreme weather events as well as the creeping progress of climate change and its associated impacts. For the sake of climate-related justice, providing support for developing countries in solidarity is a must, not least because – compared to industrialised states and threshold countries – they are responsible for just a small proportion of greenhouse gas emissions that impact on the global climate. Germany provides assistance with adaptation measures in developing and threshold countries within the framework of cooperation at a development and climate-political level. In that light, Germany assists with devising and implementing national adaptation plans (NAP) and adaptation objectives framed in the nationally determined contributions (NDC) under the Paris Climate Agreement. This assistance is provided, for example, via the NDC partnership. In 2021, 88 % of the German contribution to international climate funding was disbursed from the budget of the Federal Ministry for Economic Cooperation and Development (BMZ). Further funding is made available by BMWK, BMUV and the Federal Foreign Office (AA) predominantly within the framework of the International Climate Initiative (IKI). Other ministries, such as the BMBF or BMEL, contribute to projects by way of research cooperations. Germany strives to achieve the balance of mitigation and adaptation – mentioned in the Paris Climate Agreement – within the framework of international climate funding, also in its contributions from budgetary funds.

At the 2009 UN Climate Change Conference (COP) in Copenhagen the industrialised countries gave an undertaking to mobilise, from 2020 onwards, funds in the amount of USD 100 billion annually. At the COP 2015 in

HUE-5: International finance for climate adaptation (from budgetary funds)

In recent years, there has been a distinct increase in the endeavour to support adaptation in an international context. The proportion of adaptation-relevant funding compared to the overall international climate finance has increased from just short of 25 % in 2010 to 49 % in 2021. The demand for adaptation funding will further increase in future.



Data source: BMZ (reporting according to EU-MMR-regulations)

Paris this commitment was reviewed and the target year was extended to 2025. Within the framework of COP 26 in Glasgow in 2021 the industrialised states were requested to double their adaptation aid to developing countries in the run-up to 2025. A differentiation is made between financial contributions to multilateral programmes and bilateral development cooperation.

As far as multilateral funding is concerned, several states contribute to international funds held in multilateral development banks (MDBs) and international organisations. The Least Developed Countries Fund (LDCF) was launched in 2001 and is subordinate to the Global Environment Facility (GEF). Since 2009 this Fund has been supporting concrete adaptation projects exclusively in the Least Developed Countries (LDCs). With its contributions via the BMZ Germany has been the foremost donor, having contributed some 424 million Euros since the Fund was launched. The establishment of the Green Climate Fund (GCF) results from a decision taken at the 2010 Cancún Climate Conference. It is the GCF's declared objective to drive the transformation forward in order to achieve a low-emission sustainable development worldwide. The GCF is a key building block in the architecture of international climate funding. The GCF therefore plays a crucial role in implementing the Paris Climate Protection Agreement. When the GCF was set up and the first time its budget was replenished, the donations promised amounted to USD 20 billion. To date, 216 projects have been awarded funding totalling USD 12 billion. The GCF projects help to reach more than 900 million people, and in the process 2.5 billion tonnes of CO_2 emissions are prevented. Considering that the portfolio consists of 51 % adaptation projects and 49 % mitigation projects, it is almost completely balanced. Germany contributed to the first replenishment of the GCF for the period from 2015 to 2019 in the amount of 750 million Euros, and to the next replenishment in respect of the period from 2020 to 2023 (GCF-1) with 1.5 billion Euros. In 2022 the second replenishment phase was initiated for the period from 2024 to 2027 (GCF-2). At the Petersberg Climate Dialogue in May 2023 in Berlin, Germany's Bundeskanzler Olaf Scholz announced that Germany would donate 2 billion Euros to GCF-2. To date this is the highest single contribution since the GCF was launched[239]. Another tool in the multilateral funding toolkit was added in 2008 within the framework of the Kyoto Protocol when the adaptation fund was launched. This fund will now also implement tasks arising from the 2015 Paris Climate Agreement. Considering donations totalling some 540 million Euros, Germany is an important donor.

Within the framework of bilateral funding for projects and programmes, Germany makes contributions to specific projects promoting carbon-poor and climate-resilient economic growth. Projects are implemented predominantly by a banking group consisting of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the Kreditanstalt für Wiederaufbau (KfW) but also by private, civil-society and church sources of finance as well as political foundations in developing countries. Apart from projects whose key objective is the adaptation to climate change, there are some projects on development cooperation which include cross-sectional references to climate change. For example, numerous projects are concerned with the objectives of fighting poverty, safeguarding food security and diversification of a country's economic structure, while these projects also address the adaptation to climate change. The adaptation to climate change is an important building block in sustainable development. Conversely, sustainable development enhances the resilience to climate change impacts. The implementation of the Paris Climate Agreement plays a key role in this scenario. Moreover, linking sustainable development and climate change adaptation enhances the effectiveness of public funds. However, it is a crucial prerequisite for approving an adaptation project for international climate funding that the adaptation objectives be phrased distinctly and explicitly and that specific measures be implemented in a way as to reduce the vulnerability of systems and the risks involved in climate change, thus increasing their climate resilience. This includes measures addressing information, awareness-raising and capacity-building as well as measures in legal, planning and programmatic respects, as well as implementation measures such as the conversion to water-saving irrigation systems, the cultivation of more drought-tolerant crops, the introduction of sustainable practices in fisheries or measures concerned with malaria control.

