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Climate Impact and Risk Assessment 2021 for Germany

Summary

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Climate Impact and Risk Assessment 2021 for Germany

Summary

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Kurzbeschreibung: Climate Impact and Risk Assessment 2021 for Germany. Kurzfassung

Der vorliegende Bericht beinhaltet die Kurzfassung der „Klimawirkungs- und Risikoanalyse 2021 für Deutschland" (KWRA 2021). Die KWRA 2021 ist eine wesentliche Grundlage für die Weiterentwicklung der Anpassung in Deutschland, insbesondere für die Entwicklung der nächsten Aktionspläne Anpassung der Bundesregierung.

In der Kurzfassung der KWRA 2021 werden die Grundlagen und Ergebnisse der Studie, die in insgesamt sechs Teilberichten veröffentlicht wurden, zusammengefasst dargestellt. Dies umfasst Ausführungen zum konzeptionellen Hintergrund sowie zum methodischen Vorgehen bei der Analyse und Bewertung der Klimawirkungen und Anpassungskapazität. Zudem werden weitere Grundlagen wie Klimaprojektionen und sozioökonomischen Projektionen für Deutschland und eine Analyse der generischen Anpassungskapazität dargestellt. Weiterhin werden die Ergebnisse der Analyse- und Bewertungsschritte für jedes der 13 in der KWRA 2021 berücksichtigten Handlungsfelder in zusammengefasster Form präsentiert. Schließlich werden die wesentlichen Inhalte der handlungsfeldübergreifenden Auswertung, einschließlich der Gesamtbetrachtung der Klimarisiken ohne und mit Anpassung, der Analyse räumlicher Muster und die Gesamtbetrachtung der Handlungserfordernisse, sowie der Überblick zum weiteren Forschungsbedarf kurz wiedergegeben.

Abstract: "Climate Impact and Risk Assessment 2021 for Germany". Summary

This report contains the summary of the "Climate Impact and Risk Assessment 2021 for Germany" (KWRA 2021). The KWRA 2021 is an essential basis for the further development of adaptation in Germany, in particular for the development of the next Adaptation Action Plans of the German government.

This short version of the KWRA 2021 summarizes the concepts and results of the study as presented in the six sub-reports. This includes explanations on the conceptual background and the methodological approach to the analysis and assessment of climate impacts and adaptive capacity, as well as basic information in terms of climate and socio-economic projections for Germany and the analysis of generic adaptive capacity. Furthermore, the results of the analytical and assessment steps for each of the 13 action fields considered in the KWRA 2021 are presented in a summarised form. Finally, the main contents of the integrated evaluation, that is the overall assessment of climate risks without and with adaptation, the analysis of spatial patterns, and the overall assessment of the needs for action, as well as the overview of further research needs are presented in a concise manner.

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List of abbreviations

APA III	Adaptation Action Plan III
CMIP	Coupled Model Intercomparison Project
DAS	German Strategy for Adaptation to Climate Change
DWD	German Weather Service
EURO-CORDEX	Coordinated Regional Climate Downscaling Experiment for Europe
GWS	Society for Economic Structural Research
HYRAS	Hydrometeorological grid datasets
IMA-A	Interministerial Working Group on Adaptation
IPCC	Intergovernmental Panel on Climate Change
KWRA 2021	Climate Impact and Risk Assessment 2021 for Germany
RCP	Representative Concentration Pathway
ReKliEs-DE	Regional Climate Projections Ensemble for Germany
SROCC	Special Report on the Ocean and Cryosphere in a Changing Climate
SSP	Shared Socioeconomic Pathway
SuV	Settlement and traffic areas
VA 2015	Vulnerability Analysis 2015

1. Background and goals

On behalf of the Federal Government and in the context of the German Strategy for Adaptation to Climate Change (DAS), the Climate Impact and Risk Assessment 2021 (KWRA 2021) examined and evaluated the future risks for Germany due to climate change. This is the second such analysis since 2015. This study, which is to take place every six years at the request of the federal government (Bundesregierung 2015), is the most comprehensive climate impact and risk analysis in Germany.

In a period of over three years, the study examined all important topics related to climate change in Germany and analysed both the immediate risks of climate change and the potential to address these risks through adaptation. 25 higher federal authorities and institutions from nine ministries were closely involved in the preparation of the study. The expert knowledge of this network of authorities as well as the know-how of numerous other experts in Germany were incorporated into the study.

The central goal of the KWRA 2021 is to create an essential basis for the further development of adaptation in Germany, in particular for the development of the federal government's future adaptation action plans. In order to achieve this goal, the KWRA 2021 was designed as a systematic screening and prioritisation process with successive evaluation steps.

As part of the KWRA 2021, 13 overarching action fields and 102 individual climate impacts were assessed with regard to the level of climate risk for the present, the middle of the century and the end of the century. The primary focus of the study, both in terms of climate risks without adaptation as well as adaptive capacity, was the middle of the century. In order to depict uncertainties and realistic ranges with regard to statements about the future, two cases were considered: a "pessimistic" case with a strong change and an "optimistic" case with a comparatively weaker change. The study considered primarily the effects of climate change, but also took aspects socio-economic change into account.

Adaptation options were identified for the largest climate risks; these were then evaluated for the period in the middle of the century to determine how much adaptation can reduce future climate risks. Support options from the three cross-sectional action fields of spatial planning, civil protection and finance were also taken into account.

At the federal level, the KWRA 2021 provides an overview of the action fields and the climate impacts associated with particularly high climate risks, low adaptive capacities and urgent needs for action. Overall, this made it possible to draw a very complex and detailed picture of the future for Germany, the risks and challenges of climate change. This picture includes potential starting points for coping with these risks – but also the foreseeable limits of adaptation to climate change.

The primary addressees of the KWRA 2021 are the federal ministries in the Interministerial Working Group on Adaptation (IMA-A), which are shaping the DAS and therefore the German adaptation policy. Further target groups include federal authorities as well as states and municipalities. The results and the methodology of the KWRA 2021 can provide them and other actors in industry and civil society with information for adaptation planning and serve as a template for more detailed climate impact and risk analyses. The report is also aimed at the scientific community; it can tie in with ongoing research. In addition, this analysis provides the general public with information on Germany's general vulnerability to climate change.

The KWRA 2021 methodology is based on the last vulnerability analysis (Buth et al. 2015) and the corresponding methodological guide (Buth et al. 2017) At the beginning of the KWRA 2021, the methodological approach of the Vulnerability Analysis 2015 (VA 2015) was reviewed and refined where needed. The changes include:

- In the revised methodology, the investigated time period for the assessment of climate risks has been expanded to include the end of the century.
- For the first time, the relationships and dynamics (e.g. the cascading effects) between the systems affected by climate change in Germany have been examined and evaluated comprehensively.
- The expanded approach for assessing adaptive capacity enabled the systematic compilation of adaptive capacity not only on the generic and action field level, but also on a climate impact-specific level. This offers significant added value to the analysis.
- The prioritisation of the needs for action and the characterisation of potential actions are methodologically better secured and significantly more differentiated compared to the VA 2015. This also ensures a clearer information basis for adaptation planning.

As was the case in the VA 2015, the KWRA 2021 treated the technical analysis level and the normative assessment level separately. This was crucial to the study's methodological approach. The aim of expert consensus among the network partners involved in all evaluations was also a key part of the process.

The Climate Impact and Risk Assessment 2021 was created by a scientific consortium led by adelphi in close cooperation with the network of authorities "Climate Change and Adaptation". The scientific consortium consisted of the consulting and research institute adelphi, the planning, consulting and research institute Bosch & Partner, and Eurac Research.

This summary covers the complete final report, which consists of the following sub-reports (available in German only):

1.	Foundations	https://www.umweltbundesamt.de/publikationen/KWRA-Teil-1-Grundlagen
2.	Risks and adaptation in the land cluster	https://www.umweltbundesamt.de/publikationen/KWRA-Teil-2-Cluster-Land
3.	Risks and adaptation in the water cluster	https://www.umweltbundesamt.de/publikationen/KWRA-Teil-3-Cluster-Wasser
4.	Risks and adaptation in the infrastructure cluster	https://www.umweltbundesamt.de/publikationen/KWRA-Teil-4-Cluster-Infrastruktur
5.	Risks and adaptation in the industry and health clusters	https://www.umweltbundesamt.de/publikationen/KWRA-Teil-5-Wirtschaft-Gesundheit
6.	Integrated assessment - climate risks, needs for action and research requirements	https://www.umweltbundesamt.de/publikationen/KWRA-Teil-6-Integrierte-Auswertung
	Annex	https://www.umweltbundesamt.de/publikationen/KWRA-Anhang
	Summary	https://www.umweltbundesamt.de/publikationen/KWRA-Zusammenfassung
	English summary	https://www.umweltbundesamt.de/publikationen/KWRA-English-Summary

2. Concept and methodology

Conceptual framework

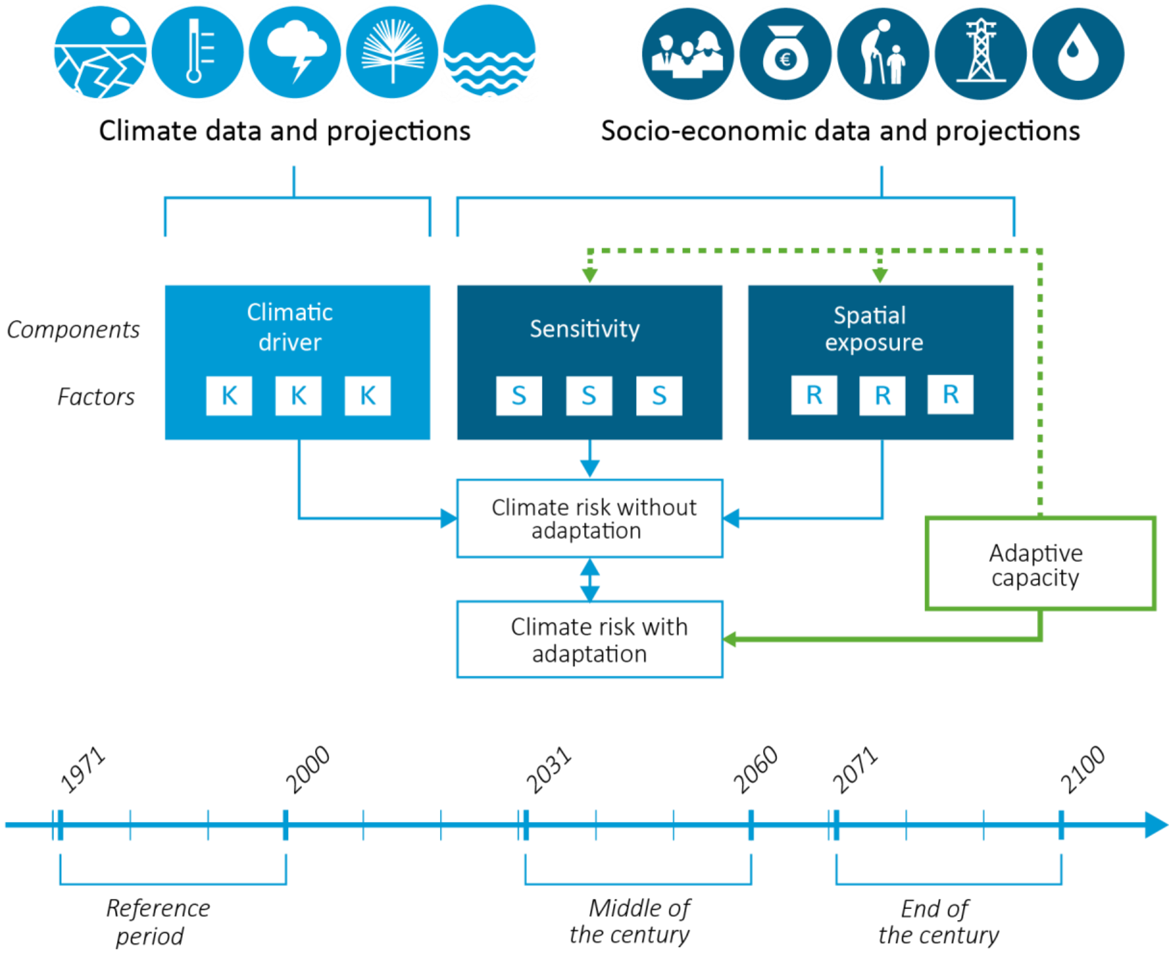
As in the VA 2015, the basis of the KWRA 2021 were climate impact chains. The impact chains logically and systematically show which climatic influence factors can lead to which climate impact (e.g. heat to health problems) and which other factors can influence this effect (e.g. age structure of the population, presence of fresh air corridors, population density). The impact chains can also be used to show how adaptation can mitigate possible climate impacts.

The KWRA 2021 employed an adapted climate risk concept, which is compatible with the approach and terminology of the VA 2015, considers the more recent developments like the publication of the fifth assessment report from the Intergovernmental Panel on Climate Change (IPCC), and allows a focused analysis and assessment:

- A **climate impact** describes an observed or potential future impact of one or more climatic drivers on a defined system. A climate impact always relates to a specific period (e.g. reference period, middle of the century, end of the century). The impact of climate change results from the difference in climate impacts between the reference period and the future period. In the guidelines (Buth et al. 2017). The influencing factors of a climate impact can be assigned to the recommended components of climate risk ("climatic driver", "sensitivity", and "spatial exposure" (Figure 1).
- The **climatic driver** describes a changing aspect of the climate system that influences a component of a human or natural system (Agard et al. 2014). The stronger the climatic driver, the stronger the climate impact tends to be.
- **Sensitivity** describes the degree to which a system is affected, either adversely or beneficially, by climate variability or change (based on Agard et al. 2014). Factors for sensitivity include, for example, the tree species composition or the age structure of the population. The higher the sensitivity, the more pronounced the climate impact tends to be.
- **Spatial exposure** describes the presence of systems such as people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure or economic, social or cultural assets in places and settings that could be affected (based on ISO 14091; Agard et al. 2014). Possible factors for describing the exposure include, for example, the population density or the occurrence of critical infrastructure. Without spatial exposure, there can be no climate impact. The higher the spatial exposure, the stronger the climate impact tends to be.
- In the case of longer impact chains, in addition to the climatic drivers, upstream impacts often play a role as a triggering factor (e.g. floods as an upstream impact for damage to infrastructure). From the point of view of a downstream climate impact, these are referred as an **upstream impact** in what follows.
- Another component is the **adaptive capacity**, which is not part of the impact chains. Adaptive capacity comprises the ability of a system to adjust to potential damage, to take advantage of opportunities or to respond to consequences. Adaptation usually reduces the sensitivity directly or, on longer time scales, the spatial occurrence (e.g. the removal of infrastructure in potential floodplains).
- A **climate risk** denotes the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as the human responses to climate change. In the context of the KWRA 2021, the

term climate risk is based on the definition of the IPCC from the point in time at which an assessment by the "Climate Change and Adaptation" network took place.

Figure 1: Methodological framework and central terms



Source: adelphi

Compared to the VA 2015, the KWRA 2021 has been expanded in various respects. For example, qualitative methods based on more theoretical principles were used to operationalise all climate impacts, and the relationships and dynamics (e.g. the cascading effects) between the systems affected by climate change in Germany have been examined and evaluated comprehensively. In addition, the methodology for analysing and assessing adaptive capacity was optimised; this enabled systematic assessment not only at the generic and action field level, but also at the level of the climate impacts. In comparison to the VA 2015, the prioritisation of needs for action and the characterisation of potential actions has been improved. As with the VA 2015, the refinement of the methodology was coordinated with the partners from the network of authorities.

According to the guidelines, a climate impact and vulnerability analysis represents an interplay of scientific analysis and normative assessment (Buth et al. 2017). The KWRA 2021 treated the technical analysis level and the normative assessment level separately; this was crucial to the study's methodological approach. The technical analysis was based on literature analyses, indicators and model results as well as interviews with experts (including individuals outside the network), so as to record the current state of knowledge in writing. The consolidation of the results was largely in the hands of the scientific consortium of the concurrent UFOPLAN research project. Based on this foundation, the representatives of the “Climate Change and Adaptation” network carried out the normative assessment steps.

A total of four groups of actors in different functions were involved in creating the KWRA 2021:

- The scientific consortium (technical working level),
- The network of authorities “Climate Change and Adaptation”, whose members (federal authorities and institutions) are hereinafter referred to as network partners (technical working level and normative decision-making level),
- External experts who do not belong to one of the network partners (technical working level) and
- The Interministerial Working Group on Adaptation (IMA-A) (normative decision-making level).

Climate scenarios and socio-economic scenarios

Scenarios are typically used to make statements about future developments despite existing uncertainties. In addition to climate scenarios in the fifth assessment report of the Intergovernmental Panel on Climate Change (the so-called “Representative Concentration Pathways”, RCPs), the KWRA 2021 also takes into account socio-economic scenarios consistent with those of the IPCC (“Shared Socioeconomic Pathways”, SSPs). Data for the climate of the reference period (1971 to 2000) and possible future developments for the middle of the century (2031 to 2060) and the end of the century (2071 to 2100) were prepared and made available by the German Weather Service (DWD) as in the VA 2015. Hydrological projections were created by the Federal Institute for Hydrology (BfG). The projections of sea level rise for Germany were prepared and made available by the Federal Maritime and Hydrographic Agency (BSH) (see Chapter 3). In order to map the possible socio-economic development of Germany, two projections of socio-economic factors were created by the Institute of Economic Structures Research (see Chapter 4) (Lutz et al. 2019): The “trend” scenario, which describes a future socio-economic development that corresponds to a continuation of the currently observed development; and the “dynamic” scenario, which corresponds to a development with a comparatively stronger population development and higher economic growth.

In accordance with the objectives of the KWRA 2021, the focus was on the identification of possible critical climate impacts and not on the analysis of the impact of mitigation scenarios. Against this background, the decision was made to use the 15th percentile of the climate projection ensemble of the RCP8.5 climate scenario as the lower limit and the 85th percentile of the RCP8.5 climate ensemble as the upper limit. With this approach, the large range between these percentiles of the RCP8.5 largely also covered results from other RCPs with lower concentrations (e.g. RCP2.6 and RCP4.5) for the middle of the century, since the various scenarios are very similar at this point in time. The selection of the RCP8.5 for the KWRA 2021 was made for precautionary reasons to ensure the sufficient dimensioning of possible adaptation measures. A look at the cumulative emissions of the last 15 years also shows that these also corresponded most closely to the retrospectives of the RCP8.5 scenario (Schwalm et al. 2020).

In principle, different global climatic conditions can be combined with socio-economic projections for Germany. In order to develop consistent scenario combinations, the 15th percentile and the 85th percentile of the climate projection ensemble of the RCP8.5 were each assigned the socio-economic projection that the experts associated with an optimistic or pessimistic expression of the climate impact. The optimistic expression (hereinafter also referred to as the optimistic case) in this way describes a path of future climatic and socio-economic development that is associated with fewer negative climate impacts compared to the alternative path. The pessimistic expression (also known as the pessimistic case) represents a path of future climatic and socio-economic development that includes the more unfavourable combination of scenarios, with higher risks compared to the optimistic scenario combinations. As a rule, the optimistic case was the combination of the 15th percentile of the RCP8.5[1] and the trend scenario.

Climate Impact and Risk Assessment 2021: overview and process

The KWRA 2021 process is shown in Figure 2 and Figure 3. The individual steps for analysing climate impacts and adaptive capacity are explained in more detail below.

[1] In climate projections related to drought and low water, and in some similar cases, the significance of the percentiles is reversed.

Figure 2: Climate impact analysis flow chart

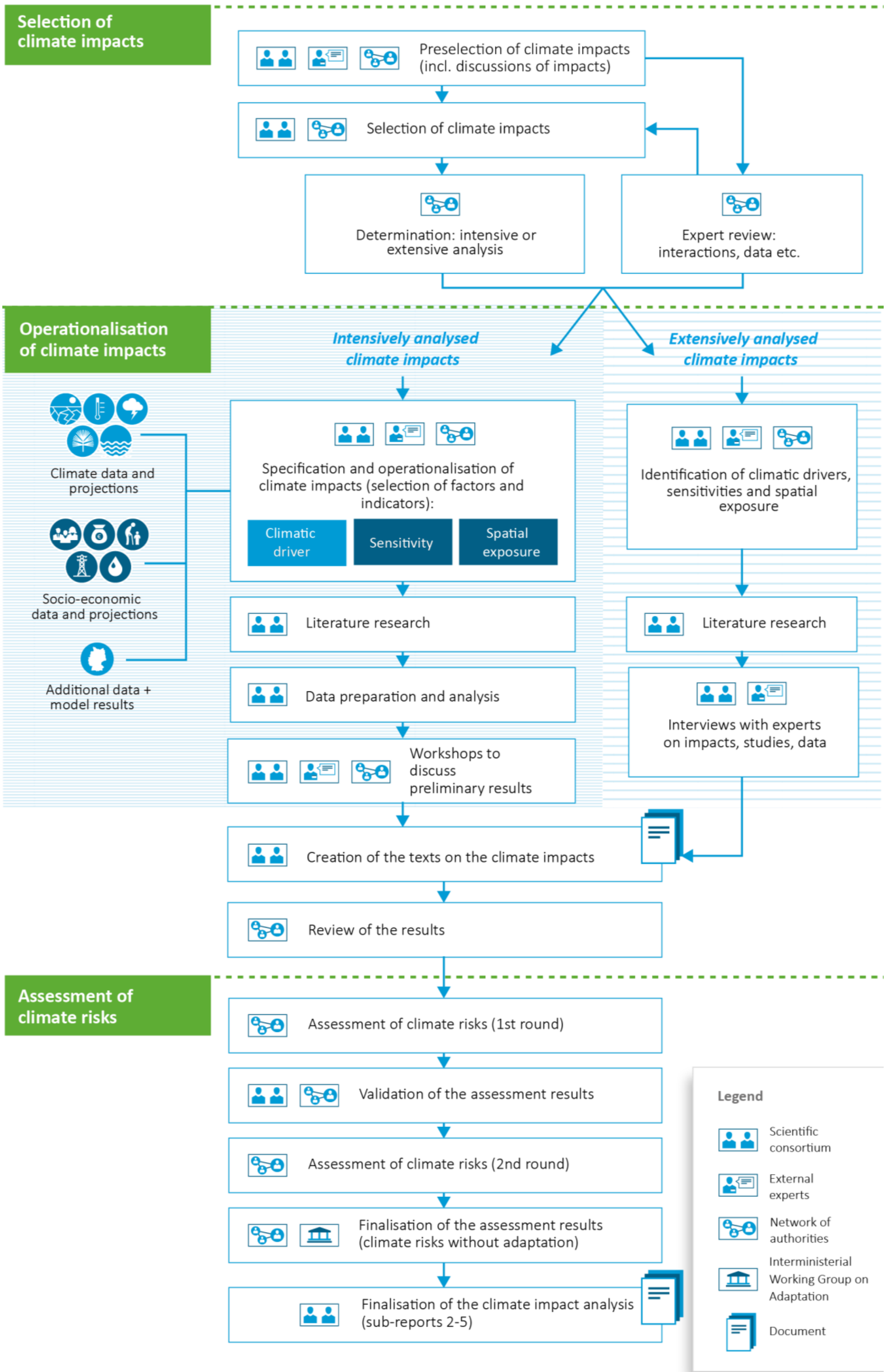
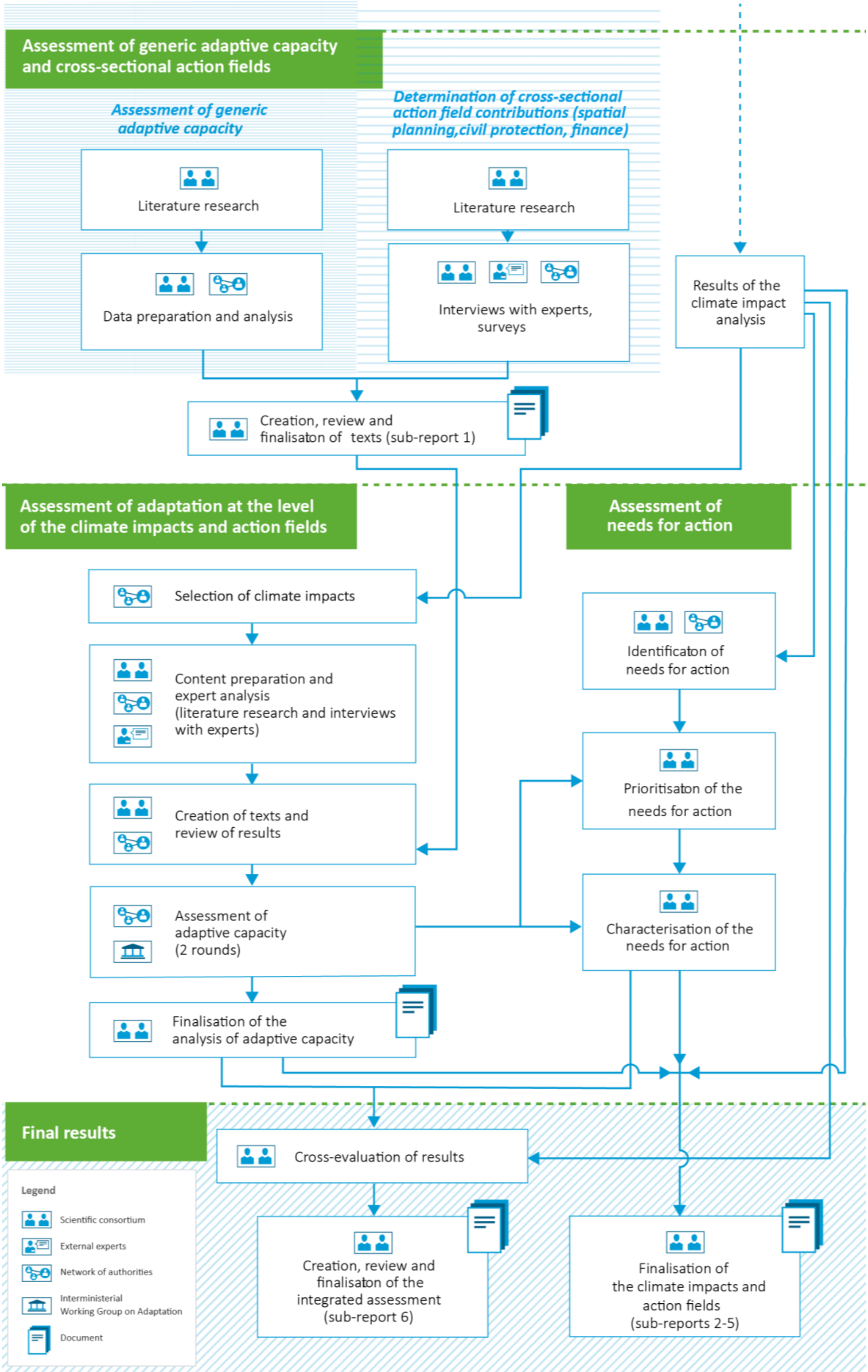


Figure 3: Adaptive capacity examination flow chart



Climate impact analysis process

Given that a comprehensive analysis of the nearly 200 potential climate impacts identified by the climate impact chains was not possible, it was necessary to reduce the number of climate impacts in a transparent and comprehensible manner. The network established the following criteria as a basis for the transparent selection of the potentially relevant climate impacts for Germany:

- the **"relevance"** of the climate impact for Germany from the point of view of climate change and adaptation,
- the **"change in relevance"** in the last five years, for example due to new circumstances,
- and the **"increase in knowledge"** in the form of new scientific findings which, compared to five years ago, allow for an improved understanding of the mechanisms of action.

The selection was made by the network of authorities. A total of 102 climate impacts in 13 action fields were selected for analysis as part of the KWRA 2021. Some of the climate impacts that were not selected were briefly addressed in the respective sections of the report. To analyse climate impacts, the study categorised them for extensive or intensive analysis.

The **extensively analysed climate impacts** were examined primarily on the basis of literature research. This made it possible to consider a relatively large number of relevant climate impacts in one action field. A technical analysis was carried out for the middle of the century (2031 to 2060) and the end of the century (2071 to 2100). In individual cases, interviews were conducted with experts in order to gain access to the most recent scientific knowledge. In addition, the results indicated needs for further research, if this was identified. On the basis of this information, the network carried out a final assessment of the risk of climate impact.

The **intensively analysed impacts** were examined as quantitatively as possible for the three periods "reference period" (1971 to 2000), "middle of the century" (2031 to 2060) and "end of the century" (2071 to 2100) using the scenario combinations. The first step provided greater detail about the climate impacts on a technical working level in light of available data and information as well as assessment criteria. The technical foundation for this comprised climate indices, data and model results, information from expert statements and selected studies; the information was discussed in workshops with the network partners and external experts. The results were presented in the form of text descriptions and, where possible, with maps. Uncertainties in the results were also taken into account.

Statements for the end of the century are associated with greater uncertainties compared to statements for the middle of the century (also because no projections of socio-economic development were available). Nevertheless, both the middle of the century and the end of the century were considered for all selected climate impacts for the KWRA 2021. For the extensively analysed climate impacts, the end of the century was addressed in the form of a corresponding text, which explains existing studies and, if necessary, information from experts. For the intensively analysed climate impacts, the same operationalisation was used for the end of the century as for the middle of the century and comparable maps were drawn up, insofar as it was possible and considered sensible by the experts. If this was not possible, their development up to the end of the century was described and explained based on the results of the climate impact for the middle of the century. Among other things, the factors influencing this development were identified.

The result of the technical analysis of the climate impacts included statements on the extent to which these impacts can impair the relevant system in the future in both the optimistic and pessimistic cases. Based on these results, all climate impacts (extensive and intensive) were assessed with regard to their climate risk, as in the VA 2015. The assessment took into account potential, possibly downstream, consequences and, as a result, the assessment of upstream and downstream climate risks. This required an iterative approach considering interactions across action fields.

The assessment of climate risks took into consideration possible macroeconomic, societal, but also ecological and cultural consequences of the climate impact on the overall system in Germany.