The sum total contributed by Germany towards international funding for climate protection in terms of mitigation and adaptation measures from budgetary funds has increased from 471 million Euros in 2005 to 5.34 billion Euros in 2021. Germany had promised prior to the 2015 Paris Climate Conference that public climate funding from budgetary funds inclusive of 'gift equivalents' would be increased by 2020 to four billion Euros annually. This promise was fulfilled as early as 2019. At the Petersberg Climate Dialogue in July 2022 the Bundeskanzler promised to increase this amount by 2025 to at least six billion Euros annually. Since 2010 Germany has been recording the adaptation share contributed to international climate funding separately. Measures taken for the adaptation to climate change in 2021 amounted to 2.59 billion Euros and were therefore seven times higher than the amount of 355 million Euros provided in 2010, thus representing 49 % of the entire international climate finance provided from budgetary funds.

Appendix

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Institution	Persons involved
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Bundesamt für Naturschutz (BfN)	Fachgebiet II 3.1 Grundlagen, internationaler Meeresnaturschutz: Christian Pusch
Bundesamt für Bevölkerungsschutz und Katastrophenhilfe (BBK)	Referat I.2 Warnung der Bevölkerung: Dr. Christoph Groneberg Referat II.3 Strategie KRITIS, Cyber-Sicherheit KRITIS: Christina Nikogosian, René Kwiatkowski Referat II.5 Baulicher Bevölkerungsschutz: Katharina Gerlach
Bundesamt für Seeschifffahrt und Hydrographie (BSH)	Referat M2 Meeresphysik und Klima: Dr. Kerstin Jochumsen Sachgebiet M21 Marine Klimafragen: Dr. Tim Kruschke, Dr. Claudia Hinrichs, Dr. Frank Janssen, Ludwig Schenk
Bundesamt für Strahlenschutz (BfS)	Fachgebiet WR 4 Optische Strahlung: Dr. Cornelia Baldermann, Dr. Sebastian Lorenz, Dr. Daniela Weiskopf
Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA)	Fachgebiet Klima am Arbeitsplatz: Dr. Kersten Bux
Bundesanstalt für Gewässerkunde (BfG)	Referat M1 Hydrologische Grundsatzangelegenheiten, Hydrometrie und Gewässerphysik: Dr. Hartmut Hein, Dr. Peer Helmke, Dr. Tim Scheufen Referat M2 Wasserhaushalt, Vorhersagen und Prognosen: Peter Krahe
Bundesanstalt für Landwirtschaft und Ernährung (BLE)	Referat 321 Informations- und Koordinationszentrum für Biologische Vielfalt: Dr. Michaela Haverkamp
Bundesanstalt für Straßenwesen (BASt)	Referat U2 Unfallanalyse, Unfallstatistik: Leon Straßgütl, Susanne Schönebeck

Institution	Persons involved
Bundesanstalt für Wasserbau (BAW)	Abteilung Wasserbau im Küstenbereich, Referat Ästuarsysteme II: Dr. Rita Seiffert
Bundesanstalt Technisches Hilfswerk (THW)	Referat E1 Grundsatz: Tobias Nothhelfer
Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR)	Referat I 1 Raumentwicklung: Dr. Brigitte Zaspel-Heisters, Dr. Klaus Einig, Claudia Benz Referat WB 6 Bauen und Umwelt: Svenja Binz
Bundesnetzagentur (BNetzA)	Referat 615 Marktbeobachtung, Monitoring Energie: Maximilian Plugge Referat 626 Versorgungsqualität: Dominik Oleff
Bundessortenamt (BSA)	Referat P2 Kommunikation, Biopatent-Monitoring, Qualitätsmanagement: Nora-Sophie Quett
Deutscher Wetterdienst (DWD)	Referat KU 21 Nationale Klimaüberwachung: Dr. Florian Imbery Referat KU 42 Niederschlagsüberwachung: Dr. Tanja Winterrath Referat KU 41 Hydrometeorologische Beratungsleistungen: Dr. Uwe Böhm, Dr. Monika Rauthe Referat KU 13 Zentrum für Medizin-Meteorologische Forschung: Prof. Dr. Andreas Matzarakis, Dr. Christina Endler, Dr. Gudrun Laschewski, Kathrin Graw, Dr. Stefan Muthers, Oliver Naß Referat KU 32 Zentrum für Agrarmeteorologische Forschung: Dr. Cathleen Frühauf, Tobias Vogt Referat KU 31 Agrarmeteorologische Fachleitung und Beratung (Außenstelle Leipzig): Falk Böttcher Referat KU3WN Außenstelle Weihenstephan: Dr. Harald Maier Referat KU 11 Zentrales Klimabüro: Dr. Saskia Buchholz Referat KU 1 EM Regionales Klimabüro Essen: Guido Halbig
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Robert Koch-Institut (RKI)	Abteilung für Infektionsepidemiologie: Dr. Matthias an der Heiden, Dr. Claudia Winklmayr
Statistisches Bundesamt (Destatis)	Referat G 24 Physische Umweltökonomische Gesamtrechnungen: Lucia Maier, Teresa Kersting, Katrin Bort
Thünen-Institut (TI)	Stabsstelle Klima und Boden: Dr. Mareike Söder, Dr. Nataliya Stupak Institut für Seefischerei: Dr. Anne Sell, Dr. Matthias Bernreuther Institut für Ostseefischerei: Dr. Patrick Polte Institut für Waldökosysteme: Prof. Dr. Andreas Bolte, Dr. Heino Polley, Dr. Joachim Rock, Dr. Thomas Riedel, Dr. Tobias Schad, Dr. Sebastian Schnell, Dr. Nicole Wellbrock, Dr. Erik Grüneberg, Dr. Dominik Jochem, Dr. Marco Natkhin, Dr. Nikolai Knapp, Dr. Denny Ohnesorge, Dr. Tanja Sanders
Ministries of the federal states	
Hessisches Ministerium für Umwelt, Klimaschutz, Landwirtschaft und Verbraucherschutz	Referat III 2 Finanzierung, fachbezogene Verwaltung, Hochwasserschutz, Hydrologie, Badegewässer: Matthias Löw, Thomas Mann
Specialist authorities of the federal states	
Landesamt für Gesundheit und Soziales Mecklenburg-Vorpommern (LAGuS MV)	Abteilung Gesundheit, Dezernat Umwelthygiene, Umweltmedizin: Dr. Gerhard Hauk
Bayerische Landesanstalt für Landwirtschaft (LfL)	Arbeitsbereich IAB1 Boden: Dr. Martin Wiesmeier

Institution	Persons involved
Landwirtschaftliches Zentrum Baden-Württemberg	Fischereiforschungsstelle Baden-Württemberg: Dr. Jan Baer
Hessisches Landesamt für Naturschutz, Umwelt und Geologie (HLNUG)	Dezernat I1, Ute Heyder (LiKi-Vertreterin)
Landesbetrieb Mobilität Rheinland-Pfalz (LBM RP)	Geschäftsbereich Betrieb, Fachgruppe Straßenunterhaltung, -betrieb: Mike Fensterseifer
Nordwestdeutsche Forstliche Versuchsanstalt (NWFVA)	Sachgebiet Waldnaturschutz / Naturwaldforschung: Dr. Peter Meyer
Staatliches Amt für Landwirtschaft und Umwelt Mittleres Mecklenburg (StALU MM)	Abteilung Küste: Knut Sommermeier
LAWA AK Climate Indicators (The working group was involved in the further development of the indicators for the action fields 'Water balance and water management' and 'Coastal and marine protection')	
Bundesanstalt für Gewässerkunde (BfG)	Referat M2: Wasserhaushalt, Vorhersagen und Prognosen: Peter Krahe, Dr. Hartmut Hein
Bundesanstalt für Wasserbau (BAW)	Abteilung Wasserbau im Küstenbereich, Referat Ästuarsysteme II: Dr. Rita Seiffert
Bundesamt für Seeschifffahrt und Hydrographie (BSH)	Referat M2 Meeresphysik und Klima: Jens Möller
Bayerisches Landesamt für Umwelt (LfU)	Referat 63 Flussbauliche Grundlagen, Hydromorphologie, Hydraulik: Dr. Gisela Kangler (bis 05/2021) Referat 83 Ökologie der Flüsse und Seen: Daniela Rau (bis 10/2021)
Hessisches Landesamt für Naturschutz, Umwelt und Geologie (HLNUG)	Dezernat W3 Hydrologie, Hochwasserschutz: Dr. Gerhard Brahmer, Dr. Thomas Wanke Dezernat W4: Dr. Georg Berthold
Landesamt für Umwelt Rheinland-Pfalz (LfU)	Abteilung 5 Gewässerschutz: Dr. Wolfgang Frey
Landesbetrieb für Hochwasserschutz und Wasserwirtschaft Sachsen-Anhalt (LHW)	Sachgebiet 5.1.3 Mengenbewirtschaftung: Christiana Mühlner
Ministerium für Ländliche Entwicklung, Umwelt und Landwirtschaft Brandenburg (MLUL)	Referat 22 Oberflächenwasser, Siedlungswasserwirtschaft: Sandra Berdermann (bis 05/2021), Julia Mussbach (nur 05/2021–05/2022)
Ministerium für Landwirtschaft und Umwelt Mecklenburg-Vorpommern	Referat 420 Gewässerkunde, Seenprogramm, Klimawandel: Eckhard Kohlhas (Obmann der Kleingruppe)
Ministerium für Landwirtschaft, Umwelt und ländliche Räume des Landes Schleswig-Holstein	Referat Küstenschutz, Hochwasserschutz und Häfen: Dr. Jacobus Hofstede
Ministerium für Umwelt, Landwirtschaft, Natur- und Verbraucherschutz NRW (MULNV)	Referat IV-5 Oberflächengewässer- und Grundwasserbeschaffenheit, Wasserversorgung: Maria Berglund
Niedersächsisches Ministerium für Umwelt, Energie, Bauen und Klimaschutz (MUEBK)	Referat 23 Grundwasser, Wasserversorgung, Fachplanungs- und Datenmanagement, Gewässerkundlicher Landesdienst: Ulrike Lipkow (bis 05/2022), Ute Brase (bis 05/2022)
Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (NLWKN)	AB 31 Grundwasser: Dr. Tobias Holt AB 36 Hochwasservorhersagezentrale, Klimafolgen, Fachdatenmanagement: Uwe Petry Betriebsstelle Norden-Norderney: Frank Thorenz
Sächsische Staatsministerium für Energie, Klimaschutz, Umwelt und Landwirtschaft (SMEKUL)	Referat 44 Oberflächengewässer, Hochwasserschutz: Christin Mudra (bis 06/2022), Dr. Kerstin Röske
Senatsverwaltung für Umwelt, Verkehr und Klimaschutz Berlin (SenUVK Berlin)	Referat II B Wasserrecht, Wasserwirtschaft und Geologie, Fachbereich B II B 24 Wasserwirtschaft, Wasserrahmenrichtlinie, Hochwasserschutz: Antje Köhler