The assessment of the climate risks was carried out for all analysed climate impacts and 13 action fields, which were assessed separately for the present[2], the middle of the century (2031 to 2060) and the end of the century (2071 to 2100). A three-stage scale of *low*, *moderate* and *high* was used to assess the climate risks, without any additional criteria. Due to the heterogeneity of the climate impacts and the complexity of the interactions and pathways, only an assessment in these three levels was possible. A cross-sectoral metric was not used, among other things because this would have involved the weighing of protected resources, which is problematic, from an ethical perspective. The assessment of climate risks for the middle and the end of the century took place for the optimistic and the pessimistic case.[3]

When assessing the climate risks, only existing and implemented adaptation measures were taken into account as part of the sensitivity. Adaptation options and measures that were only in the planning stage and that are possible in the future were not included.

Next came the specification of the degree of certainty of the underlying assumptions, data and models, both for the middle and the end of the century. A four-point scale (*very low, low, medium, high*) was used to determine the certainty.

The assessment also included a query of the estimated duration of adaptation[4], i.e. the effectiveness of comprehensive measures to reduce a climate risk over a large area. Three potential time spans were considered here (short = "<10 years", medium = "10-50 years" and long = "> 50 years"), corresponding to the three examined time frames. For those climate impacts that were selected in a later step for the examination of the adaptive capacity, the adaptation period was specified in greater detail later, as part of the assessment of the adaptive capacity. The assessment of the climate risks at the level of the climate impacts and (separately) the action fields was carried out by the network partners, with technical expertise in the respective subject area.

Since the action fields (in some cases) encompass very different climate impacts and vary thematically, a five-point scale (*low, low-medium, medium, medium-high, high*) was used to evaluate the results.

The Delphi method was used for the assessment of climate risks and the classification of the certainty of the assessment. In this way, the procedure was designed to be highly iterative, starting with information rounds on the procedure and the assessment processes. After the written

[2] The quantitative analyses of the climate impacts are not always congruent with the qualitative assessments. For example, the reference period (1971 to 2000) and mostly the lower end of the RCP8.5 scenario were used as the present in the quantitative analysis; in the qualitative assessment, on the other hand, the optimistic case was mostly understood to mean the recent present and weaker or moderate climate change. This does not reduce the value of the evaluation results, however, but makes them even more practicable for future adaptation action.

[3] A separate terminology was used for climate impacts for which climate change leads to an improvement in the situation. This refers to the opportunities of climate change. Accordingly, the significance of these climate impacts in the middle of the century and end of the century was not assessed for an optimistic and a pessimistic case, but for a high-opportunity and a low-opportunity case. This concerned the climate impacts "demand for heating energy" in the action field "energy industry" and "competitive advantage through innovative environmental technologies" in the action field "industry and commerce". Climate impacts in which climate change triggers both positive and negative effects were not included in this separate group.

[4] The adaptation period is the period for comprehensive measures to take effect on a large-scale reduction of a climate impact in Germany. The time required includes the time for preparatory work, such as securing acceptance and financing, planning, construction and other implementation processes, such as the development of new markets, as well as the time until the measure takes effect on site.

assessment by the network partners, individual consultations for clarification and validation took place before the validated results were sent back to the network partners. Possible objections were addressed in the form of written discussions or telephone conferences. The final compilation of the results represented the last step. As with the VA 2015, the final report includes only the overall assessment as the result of the technical discussions and coordination processes in the network of authorities. The results of the assessment carried out by the network partners were then presented to the IMA-A for information purposes.

Assessment of adaptive capacity

The assessment of the adaptive capacity supplemented the evaluation of the climate risks without adaptation and was based on these results in terms of content and method. The two work steps took place in direct sequence. All in all, the process represents an expert assessment of the adaptive capacity based on current scientific knowledge. As with the climate impact analysis, the technical analysis of the adaptive capacity was carried out in close cooperation with the "Climate Change and Adaptation" network, and members of this network of authorities carried out the assessment of the adaptive capacity.

When designing the analysis of the adaptive capacity, the preliminary work from the VA 2015 could only be used to a limited extent, as the consideration of the adaptive capacity in the analysis at that time was very limited. A literature search was carried out to develop the methodology, including a consideration of the methodological approaches of regional and national, cross-sectoral vulnerability and climate risk analyses for measuring and evaluating adaptive capacity.

According to the methodological concept of the KWRA 2021, a distinction can be made between climate risks without adaptation and with adaptation. Adaptation can on the one hand reduce the sensitivity of an affected system and on the other influence the spatial exposure. In the following, adaptation is understood as the actual realisation of adaptive capacity via the implementation of adaptation measures. This understanding is based on the corresponding definition of the term in the fifth assessment report of the IPCC[5], but was adapted and/or supplemented in accordance with the relevant literature as follows:

- Possible opportunities of climate change were not taken up further in the assessment of adaptability.
- Adaptive capacity is understood to mean that it can also be a defined section of the area of all possible responses to climate change. Accordingly, adaptive capacity is not to be equated with the maximum possible adaptive abilities.
- The KWRA 2021 takes into account both very specific and concrete adaptation measures that trigger an immediate effect and interventions that start on a more abstract or higher level and merely improve the framework conditions. That stated, the change in the framework conditions was in fact in the foreground in many cases.
- When analysing the adaptive capacity in the context of the KWRA 2021, autonomous adaptation was not considered separately.

Adaptive capacity was examined at the level of the action fields, at the level of climate impacts and at the generic level, i.e. with regard to general properties and resources that enable adaptation. To reduce complexity, the study employed an analysis scheme consisting of the six adaptation dimensions: knowledge; motivation and acceptance; technology and natural resources; financial resources; institutional structure and human resources; and legal framework and

[5] "The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences." (Agard et al. 2014).

political strategies. This harmonises with adaptation planning at the national level and has already been used in a similar form as part of a national vulnerability analysis (in Switzerland) (BAFU 2015; ETH Zürich 2016). The consideration of the adaptive capacity at the generic level included the contributions of the cross-sectional action fields spatial planning, civil protection and finance, whose activities are understood as part of the general framework for the implementation of adaptation processes and can contribute to adaptive capacities in the other action fields. The findings on the contributions of the cross-sectional action fields were incorporated into the analysis and assessment of the adaptive capacity at the level of the action fields and climate impacts.

The explicit consideration of a climate risk without adaptation in comparison to a climate risk with adaptation makes it possible to clarify both the severity of the climate risk and the scope for action to reduce a climate risk through adaptation. In order to specify options and urgencies in the future development of adaptive capacities and their activation, a distinction was made with regard to climate risks with adaptation as follows:

- **APAIII+ measures:** They are part of the potential for more far-reaching adaptive capacity. The adaptation instruments formulated in the Adaptation Action Plan III (APA III) were the basis for identifying these measures. In exceptional cases, the network partners were able to include other planning documents, provided that these contained plans with clear, defined measures that had already been politically approved. It is assumed that the measures will be implemented to the extent agreed under realistic conditions.
- **More far-reaching adaptation:** The maximum possible conventional adaptation, i.e. targeted climate adaptation measures that go beyond the APAIII+ measures and can be viewed as plausible under the assumed socio-economic developments and current political framework conditions. In this understanding, more far-reaching adaptation includes the APAIII+ measures (see also the definition of the APAIII+ measures).

Since adaptation is fundamentally based on influencing sensitivity or spatial exposure, i.e. can theoretically affect each individual sensitivity factor and each factor of spatial exposure – whereby there are different ways of influencing each – the observation of the adaptive capacity must take into account a variety of factors in comparison to a climate impact analysis (climate risk without adaptation). This requires an even greater reduction in complexity than is already the case in the context of the climate impact analysis. This also increases the need for normative decisions. The high number of interactions and their high level of complexity also mean that long-term prognoses for adaptation factors are often only possible to a (very) limited extent.

For the analysis of the adaptive capacity at the level of climate impacts, the most recent scientific literature and study results were evaluated. At the same time, expert interviews were used as an additional source of information for adaptation options with regard to individual climate impacts. The results of the literature review and the expert interviews were summarised in input papers, which served to prepare the content of the actual assessment of the adaptive capacity. The assessment of the adaptive capacity was carried out using the Delphi method, that is, a technical, consensual assessment of the adaptive capacity was developed by the network partners over several iteration loops. The following aspects were taken into account in this assessment: Effectiveness of the APAIII+ measures and the more far-reaching adaptation, certainty of these statements and adaptation period. In addition, assessments of the contributions that will (or would have to) be made in the individual adaptation dimensions to the effectiveness of the APAIII+ measures and the more far-reaching adaptation were requested and reported as ranges. When assessing the effectiveness of adaptation, the focus was on reducing the climate risk through adaptation. Overall, the primary focus was the mid-century period (2031 to 2060). Only trend estimates were requested for the end of the century.

To present the **generic adaptive capacity**, indicators with available, spatially differentiable quantitative data (at the district or state level for the whole of Germany) were selected. The selection of the indicators was based on the six adaptation dimensions (knowledge; motivation and acceptance; technology and natural resources; financial resources; institutional structure and human resources; legal framework and political strategies), so that the data sets are ultimately based on fundamental structural, socio-economic characteristics. Although the availability of suitable data, i.e. data that is actually meaningful and spatially resolved in terms of adaptive capacity (at the federal level) is limited, this quantitative analysis can be used to derive approximate indications of basic framework conditions and prerequisites for the implementation of adaptation. A computational or map-based compilation of all results on the generic adaptive capacity was not carried out in order to avoid the impression that this would give a clear overall picture of the generic adaptive capacity for Germany.

The identification and assessment of the current and future contributions of civil protection and the financial sector to adaptive capacity was based on literature and with the help of expert interviews. For the investigation of spatial planning, a distinction was made between the level of regional planning and the subordinate levels of municipal land-use planning. First, a literature analysis took place, in particular the period since the VA 2015. To analyse the contribution of regional planning to adaptive capacity, a written survey was carried out among regional planners in Germany. The survey covered the importance of climate adaptation in regional planning and the use, benefits and limitations of both formal and informal instruments. In addition, individual interviews took place with regional planners in pioneering regions and in regions particularly affected by climate change. The analysis of the contributions made by urban land use planning to adaptive capacity focused on the effects of two recent amendments to the building code (2011, 2013). For this purpose, the study made use of both the relevant literature and the results of concurrent or recently completed research projects.

Integrated assessment

Similar to the VA 2015, an integrated assessment of the results was carried out. To this end, a cross-field evaluation and an analysis of interdependencies and spatial patterns took place. In addition, the results of the adaptive capacity and the needs for action were evaluated and the affected areas of the system analysed.

For the comparison of the climate risks, the study determined which climate impacts, action fields and clusters were rated as high. In addition, the climate risks were evaluated in relation to the four protected assets or resources (humankind, economy, environment and cultural heritage), the affected systems and temporal change tendencies. There was also a comparison with the results of the VA 2015. The comparison was only made for those climate impacts with a similar character.

The cross-field evaluation of the climatic drivers was carried out by counting the climatic drivers that can affect the 102 climatic impacts in all action fields (positive effects of climatic drivers on climatic impacts were not included in the assessment).

The cross-comparison of the sensitivity factors was carried out by determining and evaluating the relevant sensitivity factors for each of the analysed climate impacts. The study examined which sensitivity factors occurred more frequently and which areas they could be assigned to.

The cross-field evaluation of the certainty was carried out on the basis of the certainty of the evaluation specified in the context of the assessment of the climate risks. This took place separately, initially for the climate risks without adaptation and then also for the assessment of the adaptive capacity.

For the analysis of the interactions, the connections between the individual climate impacts were identified based on the relationships presented in the chapters on the action fields. The evaluation was based on the assumption that the negative effects of climate change on a climate impact also have negative consequences for the downstream impacts. The analysis of the interactions made a distinction between climate impacts that affect other climate impacts or action fields (outgoing interactions) or, conversely, that are influenced by other climate impacts (incoming interactions).

Another focus of the evaluation was the analysis of the needs for action. The aim here was to make statements about the climate impacts for which there are priority needs for action, where the APAIII+ measures are sufficient (provided they are implemented), where significant gaps remain after the implementation of the APAIII+ measures and, if necessary, after more far-reaching adaptation, which type of action will be required and what to consider in terms of more extensive adaptation.

The statements on the need for action resulted from a combination of the results of the analysis on climate impacts and the results of the analysis on adaptive capacities. First, a prioritisation was made on the basis of the assessments of the climate risks and the adaptation period per climate impact. The pessimistic case served as the basis for the prioritisation, as this enables the determination of clearer needs for action. In this way, climate impacts with very urgent and urgent needs for action could be identified.

Second, the needs for action based on the assessment of the adaptive capacity were characterised. To this end, the very urgent needs for action were divided into five groups, each of which has different priorities in the implementation of adaptation measures - for example a focus on adaptation measures that have already been adopted or a focus on further research to develop more far-reaching adaptation options. The prerequisite for such a classification is the normative determination of an adaptation target, i.e. the maximum level of the residual risk, and the normative determination of a degree of certainty in order to develop, plan and implement adaptation measures without further research. The evaluation was also based on the previously recorded adaptation dimensions, whereby only tendencies were specified due to the uncertainty of the statements.

Finally, a cross-evaluation was carried out according to system areas. For this purpose, the climate impacts examined in the KWRA 2021 were divided into five system areas: “natural systems and resources”, “economic systems that use nature”, “infrastructures and buildings”, “economic systems remote from nature” and “people and social systems”. Classification was based on the respective focus of the individual climate impacts, i.e. not across the board according to action fields. These five system areas were considered separately with a view to their impact and the existing needs for action.

3. Climate projections[6]

Climate projections for Germany

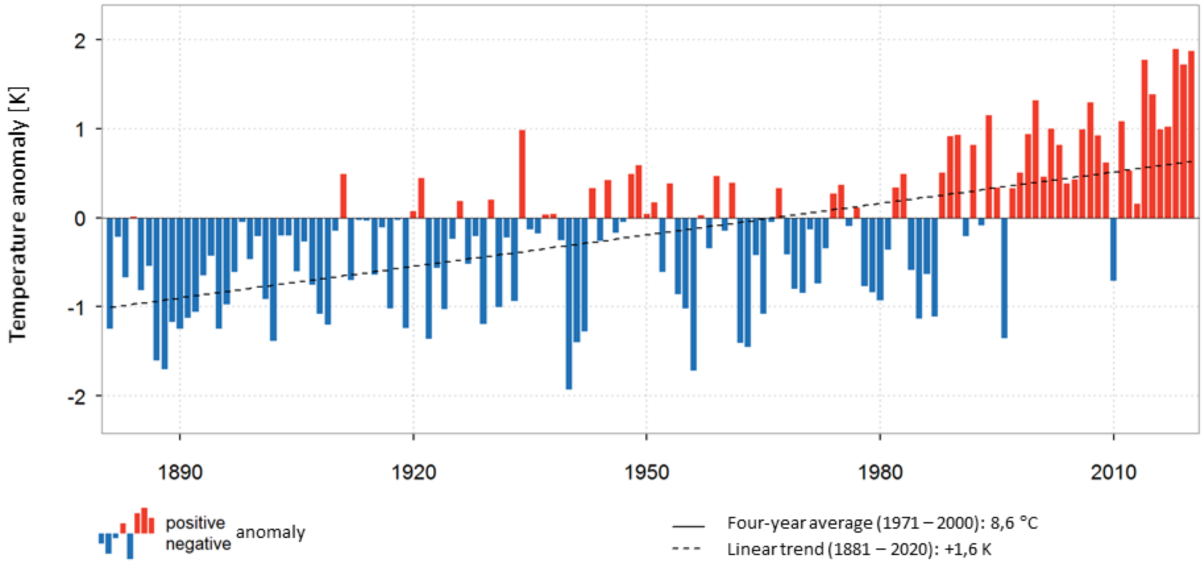
The consequences of global warming are increasingly evident and verifiable in Germany. With the help of meteorological variables, it is possible to express the climatic drivers in the chains of effects of the various climatic impacts considered in the KWRA 2021. Climate scenarios are used to enable estimations about future changes in the climate system; these scenarios are based on assumptions about potential future greenhouse gas emissions. These, in turn, are based on assumptions about the development of the world economy and world population.