Institution	Persons involved
Umweltbundesamt (UBA)	Fachgebiet I 1.6 KomPass: Dr. Petra van Rüth Fachgebiet II 2.1: Corinna Baumgarten
Universities and other scientific institutions	
Carl Albrechts Universität zu Kiel (CAU)	Geographisches Institut: Dr. Katja Kuhwald
Hochschule Kempten	Tourismus-Management: Prof. Dr. Julia Beelitz
Hochschule für Technik und Wirtschaft des Saarlandes (htw saar)	Internationales Tourismus-Management: Prof. Dr. Kerstin Heuwinkel
Leibniz-Institut für Gewässerökologie und Binnenfischerei (IGB)	Dr. Michael Hupfer, Dr. Robert Schwefel
Leibniz-Zentrum für Agrarlandschafts-forschung (ZALF) e.V.	Dr. Doreen Werner
Leibniz-Institut für ökologische Rau-mentwicklung (IÖR)	Forschungsbereich Raumbezogene Information und Modellierung: Dr. Tobi-as Krüger, Dr. Gotthard Meinel
SRH Berlin University of Applied Science	Center for Innovation & Sustainability in Tourism: Prof. Dr. Ines Carstensen
Technische Universität München (TUM)	Lehrstuhl für Grünlandlehre: Prof. i. R. Dr. Karl Auerswald
Universität Innsbruck (UIBK)	Assoz.-Prof. Dr. Robert Steiger
Non-governmental institutions	
ahu GmbH	Carolin Kaufmann-Boll, Maike Kern
akzente kommunikation und beratung GmbH	Thomas Loew
Brockmann Consult	Jorrit Scholze, Kerstin Stelzer
Deutsche Bahn AG	GUU Strategie Nachhaltigkeit und Umwelt: Dr. Michael Below, Dr. Karoline Meßenzehl
DB Netz AG	I.NAI 43 Naturgefahrenmanagement: Benjamin Schmitz
Deutscher Feuerwehrverband e. V. (DFV)	Carsten-Michael Pix
Deutsches Institut für Wirtschafts-forschung (DIW)	Abteilung Unternehmen und Märkte: Prof. Dr. Martin Gornig
Deutscher Tourismusverband (DTV)	Dirk Dunkelberg
Eider-Treene-Verband	Kerstin Fuhrmann
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Gesamtverband der Deutschen Ver-sicherungswirtschaft e. V. (GDV)	Sach- und Technische Versicherung, Schadenverhütung, Statistik: Dr. Olaf Burghoff, Axel Amkreutz
Heinze GmbH	Market Research: Katrin Klarhöfer
Helmholtz-Zentrum für Umweltforschung GmbH (UFZ)	Department Biozönoseforschung: Dr. Martin Musche, Alexander Harpke Department Naturschutzforschung: Prof. Dr. Josef Settele, Elisabeth Kühn
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Kommunale Aktionsgemeinschaft zur Bekämpfung der Schnakenplage KABS e. V.	Artur Jöst
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Zukunft – Umwelt – Gesellschaft (ZUG) gGmbH	Team Anpassung an den Klimawandel: Karin Zacharias-Langhans

Sources

Introduction

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Abbreviations

AA	Federal Foreign Office (Auswärtiges Amt)
ABAG	General Soil Erosion Equation (Allgemeine Bodenabtragsgleichung)
AdB	Autobahn GmbH des Bundes
Ah	Annual run-off depth (jährlicher Abfluss eines Wassereinzugsgebiets)
AK UGRdL	Working Group on Environmental Economic Accounts of the Federal States (Arbeitskreis Umweltökonomische Gesamtrechnungen der Länder)
ALKIS	Authoritative Real Estate Cadastre Information System (Amtliches Liegenschaftskatasterinformationssystem)
AMK	Agenda – Adaptation of Agriculture and Forestry as well as Fisheries and Aquaculture to Climate Change (Agenda Anpassung von Land- und Forstwirtschaft sowie Fischerei und Aquakulturen an den Klimawandel)
ANK	Natural Climate Protection Action Programme (Aktionsprogramm Natürlicher Klimaschutz)
APA	Adaptation Action Plan (Aktionsplan Anpassung) in versions I (2011), II (2015), III (2020)
BaFin	Federal Financial Supervisory Authority (Bundesanstalt für Finanzdienstleistungsaufsicht)
BASt	Federal Highway Research Institute (Bundesanstalt für Straßenwesen)
BAuA	Federal institute for occupational safety and health (Bundesinstitut für Arbeitsschutz und Arbeitsmedizin)
BAW	Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau)
BB	Brandenburg
BBK	Federal Office of Civil Protection and Disaster Assistance (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe)
BBodSchG	Federal Soil Protection Act (Bundes-Bodenschutzgesetz)
BB	Brandenburg
BBR	Federal Office for Building and Regional Planning (Bundesamt für Bauwesen und Raumordnung)
BBSR	Federal Institute for Research on Building, Urban Affairs and Spatial Development (Bundesinstitut für Bau-, Stadt- und Raumforschung)
BDF	Soil Monitoring Sites (Boden-Dauerbeobachtungsflächen)
BE	Berlin
BfN	Federal Agency for Nature Conservation (Bundesamt für Naturschutz)
BfG	Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde)
BfS	Federal Office for Radiation Protection (Bundesamt für Strahlenschutz)
BIBB	Federal Institute for Vocational Education and Training (Bundesinstitut für Berufsbildung)
BImA	Institute for Federal Real Estate (Bundesanstalt für Immobilienaufgaben)

BKG	Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie)
BLE	Federal Office for Agriculture and Food (Bundesanstalt für Landwirtschaft und Ernährung)
BMAS	Federal Ministry of Labour and Social Affairs (Bundesministerium für Arbeit und Soziales)
BMBF	Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung)
BMDV	Federal Ministry for Digital and Transport (Bundesministerium für Digitales und Verkehr)
BMEL	Federal Ministry of Food and Agriculture (Bundesministerium für Ernährung und Landwirtschaft)
BMF	Federal Ministry of Finance (Bundesfinanzministerium)
BMFSFJ	Federal Ministry of Family Affairs, Senior Citizens, Women and Youth (Bundesministerium für Familie, Senioren, Frauen und Jugend)
BMG	Federal Ministry of Health (Bundesministerium für Gesundheit)
BMI	Federal Ministry of the Interior and Community (Bundesinnenministerium)
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit; name of the BMUV from 1986 to 2013)
BMUB	Federal Ministry for the Environment, Nature Conservation, Construction and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit; name of the BMUV from 2013 to 2017)
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz)
BMVg	Federal Ministry of Defence (Bundesministerium der Verteidigung)
BMVI	Federal Ministry for Transport and Digital Infrastructure (Bundesministerium für Verkehr und digitale Infrastruktur; name of the BMDV from 2013 to 2021)
BMWK	Federal Ministry for Economic Affairs and Climate Action (Bundesministerium für Wirtschaft und Klimaschutz)
BMWSB	Federal Ministry for Housing, Urban Development and Building (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen)
BMZ	Federal Ministry for Economic Cooperation and Developement (Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung)
BNB	Assessment System for Sustainable Building (Bewertungssystem Nachhaltiges Bauen)
BNetzA	Federal Network Agency (Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen)
BSA	Federal Plant Variety Office (Bundessortenamt)
BSH	Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie)
BÜK	Soil Overview Map (Bodenübersichtskarte)
BUKEA	Department of the Environment, Climate, Energy and Agriculture of the Free and Hanseatic City of Hamburg (Behörde für Umwelt, Klima, Energie und Agrarwirtschaft der Freien und Hansestadt Hamburg)
BVL	Federal Office of Consumer Protection and Food Safety (Bundesamt für Verbraucherschutz und Lebensmittelsicherheit)
BW	Baden-Württemberg
BWI	National Forest Inventory (Bundeswaldinventur)
BY	Bavaria (Bayern)
BZE	Soil Condition Survey for Forestry and Agriculture (Bodenzustandserhebung)
BZE-Wald	Forest Soil Condition Surveys
BZgA	Federal Centre for Health Education (Bundeszentrale für gesundheitliche Aufklärung)
CAU	Christian-Albrechts-Universität zu Kiel
CBD	Convention on Biological Diversity (Biodiversitätskonvention)
CCM	Corn-Cob-Mix
CDC	Climate Data Center (DWD)
CDP	Carbon Disclosure Project (today only in abbreviation CDP)
CO_2	Carbon dioxide
COP	UN Climate Change Conference (Conference of the Parties, Vertragsstaatenkonferenz)
C_{org}	Organic carbon
CSR	Corporate Social Responsibility
CSRD	Corporate Sustainability Reporting Directive (EU-Strategie zur

Nachhaltigkeitsberichterstattung von Unternehmen)

DAS German Strategy for Adaptation to Climate Change (Deutsche Anpassungsstrategie an den Klimawandel)

DFV German Fire Brigade Association (Deutscher Feuerwehrverband e.V.)