Regional climate model data are used to estimate future climate change in Germany. The DWD reference ensembles v2018, based on the regional climate projections EURO-CORDEX and the simulation results of the ReKliEs-DE project, provide the uniform data foundation. The climate changes represented in the ensemble form a subset of all possible climate changes. The KWRA 2021 uses the 15th percentile of the RCP8.5 as the lower limit of possible changes and the 85th percentile of RCP8.5 as the upper limit. The hydrometeorological grid data set (HYRAS) of the German Weather Service serves as a reference; this enables the comparison of modelled climate changes with the reference period (1971 to 2000). The climate projection data were brought to the spatial resolution of the reference data set (Brienen et al. 2020).

The measured air temperature shows an upward trend over the observation period from 1881 to 2020, despite the strong variance between the years and decades. With an increase of 0.25 degrees Celsius in every decade (between 1951 and 2015), the temperature increase in Germany is well above the global average of the increase. A significant change can be seen from the late 1980s on (Figure 4). The minimum daily low temperature and the maximum daily high temperature rose even more sharply than the average air temperature (on average just under +0.5 degrees Celsius per decade in the period from 1950 to 2015).

[6] In addition to projections, the chapter also contains statements on the general development of meteorological and hydrological parameters and the rise in sea level.

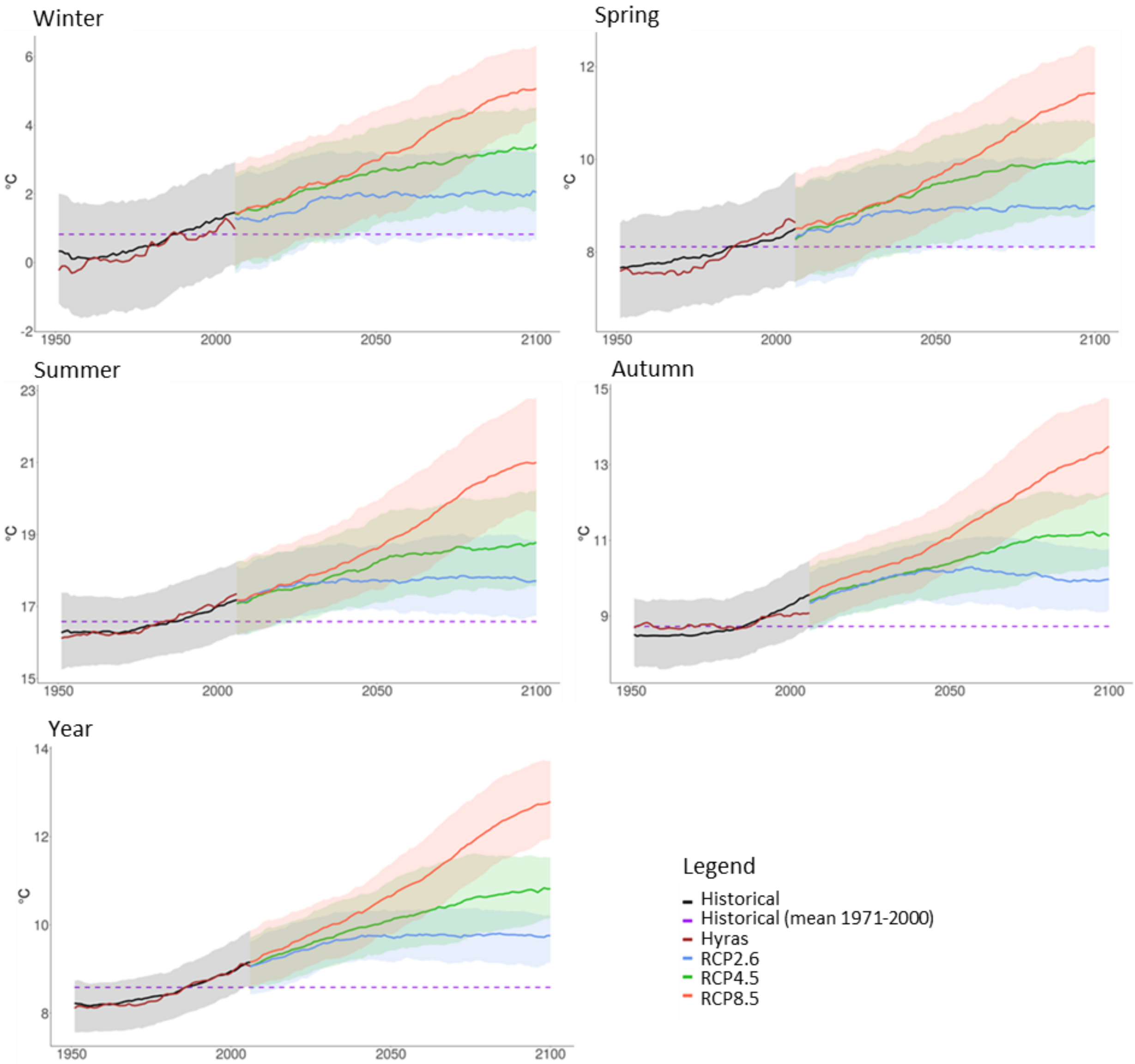
Figure 4: Average annual temperatures in Germany in the period 1881 to 2020 as anomalies from the reference period 1971 to 2000



Annual average temperatures in Germany in the observation period 1881 to 2020, shown as anomalies from the reference period (1971 to 2000), based on HYRAS-TAS. Blue bars are negative anomalies and red bars are positive anomalies. The black line shows the long-term average (1971 to 2000); the dashed line the linear trend.
Source: www.DWD.de/zeitreihen

The average annual temperature for Germany is already 1.6 degrees higher (compared to 1881, when measurements began). The climate projections show that temperatures in Germany will continue to rise in the future for all seasons and for the RCP2.6 and RCP8.5 scenarios. For the middle of the century (2031 to 2060), the choice of the emission scenario has less of an influence on the temperature change, but towards the end of the century the projections of the different scenarios diverge significantly (Figure 5). By the end of the 21st century, the RCP2.6 scenario projects a German average change in the annual average temperature of +0.9 degrees Celsius to +1.6 degrees Celsius (15th to 85th percentiles) compared to the reference period. In the RCP8.5 scenario, the annual average temperature increase for Germany at the end of the century is between 3.1 degrees Celsius and 4.7 degrees Celsius (15th to 85th percentiles) (Table 2). From a seasonal perspective, the strongest rise in temperature is expected in autumn (4.4 degrees Celsius to 5.6 degrees Celsius) and the least pronounced increase in spring (2.4 degrees Celsius to 3.5 degrees Celsius) (Figure 5).

Figure 5: Projected change in average air temperature in Germany, according to the seasons and the annual average



Projected temperature change (German average; in degrees Celsius) compared to the reference period. The ranges of the change signals for the seasons (winter, spring, summer, autumn) and the year are shown.
Data basis: German Weather Service

Furthermore, the RCP8.5 scenario assumes an increase in the average winter precipitation for large parts of Germany compared to the reference period, both for the middle and for the end of the century. This increase is more pronounced in the 85th percentile for both periods (20 to 40 percent across the board at the end of the century). The 15th percentile of the RCP8.5 shows both increases and decreases in average winter precipitation for both periods, depending on the region. In the middle of the century in the 15th percentile of the RCP8.5, a slight increase (up to ten percent) is projected for the east, the Baltic Sea coast and the south and southeast of Germany, but a slight decrease (up to -10 percent) for the low mountain ranges. At the end of the century, the 15th percentile of the RCP8.5 shows higher winter precipitation (compared to the reference period) in central Germany and on the North Sea coast, in the Rhine-Main area, on the Swabian Jura and in the foothills of the Alps, but a decrease in the low mountain ranges.

For summer precipitation, however, the RCP8.5 scenario does not show any clear trends. For the middle and end of the century, the 15th percentile projects lower average precipitation compared to the reference period: in the middle of the century, a decrease of up to -10 percent in eastern, southern and south-eastern Germany, and more pronounced decreases (up to -20 percent), in western Germany and in the northeast. At the end of the century, the decrease in average summer precipitation is most pronounced in western Germany; decreases in summer precipitation are also projected in all other regions of Germany compared to the reference period. The upper range (85th percentile) of the projections in the RCP8.5 shows a different picture: in the middle of the century, summer precipitation increases, especially in eastern and north-eastern Germany (10 to 20 percent), but slight increases were also evident in the west, south and extreme north (Schleswig-Holstein). At the end of the century, summer precipitation also increases almost everywhere in Germany. In some areas, however, the 85th percentile shows a slight decrease in summer precipitation, namely in the Black Forest, in the Palatinate, parts of Swabian Jura and on the Lower Rhine.

With regard to wind speeds in Germany, the future changes (compared to the reference period) are small compared to other variables (temperature, precipitation).

For the temperature threshold-based indices hot days[7], tropical nights[8], ice days[9], the RCP8.5 scenario in particular indicates a significant change compared to the reference period, especially towards the end of the century. By contrast, less significant changes are to be expected towards the middle of the century and for the RCP2.6 scenario. In large parts of Germany, the RCP8.5 scenario (85th percentile) predicts more than 40 hot days per year at the end of the century (just under 28 days more than in the reference period 1971 to 2000). For the middle of the century, the German average in the RCP8.5 scenario (85th percentile) predicts ten additional hot days. On the coast and at altitudes above 1,000 metres above sea level, the hot days also increase by ten to 15 days per year towards the end of the century. Furthermore, just under three more tropical nights are possible by the middle of the century and up to 16 more tropical nights by the end of the 21st century (85th percentile of the RCP8.5). The greatest increase in tropical nights can be expected in the Rhine Valley and in urban agglomerations, up to 30 nights per year. In the low mountain ranges and in the Alps, however, tropical nights will still hardly occur. Due to the sharp increase in hot days and tropical nights, the frequency of longer heat waves is also increasing. In general, the urban areas are more strongly affected by this, and there are also regional focal points in the Berlin area, in the Upper Rhine Valley, as well as in parts of Saarland and the Rhine-Main region. In addition, all RCP scenarios show a decrease in frost and ice days in the German average.

With regard to the number of days with heavy precipitation, a significant increase in all scenarios is to be expected on a long-term average in the future. The most significant increase is projected in spring and winter for the RCP8.5 scenario. During the reference period there is an average of 4.4 days per year. Between 0.1 and 0.5 days in spring and between zero and 0.5 days in winter can be added by the middle of the century. Even greater changes (+0.2 to +0.7 days in spring and +0.2 days to +0.9 days in winter) are projected for the period at the end of the century.

The change values in the RCP8.5 scenario compared to the reference period for the above-mentioned climate parameters are summarised in the following tables.

[7] Maximum daytime temperature over 30 degrees Celsius
[8] Minimum temperature over 20 degrees Celsius
[9] The maximum daytime temperature of zero degrees Celsius is not exceeded.

Table 1: Average values of the change signals for selected climate parameters for the whole of Germany for the middle of the century (2031 to 2060) compared to the reference period (1971 to 2000), RCP8.5

	Reference period (average values)	15th percentile	85th percentile
Annual average air temperature	8.6 °C	+1.5 °C	+2.2 °C
Average air temperature in summer	16.6 °C	+1.4 °C	+2.3 °C
Average air temperature in winter	0.8 °C	+1.3 °C	+2.5 °C
Number of hot days per year	4.6 d	+4.6 d	+10.3 d
Number of tropical nights per year	0.1 d	+0.8 d	+2.7 d
Average annual precipitation	774 mm	-1%	+10%
Average precipitation in spring	176 mm	+3%	+15%
Average precipitation in summer	231 mm	-10%	+9%
Average precipitation in autumn	188 mm	-7%	+10%
Average precipitation in winter	181 mm	+2%	+19%
Number of days of precipitation > 20mm	4.4 d	+0.3 d	+1.6 d
Number of dry days	236.1 d	-3 d	+11.9 d

Data basis: German Weather Service

Table 2: Average values of the change signals for selected climate parameters for the whole of Germany for the end of the century (2071 to 2100) compared to the reference period (1971 to 2000), RCP8.5

	Reference period (average values)	15th percentile	85th percentile
Average air temperature	8.6 °C	+3.1 °C	+4.7 °C
Average air temperature in summer	16.6 °C	+2.9 °C	+5.0 °C
Average air temperature in winter	0.8 °C	+3.4 °C	+4.8 °C
Number of hot days per year	4.6 d	+13 d	+27.8 d
Number of tropical nights per year	0.1 d	+4.8 d	+16.2 d
Average annual precipitation	774 mm	-1%	+15%
Average precipitation in spring	176 mm	+4%	+24%
Average precipitation in summer	231 mm	-16%	+6%
Average precipitation in autumn	188 mm	-8%	+16%
Average precipitation in winter	181 mm	+6%	+30%
Number of days of precipitation > 20mm	4.4 d	+0.9 d	+2.7 d
Number of dry days	236.1 d	-3 d	+19.8 d

Data basis: German Weather Service

Hydrological projections for Germany

Germany's water resources are unevenly distributed regionally and seasonally and also vary from year to year. The interaction of precipitation, snow storage, evaporation and runoff formation leads to the development of different runoff regimes in the river basin districts of Germany (by area in decreasing order: Rhine, Elbe, Danube, Weser, Ems, Warnow/Peene, Oder, Schlei/Trave, Eider, Maas). Overall, summer has more precipitation than winter. However, evaporation is significantly higher in summer and consumes precipitation, which is why most rivers have a minimum runoff in late summer.

The hydrometeorological grid data set HYRAS (bias-adjusted and spatially disaggregated over an area of five by five kilometres) served as the modelling basis. Based on this, simulations were carried out with the water balance model LARSIM-ME. For the RCP8.5 scenario used in the KWRA 2021, 21 projections (based on 19 global and regional climate models) are available. From this collective, after a quality check for water balance-related climate impact analyses, only 16 of the 21 RCP-8.5 simulations are currently in use at the federal level and ten at the state level. The input variables are air temperature, global radiation, wind, relative humidity and air pressure as well as the bias-adjusted precipitation. LARSIM-ME generates daily values of all water balance variables (including, for example, snow), whereby the runoff at gauges in the catchment areas of the large flowing waters (Rhine, Elbe, upper Danube, Weser, Ems) is one of the core products.