DIW German Institute for Economic Research (Deutsches Institut für Wirtschaftsforschung e.V.)

DLM250 Digital Landscape Model (Digitales Landschaftsmodell) 1:250.000

DSGVO General Data Protection Regulation (Datenschutzgrundverordnung)

DSWI Disease Water Stress Index

DWD National meteorological service of Germany (Deutscher Wetterdienst)

DzU Data on the Environment (Daten zur Umwelt)

EAFRD European agricultural fund for rural development

EBA European Banking Authority (Europäische Bankenaufsichtsbehörde)

eds. Editors (Editoren)

EEA European Environment Agency (Europäische Umweltagentur)

eEV Extended natural hazard insurance for residential buildings ((erweiterte Elementarschadenversicherung)

EnWG Federal Law on the Energy Industry (Energiewirtschaftsgesetz)

EU European Union (Europäische Union)

FAO Food and Agriculture Organisation of the United Nations (Ernährungs- und Landwirtschaftsorganisation der Vereinten Nationen)

FFH-RL Habitats Directive (EU-Fauna-Flora-Habitat-Richtlinie)

FGRDEU National Inventory of Forest Genetic Resources (Nationales Inventar forstgenetischer Ressourcen in Deutschland)

FLI Friedrich-Loeffler-Institute (Friedrich-Loeffler-Institut)

FNEWs Remote sensing based National Detection Sytem for Forest Damages (Fernerkundungsbasiertes Nationales Erfassungssystem für Waldschäden)

FONA Research for Sustainability (Forschung für Nachhaltigkeit)

FoVG Forest Reproductive Material Act (Forstvermehrungsgutgesetz)

FSB Financial Stability Board

FSME Tick-borne encephalitis (Frühsommer-Meningoenzephalitis)

FWI Canadian Fire Weather Index (Kanadischer Fire Weather Index)

GAB Statutory Management Requirements (Grundanforderungen an die Betriebsführung)

GAK Improving the agricultural structure and coastal protection (Gemeinschaftsaufgabe „Verbesserung der Agrarstruktur und des Küstenschutzes“)

GAP EU’s common agricultural policy (Gemeinsame Agrarpolitik der EU)

GBF Kunming-Montreal Global Biodiversity Framework (Kunming-Montreal Biodiversitätsrahmen)

GCF Green Climate Fund (Grüner Klimafonds)

GDV German Insurance Association (Gesamtverband der Deutschen Versicherungswirtschaft e.V.)

GDWS Federal Waterways and Shipping Agency (Generaldirektion Wasserstraßen und Schifffahrt)

GEF Global Environment Facility (Globale Umweltfazilität)

GEG Buildings Energy Act (Gebäudeenergiegesetz)

GIZ Deutsche Gesellschaft für internationale Zusammenarbeit

GLÖZ Standards for the maintenance of good agricultural and ecological condition (Standards für einen guten landwirtschaftlichen und ökologischen Zustand von Flächen)

GPK Master Plan for Coastal Risk Management (Generalplan Küstenschutz)

GRACE Gravity Recovery and Climate Experiment

GRACE-FO GRACE Follow On

GravIS Gravity Information Service

GSBTS German Small-scale Bottom Trawl Survey

HE Hesse (Hessen)

Hg. Publisher (Herausgeber)

HGÜ Extra high-voltage direct current transmission lines (Höchstspannung-Gleichstrom-Übertragungsleitungen)

HH Hanseatic City of Hamburg (Hansestadt Hamburg)

HLNUG Hessian Agency for Nature Conservation, Environment and Geology (Hessisches Landesamt für Naturschutz, Umwelt und Geologie)

HMUKLV Hessian Ministry for the Environment, Climate Protection, Agriculture and Consumer

	Protection (Hessisches Ministerium für Umwelt, Klimaschutz, Landwirtschaft und Verbraucherschutz)
HQ	Highest Discharge (Höchster Abfluss)
HQx	Flood discharge with a mean probability of occurring once in x years
HSW	Highest Navigation Level (Höchster Schifffahrtswasserstand)
HThW	Maximum tidal high water (Höchster Tidehochwasserstand)
HW	Maximum high water (Höchster Hochwasserstand)
HWRM-RL	European Floods Directive (EU-Hochwasserrisikomanagement-Richtlinie)
IARC	International Agency for Research on Cancer (Internationale Agentur für Krebsforschung)
ICES	International Council for the Exploration of the Sea (Internationaler Rat für Meeresforschung)
IfSG	Protection against Infections Act (Infektionsschutzgesetz)
IGB	Leibniz Institute of Freshwater Ecology and Inland Fisheries (Leibniz-Institut für Gewässerökologie und Binnenfischerei)
IGKB	International Water Protection Commission for Lake Constance (Internationale Gewässerschutzkommission für den Bodensee)
IKI	International Climate Iniative (Internationale Klimaschutzinitiative)
IKZM	Integrated Coastal Zone Management (Integriertes Küstenzonenmanagement)
IMAA	Interministerial Working Group for Adaptation to Climate Change (Interministerielle Arbeitsgruppe Anpassung an den Klimawandel)
IÖR	Leibniz Institute of Ecological Urban and Regional Development (Leibniz-Institut für ökologische Raumentwicklung)
IPCC	Intergovernmental Panel on Climate Change (Weltklimarat)
ISDC	Information System and Data Center
JKI	Julius Kühn Institute (Julius Kühn-Institut)
KABS	Municipal action group to combat the mosquito plague (Kommunale Aktionsgemeinschaft zur Bekämpfung der Schnakenplage KABS e.V.)
KTF	Climate and Transformation Fund (Klima- und Transformationsfonds)
KWRA	Climate Impact and Risk Analysis (Klimawirkungs- und Risikoanalyse) 2021
LABO	German Working Group on Soil Protection of the Federal States and the Federal Government (Bund/Länder-Arbeitsgemeinschaft Bodenschutz)
LAGuS	State Agency for Health and Social Affairs (Landesamt für Gesundheit und Soziales) Mecklenburg-Western Pomerania
LANUV	State Agency for Nature, Environment and Consumer Protection (Landesamt für Natur, Umwelt und Verbraucherschutz) North Rhine-Westphalia
LAWA	Working Group on water issues of the Federal States and the Federal Government (Bund/Länderarbeitsgruppe Wasser)
LAWA-AK	Standing Committee on Climate Change of the LAWA (Ständiger Ausschuss Klimawandel der LAWA)
LAZBW	Agricultural Centre (Landwirtschaftliches Zentrum) Baden-Württemberg
LDCF	Least Developed Countries Fund
LfL	Bavarian State Research Center for Agriculture (Landesanstalt für Landwirtschaft Bayern)
LfU	State Office for the Environment (Landesamt für Umwelt) Brandenburg, Bavarian Environment Agency (Landesamt für Umwelt Bayern)
LfULG	Saxon State Office for Environment, Agriculture and Geology (Landesamt für Umwelt, Landwirtschaft und Geologie Sachsen)
LHW	State Agency for Flood Protection and Water Management (Landesbetrieb für Hochwasserschutz und Wasserwirtschaft) Saxony-Anhalt
LiKi	Länder Initiative on Core Indicators (Länderinitiative Kernindikatoren)
LKN.SH	Agency for Coastal Defence, National Park and Marine Conservation (Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz) Schleswig-Holstein
LLUR	State Department of Agriculture, Environment and Rural Areas (Landesamt für Landwirtschaft, Umwelt und ländliche Räume) Schleswig-Holstein
LoD2	Level of Detail 2 – 3D-Building model with standardised roof shapes (Gebäudemodell mit standardisierten Dachformen)
LTV	State Reservoir Administration of Saxony (Landestalsperrenverwaltung Sachsen)