The annual renewable water supply in Germany has already decreased over the last few decades. There is a redistribution of the available water resources over the course of the year due to a decrease in summer and an increase in winter. Since the changes in hydrological parameters depend on many other influencing variables in addition to the air temperature, there are less significant changes in the runoff compared to the air temperature in the course of the 21st century. Assuming the RCP8.5, the ensemble of future projections for the middle of the century does not show a clear direction of change with regard to some parameters (e.g. low water). In the second half of the 21st century, the signals for change generally become clearer. The differences compared to a future with increased climate protection (RCP2.6) also emerge here. Furthermore, depending on the type of runoff regime (snow, rain), climate change has different regional effects on the annual high and low water runoff. The differences between the seasons could worsen considerably on stretches of river with a rain regime in the course of the 21st century.

Sea level rise projections for Germany

The individual components of the global sea level change are represented by different models. For example, global circulation models of the atmosphere and the ocean show the rise in sea level due to changes in the flow field and changes in the density of the seawater, which in turn are caused by the warming of the ocean and changes in the salinity.

The last assessment report by the IPCC shows that the sea level rose at an accelerated rate between 1993 and 2015, primarily due to the loss of ice on Greenland. Although the projections are subject to great uncertainty, it is expected that the melting processes on Greenland and in Antarctica will accelerate. The RCP8.5 scenario calculates a global sea level rise of around 40 centimetres to over two metres by the year 2100. These statements are based on data from the CMIP5 projections of the World Climate Research Program. Foundational data from the Integrated Climate Data Center at the University of Hamburg contains estimates of all components and their contributions to the average annual sea level rise compared to the period 1986 to 2005.[10] Since regionalised projections of the ocean tailored to Germany are only available in small numbers, change values (with ranges, 15th and 85th percentiles) relative to the period 1986 to 2005 could only be specified for individual model grid points (of the CMIP5) in northern Germany. The rise in sea level is already measurable on the German coasts and is roughly in line with global projections.

[10] A regionalisation of the SROCC projections was not available at the time of creation. However, it can be expected that the predicted values of the regionalised sea level rise will change compared to those in the 5th assessment report.

4. Socio-economic development

Socio-economic scenarios help determine the consequences of climate change in Germany. That is why socio-economic projections are taken into account when assessing future climate risks. In order to ensure consistency and comparability, the KWRA 2021 employed uniform socio-economic scenarios for Germany, i.e. the two national socio-economic scenarios developed by the Institute of Economic Structures Research (GWS): “trend” and “dynamic”.

They differ in terms of population and economic growth as well as the achievement of environmental protection goals. The trend scenario describes the national “business-as-usual” development for Germany, whereas the dynamic scenario predicts comparatively higher net immigration and stronger economic growth for the projection period between 2015 and 2045. In the trend scenario, climate protection targets as well as targets for the energy and transport sector are achieved late; in the dynamic scenario they are missed altogether. The two scenarios created for Germany can be compared with the “Shared Socioeconomic Pathways” (SSPs) of the IPCC.

The socio-economic projections for Germany were created by quantifying the two socio-economic scenarios using the PANTA RHEI model. First, the projections were quantified at the national level. These results were then projected onto the district level using the PANTA RHEI REGIO model in order to represent the demand for settlement and traffic areas (“Siedlungs- und Verkehrsfläche”, or SuV). The assumptions for the scenarios were expanded. A pronounced urban-rural divide is expected for both scenarios. A comparatively stronger urbanisation is assumed for the dynamic scenario.

In addition, the scenarios differ with regard to the population development up to 2045: While the total population falls by 1.2 percent in the “trend” scenario, it increases by 3.6 percent in the “dynamic” scenario. Both scenarios show a population decline in the new federal states outside the large cities and their agglomeration, as well as in isolated regions in western Germany. Both scenarios show the smallest decrease in population and the greatest increase in population density in urban districts. In contrast to population development, living space increases in both scenarios in all district types. The “dynamic” scenario notes an average higher economic growth than the “trend” scenario, whereby in both scenarios the income per capita increases significantly faster in the new federal states than in the old federal states. With regard to the number of persons in employment, there is a relatively weak development in the new federal states compared to the old federal states. The development of land use is influenced in both scenarios by the expansion of the settlement and traffic area (SuV) and the slight increase in the forest area. The expansion of the SuV is somewhat stronger in the “dynamic” scenario than in the “trend” scenario; otherwise both scenarios show very similar developments in terms of spatial patterns.

5. Generic adaptive capacity and contributions of the cross-sectional action fields to adaptive capacity

Generic adaptive capacity

In the context of KWRA 2021, generic adaptive capacity is understood to mean general adaptation-relevant factors and framework conditions for adaptation in Germany that are helpful for successful adaptation, but are neither absolutely necessary nor sufficient. Successful adaptation depends on so many different influencing factors that they cannot be captured by simple quantitative analyses (see Chapter 2). In order to depict the generic adaptive capacity, indicators with available, spatially differentiable quantitative data (at the district or state level for the whole of Germany) were selected. The selection of the indicators was based on the six adaptation dimensions (knowledge; motivation and acceptance; technology and natural resources; financial resources; institutional structure and human resources; legal framework and political strategies), so that the data sets are ultimately based on fundamental structural, socio-economic characteristics. The indicators are proxies, so they can only approximate the actual dimensions. Although the availability of suitable and spatially distributed data (at the federal level/for all of Germany) is limited, this quantitative analysis can be used to derive approximate indications of basic framework conditions and prerequisites for the implementation of adaptation. There are three (rough) spatial-structural patterns of conducive or less conducive conditions:

- First, there is a south-north divide in terms of economic and knowledge-/technology-enhancing dynamics. The number of residents employed in research- and knowledge-intensive industries (dimension "knowledge") and investments in manufacturing (dimension "technology and natural resources") were considered here. Both show lower values in northern German federal states or districts (compared to those in southern Germany).
- Second, there is a west-east gap in terms of financial resources based on gross domestic product and municipal taxpayers. This suggests that the prerequisites for coping with the financial challenges of adaptation tend to be less favourable in the eastern part of Germany. In contrast, comparatively favourable conditions exist in eastern federal states with regard to the dimension of technology and natural resources, at least based on data on public spending on science, research and development per inhabitant.
- Third, there is a discernible urban-rural gap in terms of financial resources and knowledge at the structural level, at least as measured by gross domestic product or university degrees.

Spatial planning

Climate adaptation is anchored in the Spatial Planning Act and in the models of spatial planning (at federal level). The concrete consideration of the requirements of climate change adaptation takes place at the level of regional planning and urban development planning. Adaptation-relevant specifications have already gained in importance in regional planning over the past ten years, especially with regard to preventive flood protection in river areas (securing retention areas), coastal protection and preservation of water resources, as well as the reduction of thermal stress in urban agglomerations. Most regional plans have also already made provisions for the shifting habitats of animals and plants (Knieling et al. 2013; Schmitt 2016; Knieling et al. 2018; Ahlhelm et al. 2020).

It is possible to put this in concrete terms based on the results of the KWRA 2021 survey of regional planning officers regarding change adaptation in regional planning management (see Sub-report 1, Chapter 5.2). So far, the focus of regional planning stipulations has primarily been directed towards the following key issues from the action fields of spatial planning, which are relevant for climate change adaptation: securing floodplain areas as retention areas; controlling settlement and infrastructure development; and protecting open spaces with an impact on the climate. Risk prevention in flood areas and the minimisation of the further fragmentation of habitats are taken into account relatively often when determining reserved and priority areas. In addition, the mentioned survey showed that the focus of regional planning activities is also directed towards adaptation-relevant topics such as securing interconnected networks of ecologically significant open spaces and increased securing of water resources, whereby, in contrast to the topics mentioned above, informal instruments of regional planning are increasingly used. As part of its range of instruments, regional planning can certainly contribute to climate adaptation in Germany. Specifically, in more than three quarters of the regions[11] involved, climate adaptation is already taken into account in targets, principles or information in regional plans (formal instruments) or this is planned. And a little more than half of the regions involved take topics relevant to climate change into account in planning processes using informal instruments[12] or plan to.

Basically, regional planning contributions to climate adaptation consist in the designation, keeping free or securing of areas to reduce the damage potential and climate risks, in particular with regard to ecosystems (forest, soil, biodiversity, terrestrial, aquatic habitats), flood protection and infrastructure (traffic areas, settlement areas). It is predominantly considered necessary to further expand climate adaptation in regional planning processes, for example by making climate adaptation an explicit consideration or strengthening climate adaptation as a consideration. In view of the climate risks assumed for the future in Germany, there is a particular need to weigh the interests in the use of natural resources (water, soil) and existing areas, which can be coordinated and controlled via regional planning.

At the land-use planning level, the amendments to the Federal Building Code (2011, 2013) in particular have a strengthening effect on the implementation of climate adaptation, as they make it easier to justify climate-adaptation-relevant representations and stipulations in land-use plans and their enforcement in relation to other issues. The contributions of land use planning to climate change adaptation are based, in particular, on the possibility of setting them in the plans or on the pursuit of certain goals at the level of land use planning. This includes reducing land use and soil sealing, maintaining and securing biotope network systems, promoting cohesive networks of ecologically significant open spaces, as well as water retention in the area and decentralised rainwater management (for dealing with heavy rainfall, but also drought). Furthermore, there are adaptation-relevant determinations in the securing of transport areas and the relocation or abandonment of vulnerable transport infrastructure, in building restrictions in flood and high-risk areas or the withdrawal of existing area designation rights, in roof and facade greening, the securing of air ducts and the upgrading of flood protection systems. Such options are already in use in many municipalities.

Civil protection

The central task of civil protection is to cope with current and the best-possible preparation for future damaging events, which also include extreme weather events caused by climatic conditions. Here, coping[13] and adaptive capacities are closely linked, with coping in this context being

[11] n = 58 (of a total of 107 regional planning units in Germany)

This includes the creation of regional development concepts, participation in regional conferences, the development of spatial models and scenarios, advice, moderation of regional processes, contractual agreements, informal specialist planning such as climate protection and climate adaptation concepts.[12]

[13] Coping capacity is defined as the ability to use existing resources and skills in order to reduce or avoid the effects of a catastrophic event in the short to medium term (UNDRR 2004).

understood as a preliminary stage to adaptation. For example, operational experience can enable better preparation for future damage events. In Germany, municipal, state and federal authorities and institutions as well as non-governmental organisations help protect the population. Based on operational experience and knowledge of operational procedures, cooperation with other groups of actors to develop and/or plan adaptation measures represents a key contribution of civil protection to adaptation. This applies in particular to cases of damage caused by extreme weather events such as heat waves, periods of drought, heavy precipitation, river floods or storms. Specifically, exchanges between fire brigades and rescue services with municipal authorities and infrastructure operators, among others, can provide critical support for adaptation. Guidelines created by civil protection organisations for the identification of suitable adaptation measures or recommended conduct can also contribute to adaptation. Future contributions by civil protection to climate adaptation could result from an increased use of operational experience beyond the municipal level on the basis of an improved data situation. This requires greater compatibility between the registration systems used throughout Germany and the operational information collected. Furthermore, the continuation of and increase in communication with the public about climate risks and possibilities for increasing self-protection through target group-specific communication materials can contribute to strengthening adaptive capacity in the future.

Civil protection as an action field

In addition to the contributions that civil protection makes to climate adaptation in other action fields, civil protection organisations are increasingly affected by the consequences of climate change themselves. In particular, extreme weather events such as heavy rainfall are a challenge for those involved in civil protection, as the resulting damage not only pushes the coping capacities to their limits, but can also affect civil protection structures. This can include damaged equipment and property, blocked access routes, failures of power-dependent equipment and means of communication as well as considerable staff losses or absences.

Finance

Financial institutions are key actors in the control and administration of capital flows, which makes them extremely important to the financing of climate adaptation measures. Contributions to climate adaptation arise for both the banking and insurance industries.

With its products, the insurance industry makes a fundamental contribution to social risk transfer. Insurance policies cover risks, such as the risk of possible damage to a building, and in the event of damage, lead to the transfer of the costs. Insurance can, for example, cover the risk of climate-related loss of income in agriculture, damage from forest fires or storms in forestry, or damage to buildings due to floods. The models used by insurers for risk projection to quantify climate risks can also be used as a basis for planning, for example to define flood risk zones as part of urban planning. Awareness campaigns and behavioural recommendations, such as those from health insurance companies, can help increase risk awareness among the population.

The banking industry can make a contribution to climate adaptation in all action fields by granting loans and subsidies. In addition, banks are increasingly bundling private capital in financial products such as green bonds for investment in adaptation measures. Development banks offer, among other things, subsidy programs for climate adaptation projects or, in their role as investors, support adaptation to climate change.

The increasing establishment of guidelines and legal frameworks in the field of sustainable financing is a key factor in the financial industry's future contributions to climate adaptation in Germany. One potentially important aspect is the EU taxonomy for sustainable investments. In particular, the definition of adaptation measures and the further details on the identification of investments in climate adaptation can create liabilities for the financial sector.

In the future, the financial sector can, among other things, make a contribution to adaptation by providing specialist knowledge for planning adaptation measures. Occasionally, insurance companies already offer such advisory services in relation to flood-adapted construction methods. Increased provision of such expertise could contribute to knowledge transfer and awareness-raising. For the insurance industry, there will be further future contributions in the refinement of existing insurance products, such as in agriculture, or the creation of new insurance solutions that can, for example, support the preservation of ecosystems and their adaptation services. In addition, insurance companies can link the conclusion of insurance policies to certain standards for adaptation and development banks can set adaptation standards for actors in the private sector in their packages of measures.

6. Central results per cluster

6.1 Land cluster

6.1.1 Biodiversity action field

Relevance of the action field and new developments

Biodiversity is an existential basis for human life. It includes the variability of organisms from land, marine and other aquatic systems, the genetic diversity within species and the diversity of communities and ecosystems. All these aspects are linked to one another through interactions. One third of all species in Germany are endangered. The causes generally include intensive agriculture and forestry, hydraulic engineering and water maintenance, construction work, and sports and leisure activities. Marine organisms are particularly endangered by the impairment or destruction of habitats on the seabed through fishing or sand mining, increased nutrient inputs from rivers and the direct removal of organisms through fishing or hunting.

In addition to growing human usage demands, climate change represents an additional stress factor. Climate changes often have direct and indirect effects on plants, animals and the natural balance in multiple ways. Plants are directly dependent on climate elements (temperature, humidity, radiation, carbon dioxide). In addition to gradual changes in temperature and precipitation, the increase in extreme climatic events such as heavy rain or long periods of drought also affect biodiversity. In addition to physiological processes, climate change also affects fitness and the competitive relationships between species. Abiotic site conditions are influenced by a changing climate, for example water retention, erosion rates and nutrient availability. A rise in temperature affects the water level as well as the condition of surface water. The effects on aquatic habitats are particularly great. Ultimately, ecosystem services can be impaired. Climatic factors significantly determine the distribution of genotypes, populations, ecosystems and large habitats. Many of these processes are complex and the effects are difficult to predict.

Selected climate impacts in the action field and central analysis results

Changes in the vegetation period and phenology due to climate change have been observed for a majority of all groups of living beings (limnic, marine and terrestrial). Changes in phenology can lead to asynchrony between links in the food chain (different rates of change). A temporal and spatial decoupling has effects on the economy and society, as the phenological synchronicity is influenced by relevant processes for agriculture, forestry and fishing, such as pollination, pests or the occurrence of certain fish species. Disruptions to the functionality of ecosystems could have a major impact on the environment and impair the provision of ecosystem services, especially food.

Climatic changes can be an influencing and, in many species, promoting factor in the spread of alien species. A large proportion of the invasive species that already exist in Germany is thermophilic and is spreading even more as the temperature increases. Urban and close-to-nature areas as well as areas along modes of transport are particularly affected. In both terrestrial and aquatic habitats, the existing lack of close-to-nature habitats, networks and retreats increases the vulnerability of native species. This is compounded by displacement from invasive species. Climate continues to have a decisive influence on the distribution of genotypes; in this way, it functions as a selection factor. Modelling of aquatic insects in low mountain ranges under climate assumptions for 2080 have shown that insect species bound to these locations can survive, but that a large portion of the genetic variants is lost.

Changes in area boundaries can also result from climate-induced changes in the competitive conditions in species communities. For many species, modelling shows the potential relocation of area boundaries – on the one hand, this allows new areas to be colonised; on the other hand, it causes the species to disappear in other places. However, frequently species are not able to reach places with favourable living conditions due to climate change, or only reach them with a delay. As a result of changes in the climatic water balance, a large part of the currently bioclimatically suitable areas in Germany would disappear for around a fifth of the plant species. In breeding bird species, butterflies, dragonflies and fish species, there are initial indications of a shift in relative frequencies in favour of species that need warmth and to the disadvantage of species that need cold. In the North Sea, rising temperatures lead to changes in the species composition. The coastal ecosystems in the North Sea can also be adversely affected by the erosion of the outer coasts and a reduction in the area of the Wadden Sea as a result of the rise in sea levels by 2050. For the Baltic Sea region, experts anticipate an increase in the probability of extreme blue algae blooms by the end of the century as a result of the increasing nutrient loads. In addition, the increasingly warmer water, together with an increased lack of oxygen, has serious effects on biodiversity in large areas of the Baltic Sea.

Wetlands have already declined sharply in terms of their existence (area and quality) due to drainage and subsequent intensification of use. Climate change is a further source of danger and, through prolonged (spring) dry periods and high temperatures, leads to increased drying out of wetlands and streams, which increases the risk of further decline and degradation of wet habitats. In rivers, suitable habitats and stocks of fish species, such as grayling and trout, are declining due to rising water temperatures, and species from the lower course of the river are increasingly spreading to higher stretches of water.

In the mountains, one degree of temperature increase results in an expected shift of 200 metres in the vegetation zones. Species in the highest altitudes decrease in their occurrence because they cannot move upwards. Plant species from lower altitudes are increasingly migrating into alpine grass communities of the higher altitudes.

In German forests, severe damage from dry and hot years in combination with storm events and bark beetle multiplication as well as a decrease in the growth and vitality of forest trees are currently observed. The susceptibility of trees to late frost damage can increase as a result of temperature increases, which lead to earlier leaf shoots. Ecosystem types of subalpine crooked wood, high forest and mountain forest areas are decreasing and ecosystem types of deep to lower mountain forest areas are increasing.

Any change in species composition and occurrence affects ecosystem processes and can have negative consequences for ecosystem services. Increasing periods of drought lead to a further threat to carbon storage in bogs and bog soils. With increasing climate change, certain ecosystem services will become more important for cushioning the negative effects of climate change.

Assessment of the climate risks in the action field

Table 3: Climate risks without adaptation in the biodiversity action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period[14]
			optimistic	pessimistic	optimistic	pessimistic	
Change in the growing season and phenology	Climate risk	low	medium	high	medium	high	no reaction possible
	Certainty		medium		low		
Spread of invasive species	Climate risk	medium	medium	high	high	high	10-50 years
	Certainty		medium		low		
Loss of genetic diversity	Climate risk	low	low	medium	medium	high	10-50 years
	Certainty		medium		very low		
Shift in areas and decline in numbers	Climate risk	low	medium	medium	medium	high	10-50 years
	Certainty		medium		low		
Damage to coastal ecosystems	Climate risk	low	medium	medium	medium	high	10-50 years
	Certainty		medium		medium		
Damage to mountain ecosystems	Climate risk	low	medium	high	medium	high	no reaction possible
	Certainty		medium		medium		
Damage to water-bound habitats and wetlands	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		medium		
Damage to forests	Climate risk	medium	medium	high	medium	high	> 50 years
	Certainty		medium		low		
Ecosystem services	Climate risk	low	low	medium	medium	high	10-50 years
	Certainty		very low		very low		

Spatial exposure and sensitivity

Coastal, mountain and forest ecosystems as well as water-bound habitats and wetlands are particularly affected by climate change. In addition to urban and close-to-nature areas, the spread of invasive species promoted by climate change also has a particular impact on and along transport routes. Disrupted ecosystems, small habitats, habitats at high altitudes, as well as coastal and tidal rivers are particularly sensitive.

Adaptive capacity

In the “biodiversity” action field, spatial shifts in ecological gradients, for example the amount of precipitation, are of great importance. The adaptive capacity is largely dependent on the extent to which species colonise new, climatically suitable habitats or can adapt to new conditions in the old habitat. If neither is possible, the species will die out in the affected area. The APA III provides for a large number of adaptation measures for the action field. Most common are measures to expand knowledge through research and monitoring activities. This includes, among other things, the observation of the water temperature and the nutrient content for the North Sea and Baltic Sea, research activities on sustainable peatland use and the development of models or other approaches to quantify ecosystem services. There are also plans to examine the potential for a coordinated approach by the federal and state governments to set up monitoring of the direct and indirect effects of climate change on biodiversity in Germany.

More far-reaching adaptation measures arise, among other things, with regard to the connection of areas and biotopes. Specifically, this is about a comprehensive implementation of a biotope network and the simultaneous reduction of barriers such as traffic routes, river management and areas used intensively for agriculture and forestry. Furthermore, an increased consideration of the principles of organic agriculture can contribute to an increasingly biodiversity-focused adaptation to climate change.

The climate impacts of the action field are closely linked and influence one another. They all tend to have a restrictive influence on the possibility of using ecosystem services. The adaptation options for the "biodiversity" action field also overlap with other action fields. Adaptation activities in the fields of "agriculture", "forestry", "soil", "water balance, water management" and "coastal and marine protection" influence the adaptive capacity in "biodiversity". With regard to the contributions of the cross-sectional action fields to the adaptive capacity, there are possibilities to support the adaptive capacity of "biodiversity" through the implementation of strategies and models of spatial planning, state, regional and urban development planning and through financial activities.

Assessment of the adaptive capacity and the need for action

In the action field "biodiversity", the study analysed and assessed the adaptive capacity to the climate impacts "spread of invasive species", "loss of genetic diversity", "relocation of areas and decline in populations", "damage to water-bound habitats and wetlands" and "damage to forests".

The climate risks with adaptation can be derived from the assessment of the climate risks without adaptation and the effectiveness of the adaptation options. While the implementation of the APAIII+ measures will probably not change the climate risk of the "spread of invasive species", the risk of the climate impacts "damage to water-bound habitats and wetlands" and "damage to forests" could (only) be reduced to "medium-high" (in the pessimistic case). The climate risk of the climate impacts "spread of invasive species" and "damage to forests" could also only be reduced to "medium-high" through more far-reaching adaptation (in the pessimistic case). In the case of the climate impact "damage to water-bound habitats and wetlands", the experts estimate that the climate risk can be reduced to a medium level through more far-reaching adaptation (Table 4).

Table 4: Climate risks with adaptation in the biodiversity action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	low	medium	medium-high	low	low-medium	medium-high	low	medium
Climate risks with and without adaptation at the level of climate impacts								
Spread of invasive species	medium	medium	high	medium	low-medium	high	low	medium-high
Loss of genetic diversity	low	low	medium	low	low	medium	low	low-medium
Shift in areas and decline in numbers	low	medium	medium	low	low-medium	medium	low	low-medium
Damage to water-bound habitats and wetlands	medium	medium	high	medium	low-medium	medium-high	low	medium
Damage to forests	medium	medium	high	medium	low-medium	medium-high	low	medium-high

There is a very urgent need for action for the climate impacts “spread of invasive species”, “damage to water-bound habitats and wetlands” and “damage to forests”, as these were already classified as high climate risks in pessimistic cases for the middle of the century and an adaptation period of several decades is assumed. There is an urgent need for action for the climate impacts “damage to coastal ecosystems”, “ecosystem services”, “shift in areas and decline in numbers” and “loss of genetic diversity”.

Basically, no adaptation options are seen in the purely upstream climate impacts at the level of physical changes in natural systems. These purely upstream climate impacts were therefore only assessed with regard to the climate risk without adaptation. In the case of the climate impacts “damage to mountain ecosystems” and “change in the length of the vegetation period and phenology”, a high risk is attested, but no options for action are seen. This means that these high-risk climate impacts could not be methodologically assigned to the list of (very) urgent action requirements. This shows the limits of adaptation to climate change.

6.1.2 Soil action field

Relevance of the action field and new developments

Soil, as a limited, essential resource, is used not only for agricultural and forestry production and as a building ground, but also as a habitat for animals and plants. It forms an interface between the atmosphere, the hydrosphere and the stony subsoil, in which many essential water and nutrient conversions take place, such as filtering and protecting the groundwater. Although the soil is legally protected, in Germany it is often endangered or damaged by erosion, compaction, pollution and sealing. It recovers from disruption only slowly, if at all. All processes in the soil depend heavily on the temperature and the availability of water and extend over long periods of time. If these framework conditions change, this not only affects the soil, but also has far-reaching consequences for agriculture, forestry and water management. As of yet, the consequences of climate change have been difficult to estimate and quantify.

Selected climate impacts in the action field and central analysis results

In the case of soil erosion by water, soil particles are loosened from the soil by heavy precipitation and surface runoff, transported away and sedimented elsewhere. This impacts all affected soil surfaces. The risk of soil erosion is significantly influenced by the intensity of the precipitation, among other things. Due to climate change, precipitation patterns are shifting, which can lead to an increase in heavy rain events and, as a result, to increased soil erosion, especially in times of low vegetation. The modelling results show medium to strong increases in the risk of erosion in places in the future.

Soil erosion caused by wind affects dried-out soils that are not adequately protected by vegetation. Sandy soils with a high proportion of fine and medium sand and soils with a high humus content in cleared landscapes that do not slow the wind are particularly susceptible. In particular, the humus and fine soil are lost, which has a negative effect on the water capacity of the topsoil, damages the soil structure and promotes topsoil acidification. Increasing spring and summer drought due to climate change and the possible increase in strong wind events could make soils even more susceptible to wind erosion in the future.

Landslides and mudslides transport rock and/or soil masses, sometimes with a considerable proportion of water, down a slope, sometimes at high speed. They occur after precipitation peaks, rapid snowmelt and prolonged precipitation or when precipitation resumes after a long period of drought because deep cracks have formed in the ground. These mass relocations occur increasingly at transitions from flat to steep terrain, at reservoir horizons close to the surface or at water outlets. So far, no compelling connection between these processes and climate change has been proven, because they are difficult to differentiate from the consequences of land use and other human influence.

A lack of water in the soil has far-reaching consequences for agriculture and forestry because most processes in the soil (e.g. supplying plants with nutrients) only take place with the help of water. Furthermore, the soil functions as an important interface for hydrological processes such as lateral material and water flows, groundwater recharge and the storage of water in the soil. With climate change, the temperature rises and the precipitation varies more, so that there will be longer dry phases. The modelling results of the effective water balance during the growing season show a slight decrease across the board. It is particularly serious for semi-terrestrial soils or soil types that are permanently under water (e.g. moors) and for land uses with high water requirements.

Leachate is the portion of the precipitation that is not stored in the ground, but flows into the depths, where it contributes to the formation of new groundwater. During this process, the water shifts soluble substances into deeper layers. In the future, the increase in summer drought will lead to lower seepage water rates during this time of year and the formation of new groundwater will increasingly shift to late autumn and winter. Since this takes place outside of the growing season, unused fertilisers and nutrients end up in the aquifer. The heavy rain events in summer often do not contribute to the formation of seepage water because the precipitation runs off the surface.

Adequate aeration of the soil is important for the oxygen supply to the plants. If there is waterlogging due to prolonged and heavy precipitation that does not seep away, this impairs ventilation and, among other things, the navigability of soils that are used as arable land. Due to climate change, a slight increase in wetting precipitation events is to be expected in autumn. In spring and summer, on the other hand, there may be less waterlogging.

Soil biology is largely regulated by temperature, water balance and soil carbon. A high level of biological activity is a prerequisite for the natural functions of the soil and for maintaining soil fertility. On the one hand, climate change leads to higher temperatures, which can increase soil activity. At the same time, heat and prolonged periods of drought could reduce soil diversity and the resilience of soils to compaction and erosion as well as soil activity. The expected consequences remain uncertain.

The soil substance balance is determined by the amount of organic matter. This is mineralised faster when temperatures rise and drought increases. In wet phases there could be more humus formation. At the same time, the risk of nutrient leaching is greater if nutrients cannot be absorbed. Since there are a number of feedback and reinforcement effects in the soil balance, no generalised statements can currently be made on the climate impacts. The same applies to the filter and buffer functions.

The existing problems in the soil will be exacerbated by climate change. The production function in particular can be weakened in the long term by a loss of soil fertility. In addition, there is the ongoing land consumption due to sealing, the influence of which on soil biology can only be reversed with great difficulty.

Assessment of the climate risks in the action field

Table 5: Climate risks without adaptation in the soil action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Soil erosion by water	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		low		
Wind erosion	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		low		
Landslides and mudslides	Climate risk	low	low	medium	low	medium	10-50 years
	Certainty		low		low		
Lack of water in the soil	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		low		low		
Leachate	Climate risk	medium	medium	high	medium	high	no reaction possible
	Certainty		low		low		
Waterlogging	Climate risk	low	low	medium	low	medium	no reaction possible
	Certainty		low		low		
Soil biology: micro-biological activity / biodiversity / bio-logical functionality	Climate risk	low	low	medium	low	medium	no reaction possible
	Certainty		very low		very low		
Soil balance	Climate risk	low	low	medium	low	medium	< 10 years
	Certainty		low		low		
Soil functions: filter and buffer function	Climate risk	low	low	low	low	medium	no reaction possible
	Certainty		low		low		
Production function	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		low		low		

Spatial exposure and sensitivity

In Germany, the areas with the greatest risk of erosion by water are on arable land in southern Germany, such as the Bavarian Tertiary Hills, in the Hallertau, in the Kraichgau and in the Saar-Nahe Hills. Landslides and mudslides occur mainly in low mountain ranges and on the edge of the Alps, but also along steep railway lines and road cuts. In the tertiary hill countries in the foothills of the Alps and in the loamy, sandy, calcareous old moraine landscapes in the south of Bavaria and Baden-Württemberg, the soil is also at risk of becoming wet in autumn. Parts of central Germany, especially areas in northern Bavaria, Hesse and Rhineland-Palatinate as well as all hydromorphic soils, are particularly affected by the decline in the effective water balance during the growing season. The decline in the seepage water rate has its main focus in the eastern federal states, mainly in Brandenburg and Saxony-Anhalt. The spatial focus of erosion by wind is in northern Germany, where the young moraine soils of Schleswig-Holstein and Mecklenburg-Western Pomerania, the East Frisian Geest, the Emsland and western Brandenburg are particularly affected.