LUBW	State Institute for the Environment (Landesanstalt für Umwelt) Baden-Württemberg
LUNG	State Agency for Environment, Nature and Geology (Landesamt für Umwelt, Naturschutz und Geologie) Mecklenburg-Western Pomerania
MELUND	Ministry for Energy Transition, Climate Protection, Environment and Nature (Ministerium für Energiewende, Landwirtschaft, Umwelt, Natur und Digitalisierung) Schleswig-Holstein
MHQ	Mean flood discharge (Mittlerer Hochwasserabfluss)
MHW	Mean high water (Mittlerer Hochwasserstand)
MLU	Ministry for Climate Protection, Agriculture, Rural Areas and the Environment (Ministerium für Klimaschutz, Landwirtschaft, ländliche Räume und Umwelt) Mecklenburg-Western Pomerania
MNQ	Mean low-water discharge (Mittlerer Niedrigwasserabfluss)
MonViA	National Monitoring of Biodiversity in Agricultural Landscapes (Nationales Monitoring der biologischen Vielfalt in Agrarlandschaften)
MORO	Action programme ‘Demonstration Projects of Spatial Planning’ (Aktionsprogramm „Modellvorhaben der Raumordnung“)
MQ	Mean water discharge
MSY	Maximum Sustainable Yield (Höchstmöglicher Dauerertrag eines Fischbestands)
MThw	Medium tidal high-water level (Mittlerer Tidehochwasserstand)
MTmw	Medium tidal mid-water level (Mittleres Tidemittelwasser)
MV	Mecklenburg-Western Pomerania (Mecklenburg-Vorpommern)
MW	Medium water level (Mittelwasserstand)
NAP	National Action Plan on the Sustainable Use of Plant Protection Products (Nationaler Aktionsplan zur nachhaltigen Anwendung von Pflanzenschutzmitteln)
NASA	National Aeronautics (US-Bundesbehörde für Raumfahrt und Flugwissenschaft)
NBS	National Biodiversity Strategy (Nationale Strategie zur biologischen Vielfalt)
NDC	Nationally Determined Contributions (Nationale Klimabeiträge)
nFK	Usable field capacity (nutzbare Feldkapazität)
NHN	Standard Elevation Zero (Normalhöhennull)
NHWSP	National Flood Protection Programme (Nationales Hochwasserschutzprogramm)
NI	Lower Saxony (Niedersachsen)
NINA	Emergency Information and Warning App of the BBK (Notfall-Informations- und Nachrichten-App des BBK)
NLP	National Park (Nationalpark)
NLWKN	Lower Saxony Water Management, Coastal and Nature Protection Agency (Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz)
NMZB	National Monitoring Centre for Biodiversity (Nationales Monitoringzentrum zur Biodiversität)
NOAA	National Oceanic and Atmospheric Administration (Nationale Ozean- und Atmosphärenbehörde der USA)
NQ	Lowest water discharge (Niedrigster Abfluss)
NRW	North Rhine-Westphalia (Nordrhein-Westfalen)
NSG	Nature conservation area (Naturschutzgebiet)
Nt	Total nitrogen (Gesamtstickstoff)
ÖPNV	Public passenger transport (Öffentlicher Personennahverkehr)
ÖR	Voluntary eco-schemes (Freiwillige Öko-Regelungen)
PID	Foundation for pollen information services Germany (Stiftung Deutscher Polleninformationsdienst e.V.)
PIK	Potsdam Institute for Climate Impact Research (Potsdam-Institut für Klimafolgenforschung e.V.)
RCP	Representative Concentration Pathways (Repräsentative Konzentrationspfade)
RHLS	Rügen herring larvae survey (Rügen-Heringslarven-Survey)
RKI	Robert Koch Institute (Robert Koch-Institut)
RP	Rhineland-Palatinate (Rheinland-Pfalz)
ROPLAMO	Regional Spatial Structure Plan Monitor (Raumordnungsplan-Monitor) of BBSR
SenMVKU	Senate Department for Urban Mobility, Transport, Climate Action and the Environment (Senatsverwaltung für Mobilität, Verkehr, Klimaschutz und Umwelt) Berlin
SH	Schleswig-Holstein
SN	Saxony (Sachsen)
SSP	Shared Socioeconomic Pathways (Gemeinsame sozioökonomische Entwicklungspfade)
ST	Saxony-Anhalt (Sachsen-Anhalt)

StALU	State Agency for Agriculture and the Environment (Staatliches Amt für Landwirtschaft und Umwelt) Mecklenburg-Western Pomerania
StBA	Federal Statistical Office (Statistisches Bundesamt)
TCFD	Task Force on Climate-related Financial Disclosures
TFW	Thuringian long-distance water supply (Thüringer Fernwasserversorgung)
TH	Thuringia (Thüringen)
THW	Federal Agency for Technical Relief (Bundesanstalt Technisches Hilfswerk)
TI	Johann Heinrich von Thünen Institute – Federal Research Institute for Rural Areas, Forestry and Fisheries (Johann Heinrich von Thünen-Institut – Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei)
TLUBN	Thuringian State Office for the Environment, Mining and Nature Conservation (Thüringer Landesamt für Umwelt, Bauen und Naturschutz)
UBA	German Environment Agency (Umweltbundesamt)
UFZ	Helmholtz Centre for Environmental Research (Helmholtz-Zentrum für Umweltforschung GmbH) Leipzig
UN	United Nations (Vereinte Nationen)
UNEP	UN Environment Programme (Umweltprogramm der Vereinten Nationen)
UV	Ultraviolet radiation (Ultraviolette Strahlung)
UVI	UV-Index
WHG	Water Resources Act (Wasserhaushaltsgesetz)
WHO	World Health Organisation (Weltgesundheitsorganisation)
WOAH	World Organisation for Animal Health (Weltorganisation für Tiergesundheit)
WRRL	EU Water Framework Directive (EU-Wasserrahmenrichtlinie)
WSV	Federal Waterways and Shipping Administration (Wasser- und Schifffahrtsverwaltung des Bundes)
WWA	World Weather Attribution
ZALF	Leibniz Centre for Agricultural Landscape Research (Leibniz-Zentrum für Agrarlandschaftsforschung e.V.)
ZKA	Information Centre for Climate Adaptation (Zentrum für KlimaAnpassung)

Units

°C	Degree Celsius
g	Gram
ha	Hectare
KbE	Colony-forming units (Koloniebildende Einheiten)
kg	Kilogramme
km	Kilometre
km²	Square kilometre
l	Litre
m	Metre
m²	Square metre
mg	Milligram
mm	Millimetre
%	Per cent
t	Tonne
USD	US Dollar
W	Watt

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