The sensitivity of the soil to climate change is particularly high when the organic content is low, the diversity of soil organisms is degraded by land use and the soil structure has already been damaged by traffic, erosion or compaction, among other things. Hydromorphous soils, which can be damaged by the expected fluctuations in precipitation, are particularly at risk.

Adaptive capacity

Essentially, the sensitivity of soils to changes caused by climate change depends on the natural soil functions. If these are maintained or restored, for example by reducing land use and sealing due to settlement and infrastructure or the renaturation of affected or disturbed areas or habitats, the climate change-related sensitivity of the soils can be reduced. The site-specific and climate-adapted agricultural and forestry land use also increases the adaptability of soils. A primary focus of selected adaptation measures (APA III) against soil erosion by water or wind is the generation of knowledge. They also include the establishment of a climate impact soil monitoring network, intended to enable nationwide statements on changes in the soil caused by climate change. Furthermore, APA III contains measures and instruments that are intended to promote adaptation to several (interlinked) climate impacts in the action field at the same time. This includes, for example, soil cultivation techniques that reduce erosion, which serve to build up soil organic matter and counteract the lack of water in the soil. More far-reaching adaptation options exist primarily with regard to the creation of a legal framework, for example by taking preventive and hazard-related adaptation measures into account in the Federal Soil Protection Act and the Federal Soil Protection and Contaminated Sites Ordinance. Spatial planning, in particular regional planning, contributes to the adaptive capacity of soil. Commitments like securing areas against sealing (development) and goals related to the environment, nature conservation and biodiversity are key here.

Assessment of the adaptive capacity and the need for action

In the “soil” action field, the study analysed and assessed the adaptive capacity to the climate impacts “soil erosion by water”, “water shortage in the soil”, “soil erosion by wind” and “production functions”.

By implementing the APAIII+ measures, the climate risk could be reduced to “medium-high” for all of the climate impacts mentioned, with the exception of the climate impact “production functions”. Despite more far-reaching adaptation (in the pessimistic case), medium-high climate risks could remain for the climate impacts “soil erosion by water” and “production function”. However, the climate risks “water shortage in the soil” and “soil erosion by wind” could be reduced to a medium level (Table 6).

Table 6: Climate risks with adaptation in the soil action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	low-medium	low-medium	medium-high	low medium	low	medium	low	low-medium
Climate risks with and without adaptation at the level of climate impacts								
Soil erosion by water	medium	medium	high	medium	low-medium	medium-high	low	medium-high
Lack of water in the soil	medium	medium	high	medium	low-medium	medium-high	low	medium
Wind erosion	medium	medium	high	medium	medium	high	low	medium
Production function	medium	medium	high	medium	low-medium	medium-high	low	medium-high

The climate impacts “soil erosion by water”, “water shortage in the soil”, “soil erosion by wind” and “production function” have very urgent needs for action, since they are classified as high risks for the middle of the century (pessimistic case) with an assumed an adaptation period of several decades. Urgent action requirements arise for the climate impact “landslides and mudslides”.

There are no adaptation options for the climate impacts “soil biology” and “soil functions: filter and buffer functions”. This means that these medium-risk climate impacts could not be methodologically assigned to the list of urgent action requirements. This shows the limits of adaptation to climate change.

6.1.3 Agriculture action field

Relevance of the action field and new developments

Weather, atmospheric conditions and climate have a massive influence on agriculture. In crop production, the climate determines which plants can grow. The weather in a vegetation period as well as individual weather events determine the level and quality of the yield of agricultural crops. Animal agriculture depends on the yield of crop production, and the weather and atmospheric conditions determine animal welfare and health – nearly every living being has an optimal temperature range for health and productivity. In this way, the weather also influences the performance of livestock farming. Extreme events such as floods can damage agricultural production systems and their infrastructure. In addition, the consequences of climate change on the soil and water balance are of central importance for agriculture.

Selected climate impacts in the action field and central analysis results

The KWRA 2021 presents the possible consequences of climate change for livestock farming using the example of dairy cattle. The milk yield of cows decreases with even minor levels of heat stress. This also changes the quality of the milk. The analysis shows that the number of days of heat stress for dairy cows could increase significantly. Other livestock could also suffer from heat stress more frequently in the future. Pigs react to this, among other things, with reduced feed consumption and correspondingly lower growth. Poultry also show reduced food intake and slower growth. In addition, heat stress leads to smaller eggs with a thinner shell and lower quality.

Heat can also damage plants. For example, heat during the wheat flowering in May and June can lead to sterile pollen. The number of hot days in this critical phase could increase significantly in the future. For plant production, however, drought is even more important than heat. The KWRA 2021 shows the possible development of soil moisture in two sensitive periods of the development of winter wheat: sprouting and shooting. In autumn, the seeds develop into seedlings that are visible on the surface of the soil ("sprouting"). In spring, the main shoot stretches ("shoots") before the ears swell. While the future development of soil moisture in spring is still uncertain, drier soils can be expected in autumn in the long term. There are other abiotic stressors that can damage crop production systems, for example strong winds or floods.

In addition to abiotic stress, biotic stress on agricultural crops could also increase. Insects usually benefit from higher temperatures. The damage they cause and plant diseases will consequently increase as a result of higher temperatures and also drought. Fungal infestation and root diseases, on the other hand, could become rarer due to the increasing (summer) drought. In addition to the known pests, new ones could also establish themselves in Germany with the rising temperatures.

In addition to damage to plants, each affecting one season, the conditions in agriculture will also fundamentally change in the long term. With the rising temperatures, climatic zones and the favourable areas for the various crops are shifting to the north and higher regions. As a result, crops that require a certain cold stimulus in winter can no longer grow regionally. But there are also new warmth-loving cultures, such as soy and certain red wines, which were previously not possible in Germany. The extent to which agricultural crops can be grown in a changed location setting is not only determined by the temperature. The availability of water is also an important factor. In addition, with climate change, the favourable areas for weeds, fungal diseases and pests are shifting.

At the same time, the rising temperatures make the start of vegetation arrive earlier, while the end of the growing season remains relatively stable. The consequence of this is a longer vegetation period. This could benefit agriculture, particularly when growing batches and perennial crops. The change in the agrophenological phases[14] can also have negative consequences, for example reduced wheat yields. Losses from late frosts could increase. A decoupling of flowers and pollinators is also possible for some crops.

Overall, the effects of climate change described here can lead to more frequent yield reductions. The quality of some harvested products could also decrease, as the climatic parameters temperature and precipitation as well as the atmospheric CO_2 concentration influence the physiological processes of the plants. Weather events can likewise reduce their visual quality. However, there are also mechanisms by which climate change could promote both the yield and the quality of the produce (for example, the longer vegetation period can enable an additional yield per year in vegetable cultivation). Overall, the pathways of action are complex and must be assessed on a regional and culture-specific basis.

[14] Phenology describes the annually recurring development phases, for example flowering and fruit ripening.

Assessment of the climate risks in the action field

Table 7: Climate risks without adaptation in the agriculture action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Heat stress on and productivity of livestock	Climate risk	low	low	medium	medium	high	< 10 years
	Certainty		medium		medium		
Abiotic stress (plants)	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		medium		
Shift in growing areas	Climate risk	low	low	medium	medium	medium	< 10 years
	Certainty		high		medium		
Agrophenological phases and growing seasons	Climate risk	low	low	medium	medium	medium	< 10 years
	Certainty		high		medium		
Stress from pests and diseases (plants)	Climate risk	low	low	medium	low	medium	< 10 years
	Certainty		medium		low		
Loss of yields	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		low		low		
Quality of harvest products	Climate risk	low	low	medium	low	medium	< 10 years
	Certainty		high		medium		

Spatial exposure and sensitivity

The changes in agriculture described above will have consequences throughout Germany. However, the affected production systems are not equally distributed. Livestock farming, for example, mainly takes place in the north-west of the republic and in Bavaria. Fruit cultivation is most common on Lake Constance and in the Altes Land, among other places. Grain cultivation is widespread almost all over Germany.

For livestock and crops, it is equally true that they are particularly sensitive to stressors if they are already stressed. In the livestock sector, modern high-performance breeds are often in use today; these animals constantly “work” at the edge of their physiological load limit and can only compensate for heat with difficulty. And plants, for example, are more susceptible to pests if they have previously suffered drought stress. For agricultural businesses, the more their income depends on the damaged production system, the more they are affected by yield or quality reductions and the associated loss of income. Very specialised companies in particular may find it difficult to compensate for lost income.

Adaptive capacity

In the "agriculture" action field, there are a number of adaptation options; these are based primarily on the generation of knowledge, the mobilisation of financial resources and the use of technologies and natural resources. In addition to – and partly based on – the adaptation that is already taking place in the agricultural sector, APA III contains a number of measures and instruments for adaptation to the consequences of climate change in agriculture. One focus: measures that promote the careful, climate-adapted treatment of the soil, an essential resource. Measures to deal with abiotic stress in crops and other potential yield losses primarily focus on irrigation options and techniques, the choice of varieties and frost protection, but are also aimed at promoting the activity and diversity of soil life, the stability of the soil structure and protection against erosion. In addition to measures to prevent loss of yields, measures to reduce the corresponding economic risk also play a major role. Above all, the potential expansion of insurance against extreme weather-related damage is important. With regard to more far-reaching adaptation, numerous possibilities are conceivable; in terms of adapted production processes, existing practices should be increasingly applied (diversified crop cultivation systems, crop rotation, land cover). Such methods are anchored in organic agriculture in particular, and the widespread application of such principles is of great importance for the adaptive capacity in agriculture. The expansion of organic agriculture can also be understood and used in terms of transformative climate adaptation. Dealing with climate risks in agriculture also requires far-reaching changes in the markets and a willingness to change on the demand side (with regard to product selection and prices), not least because businesses can incur higher costs. In addition to the generally strong competition of ecological and economic goals in agriculture, for example, water-related conflicts of use with the natural balance, industry and drinking water supply can also represent obstacles to adaptation. As of yet, however, it is not possible to adequately assess these risks. To a certain extent, the cross-sectional action fields of finance management (insurance) and spatial planning (flood prevention, promotion of soil unsealing, which serves to retain precipitation in the area, which in turn improves groundwater recharge) contribute to increasing the adaptive capacity in agriculture.

Assessment of the adaptive capacity and the need for action

Since the climate impacts "abiotic stress (plants)" and "yield losses" are classified as high risks as early as the middle of the century (in the pessimistic case), and a duration of ten to 50 years is assumed for comprehensive adaptation measures, there are very urgent needs for action here. While the high climate risk in the case of "abiotic stress (plants)" could remain even after the APAIII+ measures have been implemented, the climate risk in the case of "yield losses" could be reduced to medium-high. More extensive adaptation could reduce the risks for both climate impacts to medium (in the pessimistic case) (Table 8).

Table 8: Climate risks with adaptation in the agriculture action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	medium	medium	high	medium	low-medium	high	low	medium
Climate risks with and without adaptation at the level of climate impacts								
Abiotic stress (plants)	medium	medium	high	medium	medium	high	low	medium
Loss of yields	medium	medium	high	medium	low-medium	medium-high	low	medium

6.1.4 Forestry action field

Relevance of the action field and new developments

The forest fulfils various economic, social and ecological functions. But climate change poses great challenges. As a "plant fertiliser", atmospheric CO_2 can accelerate forest growth, but extreme events such as periods of heat and drought or storms severely damage the forest and forestry. Pest infestation or forest fires can also cause extensive damage. In addition, long-term climate changes can cause unexpected dynamics in the forest ecosystem as trees are very long-lived.

Selected climate impacts in the action field and central analysis results

Heat and drought stress can severely impair the vitality of trees. Although mature trees rarely die from the direct effects of drought (dying of thirst or starvation), drought increases their sensitivity to other stressors. For trees that have died due to windthrow, pests or forest fires, drought was not infrequently a predisposing or accompanying factor. Young trees are more sensitive to drought because their roots are not yet sufficiently developed to tap water from deeper soil horizons. They die faster as a direct result of drought. Periods of drought can significantly increase the probability of death for certain types of trees between the ages of zero to five years, in particular. This applies to all main tree species in the German forest; as adult trees, however, their sensitivity varies. Compared to oak and pine, spruce and beech are considered to be more sensitive to drought. The analysis in the KWRA 2021 shows that, by the end of the century in the pessimistic case, the trees of around 26 percent of the BWI[15] tracts examined could suffer from drought stress.

Many harmful organisms benefit from the weakening (devitalisation) of forest trees, which is mainly due to increasing drought. In addition, some harmful organisms – especially insects – benefit from the rising temperatures and can multiply faster and more intensively. Spruce beetles in particular are likely to cause even more damage in the future. While strong devitalisation of the spruce is assumed, bark beetles will probably be able to reproduce better. They also benefit from windthrows, as they use the freshly thrown trunks as breeding space. In addition to the

[15] BWI = "Bundeswaldinventur", National Forest Inventory

familiar harmful organisms, pests that have not yet occurred here could also establish themselves in Germany in the future.

Storms also cause great damage, and not just by creating breeding space for insect pests. Storm gusts can be particularly strong on the coast (especially the North Sea coast) and at high altitudes in the mountains. It is not yet possible to determine the development trend regarding the frequency of storms or their strength however, and projections of strong winds are still subject to great uncertainty.

In particular, drought and heat increase the risk of forest fires. There could therefore be an increasing risk of forest fires in the future. However, in addition to the meteorological factors and the water supply in the soil, other factors such as the tree species composition and management also play a role. This increases the uncertainty of projections into the future. An increasing risk of forest fires does not necessarily have to lead to more or larger forest fires, because half of the forest fires are still caused negligently or deliberately by humans. In addition, effective forest fire monitoring and corresponding risk management have already been implemented.

Given the climate effects described, the quality and availability of wood and ultimately its price can change. Climate change could also mean additional work for forest companies: clean-up work after extreme events could become more frequent and pest management more time-consuming. In addition, the management of forests could change, such as when the wood is harvested.

The forest not only provides wood and is a valuable ecosystem; it also serves as a place of relaxation for people. The recreational function of the forest has increased in importance in recent years. It can be assumed that it will continue to gain in importance as the temperature rises and the number of hot days increases. Large-scale forest damage severely restricts the recreational function and reduces the attractiveness of forests. Such large-scale sights of damage could be more common in the future. Should they reduce the attractiveness of forests in the future and at the same time their recreational function gain in importance, the pressure on healthy forests could increase.

Assessment of the climate risks in the action field

Table 9: Climate risks without adaptation in the forestry action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Heat and drought stress	Climate risk	medium	medium	high	medium	high	> 50 years
	Certainty		medium		medium		
Pest/disease stress	Climate risk	medium	medium	high	medium	high	> 50 years
	Certainty		medium		low		
Damage from windthrow	Climate risk	medium	medium	medium	medium	medium	10-50 years, > 50 years
	Certainty		medium		low		
Forest fire risk	Climate risk	low	low	medium	medium	high	> 50 years
	Certainty		medium		low		
Utility: timber yield	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		low		
Utility: recreation	Climate risk	low	low	medium	low	medium	10-50 years, > 50 years
	Certainty		medium		low		

Spatial exposure and sensitivity

The sensitivity of a forest is influenced by the trees growing there, their properties and their interaction as an ecosystem. Trees are particularly sensitive where they do not grow natively. For this reason, the tree species composition of a forest plays a key role. Given the naturally long growth period of trees, forest conversion is a slow process – adaptation to reduce sensitivity takes a lot of time. The tree species spruce and beech, which are particularly sensitive to drought, are especially important in the Alpine foothills up to the highlands and in the low mountain ranges (spruce), as well as in the low mountain range from the Swabian-Franconian Alb to the Palatinate Forest, Eifel, Odenwald, Spessart and Hainich (beech).

Trees are also sensitive when different stressors come together: weakened trees are more prone to windthrow, pests, and disease. Forest companies are sensitive when they are not adequately equipped with the human, technical and financial resources to react to the new challenges.

Adaptive capacity

In the “forestry” action field, there is a broad spectrum of measures for adaptation to changed climatic conditions, which is reflected in the various measures in the federal government’s Adaptation Action Plan (APA III). The program of measures on the agenda “Adaptation of Agriculture, Forestry, Fisheries and Aquaculture to Climate Change” and the funding instrument of the Forest Climate Fund play a key role. In addition to measures in the area of forest conversion and the financing of adaptation options, activities in research to deepen the knowledge base on topics such as silviculture, genetics or the influence of extreme weather events caused by climate change are particularly important. Further options for adaptation relate, among other things, to raising awareness among forest owners and the actors involved, as well as training and funding qualified personnel. Other measures address conversion towards climate-resistant forests, with the choice of tree species composition in particular being an important factor for all climate impacts in the action field. An increase in the proportion of non-managed forests to strengthen natural adaptation processes and the conversion of forest operations (for example to longer production periods) could be seen as transformative adaptation options. The adaptation of forests to changing climatic conditions can face obstacles, above all, because it is very difficult to evaluate long-term measures like forest conversion, both in terms of their duration and their potential for success. In addition, forest conversion is associated with considerable costs for forest operations and forest owners. The cross-sectional action fields make various contributions to improving the adaptive capacity of forestry and forest management. For example, regional plans and landscape structure plans include forest conversion measures, and civil protection risk analyses (e.g. on drought) can contribute to risk perception. The financial sector offers specific insurances, such as storm and forest fire insurance, which offer forest owners protection in the event of damage.

Assessment of the adaptive capacity and the need for action

In the “forestry” action field, the study analysed and assessed the adaptive capacity to the climate impacts “heat and drought stress”, “stress from pests/diseases”, “forest fire risk” and “utility: timber yield”.

The climate risk (in the pessimistic case) for the mentioned climate impacts – with the exception of the “forest fire risk” – could be reduced to “medium-high” both through the APAIII+ measures and through more far-reaching adaptation. For the “forest fire risk”, a medium climate risk is assumed for the mid-century period, which could be reduced to “low-medium” through more far-reaching adaptation (in the pessimistic case) (Table 10).

Table 10: Climate risks with adaptation in the forestry action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	medium	medium	high	medium	low-medium	high	low	medium-high
Climate risks with and without adaptation at the level of climate impacts								
Heat and drought stress	medium	medium	high	medium	low	medium-high	low	medium-high
Pest / disease stress	medium	medium	high	medium	low-medium	medium-high	low	medium-high
Forest fire risk	low	low	medium	low	low	medium	low	low-medium
Utility: timber yield	medium	medium	high	medium	low	medium-high	low	medium-high

For the climate impacts “heat and drought stress”, “stress from pests/diseases” and “utility: timber yield” there are very urgent needs for action, as these were assessed as having a high climate risk in the middle of the century and have an adaptation period of over 50 years. There is also a very urgent need for action for the “forest fire risk” climate impact, as the pessimistic climate risk for this at the end of the century was classified as “high” and the adaptation period was estimated to be over 50 years (Table 9). There are urgent needs for action for the climate impacts “damage caused by windthrow” and “utility: recreation”.

6.2 Water cluster

6.2.1 Fisheries action field

Relevance of the action field and new developments

Climate change is changing aquatic ecosystems, which has an impact on fisheries – both in the maritime and inland areas. As cold-blooded animals, fish are highly dependent on their environment. Rising water temperatures can affect the metabolism and health of fishing-relevant species, including by promoting disease. They can change the phenology[16] of fish so that food relationships are decoupled and species are driven from their original habitats. The habitats of heat-adapted fish species, on the other hand, can expand with rising water temperatures. The fisheries are directly affected by these consequences: they can break up stocks, but also make new target species available.

Selected climate impacts in the action field and central analysis results

Climate change threatens the offspring of the herring in the western Baltic Sea, an economically very relevant stock for fisheries in the region: with increasing water temperatures, the herring spawns earlier in the year. In addition, the development of herring eggs and larvae is accelerated by the rising temperatures. Both processes together mean that the herring offspring are dependent on external food earlier in the year. However, the prey of the herring larvae are not available earlier than before, as their presence is not temperature-controlled, but light-dependent. This leads to a decoupling of this food relationship with increasing frequency. The result is a drastic decline in herring reproduction numbers. If the herring stock in the western Baltic Sea were to collapse, this would not only have serious consequences for the fishery. In this case, sprat would be a single species of fish to fill the place of the herring in the food pyramid of the ecosystem – the ecosystem would then be significantly more sensitive.

As the open marginal sea of the Atlantic, the North Sea offers marine fauna more opportunities to shift their habitats with rising water temperatures. In the largely closed Baltic Sea, however, larger habitat shifts are not possible. In the German North Sea, there is already an increase in heat-adapted fish species and a decrease in cold-adapted species. Overall, the species’ habitats are shifting to the north. The example of the hake detailed in the KWRA 2021 shows that the habitats of heat-adapted species that are now migrating to the North Sea can also shrink again in the long term if the water temperature continues to warm beyond the preferred temperature window of a species.

As with the fish species in the sea, the target fish species in inland fisheries include species whose habitat increases as a result of rising water temperatures and changes in precipitation, and species that are losing their habitat. With increasing warming of the rivers, the habitats suitable for cold-adapted fish species will move to higher altitudes. The KWRA 2021 presents the

[16] Phenology describes periodic recurring behaviour, for example spawning.

habitat suitability of the flowing waters of Baden-Württemberg for four fish species: brown trout, bull trout, souffia and bream. The analysis shows that some cold-loving fish species from German waters could disappear completely by the middle of the century, as their habitat requirements are no longer met. The heat-loving bream, on the other hand, could expand its habitat. Bream are popular angling fish, but they are of little importance for professional fisheries. The brown trout is more important for the fishery, but its habitat could become significantly smaller.

The KWRA 2021 presents possible effects of climate change on the spread and risk of pests and diseases that endanger fish in inland areas. There is still little knowledge about it. What is certain, however, is that there are pathogens that benefit from rising water temperatures. They could lead to stock failures more frequently in the future and possibly expand their areas of distribution. Proliferative kidney disease is described as an example. It is caused by a parasite and attacks salmonids (salmon and trout varieties). The severity of the disease depends largely on the water temperature. The disease is suspected of causing high losses in farmed (up to 90 percent) and wild populations. In principle, it is also true that pests or pathogens can cause greater damage if they encounter fish that are already weakened by excessively high water temperatures.

Aquaculture cannot only be affected by pests and diseases. The temperature and water availability (and the amount and distribution of precipitation) are relevant climatic drivers that can determine the success or failure of aquaculture. Mainly carp and trout are farmed in Germany. Both rising temperatures and a potential decrease in water availability could have negative effects on trout farming, as trout need cool, oxygen-rich water. Carp farming, on the other hand, could benefit from rising temperatures, but the potentially decreasing water availability would also have an unfavourable effect on them, as they have a high water requirement, especially in warm summers, to compensate for evaporation losses and in late summer/early autumn. In addition, the increasing frequency and intensity of flooding can cause serious damage to aquaculture, for example by flooding ponds and contributing pollutants.

Assessment of the climate risks in the action field

Table 11: Climate risks without adaptation in the fisheries action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Decoupling of food relationships in the Baltic Sea	Climate risk	medium	high	high	medium	high	< 10 years
	Certainty		high		very low		
Distribution of thermophilic species in the North Sea	Climate risk	low	medium	medium	medium	medium	< 10 years
	Certainty		medium		low		
Distribution of fish species in rivers	Climate risk	low	medium	high	medium	high	10-50 years
	Certainty		high		low		
Pest / disease stress	Climate risk	low	low	medium	medium	high	< 10 years
	Certainty		medium		very low		
Damage to aquaculture	Climate risk	low	low	medium	medium	medium	< 10 years
	Certainty		medium		low		

Spatial exposure and sensitivity

While sea fishing is particularly important in regions near the coast, industrial and recreational fishing in inland areas is widespread. There are priority regions in aquaculture: carp pond farming is mainly located in Lusatia and northern Bavaria, trout farming in Bavaria and Baden-Württemberg, Lower Saxony and North Rhine-Westphalia. All forms of fishing and aquaculture, as well as fish stocks, are particularly sensitive to the described consequences of climate change if they cannot avoid them. If the habitat of fish changes in such a way that they can no longer live and reproduce there, and if they then have no opportunity to move to other areas due to natural conditions or barriers, the stocks themselves or their usability are threatened. The areas where the fish can be caught are restricted by political and legal conditions.

Adaptive capacity

Adaptation options in this action field relate to inland and sea fishing as well as to aquaculture operations. The “Adaptation of Agriculture, Forestry, Fisheries and Aquaculture to Climate Change” agenda brings together APAIII+ measures, although the instruments have not yet been made more concrete. To adapt to the high climate risk “decoupling of food relations in the Baltic Sea”, individual measures in the area of “knowledge” (research) are only indirectly relevant. An integrated approach to adapting to this climate impact has not yet emerged, but more far-reaching adaptation can start to reduce other pressures on fish stocks, especially with the help of legal framework conditions. In addition, the motivation for and acceptance of measures for sustainable inventory management are extremely important and show clear potential for growth. The timeframe for these measures is estimated at less than ten years. For sea fishing in general, the intensification of research and monitoring as well as the negotiation and legally binding nature of catch quotas are important, but the merger of fishing companies and producer cooperatives at the local level can also help to maintain efficiency. For inland climate adaptation, water engineering measures and renaturation are particularly relevant. Selected measures (APA III) of particular relevance to the distribution of fish species in rivers include, for example, the renaturation of rivers and floodplains and the creation of ecological continuity on federal waterways. Adaptation can reach its limits when water levels become very low or, in extreme cases, water bodies dry out.

Finally, aquaculture farms can adapt to ventilation systems, multiple uses of water, digital oxygen supply systems and feeding techniques, shading production facilities and orientation towards new breeding goals. Interactions for adaptation arise with the action fields “coastal and marine protection”, “water balance, water management”, “agriculture” and “biodiversity”. The cross-sectional action field “spatial planning” contributes to strengthening the adaptive capacity in the action field, whereby conflicts between adaptation measures of fisheries and flood protection can arise on the coasts (for example through the use of sea sand for building dykes). On the other hand, synergies are more likely in the context of rivers (for example renaturation or deepening of floodplains).

Assessment of the adaptive capacity and the need for action

In the “fisheries” action field, the study analysed and assessed the adaptive capacity to the climate impacts “decoupling of food relationships in the Baltic Sea” and “distribution of fish species in rivers”.

For the climate impact “decoupling of food relations in the Baltic Sea”, only the implementation of more far-reaching adaptation could lead to a reduction of the climate risk to “medium-high”. The assessed climate risk of the climate impact “distribution of fish species in rivers” could be reduced to “medium-high” through APAIII+ measures and more far-reaching adaptations in the pessimistic case (Table 12).

Table 12: Climate risks with adaptation in the fisheries action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	low-medium	medium	high	low-medium	low-medium	medium high	low	medium-high
Climate risks with and without adaptation at the level of climate impacts								
Decoupling of food relationships in the Baltic Sea	medium	high	high	medium	high	high	medium	medium-high
Distribution of fish species in rivers	low	medium	high	low	low-medium	medium-high	low	medium-high

There is a very urgent need for action for the climate impact “distribution of fish species in rivers”, as it was assessed as having a high climate risk as early as the middle of the century with an assumed adaptation period of up to 50 years for comprehensive measures. There is an urgent need for action for the climate impact “decoupling of food relationships in the Baltic Sea”.

6.2.2 Coastal and marine protection action field

Relevance of the action field and new developments

The German coastal areas are of great cultural, socio-economic and ecological importance. At the same time, they are severely affected by the consequences of climate change. A key influencing factor is the warming of the sea temperature caused by the average rise in temperature, which has a negative impact on marine ecosystems. The average rise in temperature is also related to the accelerated rise in sea level, which leads to rising (extreme) water levels. These put a strain on coastal protection systems and can cause damage to settlements and infrastructure near the coast. In Germany, some 3.2 million people live in coastal areas at risk of flooding. In addition, the rise in sea level leads to changes in sensitive natural areas such as the Wadden Sea on the North Sea coast, a unique, ecologically and culturally valuable coastal area. Recent publications show that the state of seas and coasts around the world has deteriorated. In Germany, significant changes due to climate change have been observed, in particular the rise in sea level, the associated morphological changes on the North Sea coast, higher water levels in the North Sea and Baltic Sea (but no more frequent or stronger storm surges) and higher water temperatures in the North Sea and Baltic Sea. The latter have led to strong blue-green algae blooms on the coasts. The protection of the oceans has come more and more into the focus of the public in recent decades, and numerous national and international agreements recognise this importance. In the meantime, near-natural and nature-based protective measures are increasingly coming into focus again; in the past, technical solutions and increasing development in coastal areas were the main priorities.

Selected climate impacts in the action field and central analysis results

The rise in sea temperature in the North and Baltic Seas will continue. Projections with the RCP8.5 scenario show an average increase of 2.5 degrees Celsius in the German Bight and 2.5 to 3.5 degrees Celsius in the southwestern Baltic Sea by the end of the century. Marine heat waves are expected to increase significantly in frequency and intensity in the future. That stated, cold winters with ice conditions will remain possible for the North Sea into the distant future. Nonlinear interactions are a major source of uncertainty; they can lead to abrupt changes in sea temperatures and ecosystems. In addition to changes in water temperature, climate change also causes numerous changes in water quality. The rise in atmospheric CO_2 concentration and anthropogenic nutrient inputs in the coastal area intensify eutrophication and the lack of oxygen and lead to the acidification of the seas with negative effects on marine ecosystems. Groundwater salinization in coastal areas can be increased by rising sea levels. Increased freshwater runoff in winter can also cause a decrease in the salinity of the Baltic Sea.

The rise in sea level due to climate change is already measurable on German coasts and is roughly in line with global projections, which, in the absence of the latest regionalisations, can be used as an indication of expected changes. For the RCP8.5 scenario, the SROCC report from the IPCC projects a global average sea level rise of 0.32 metres with a probable range of 0.23 to 0.40 metres by the middle of the century (here: 2050). By the end of the century (here: 2100), the report predicts an increase of 0.84 metres with a probable range of 0.61 to 1.10 metres (in each case relative to the period 1986 to 2005). On the German North Sea coast there is a change in the tidal amplitude and changes in the inflow of salty Atlantic water into the North Sea. An increase in westerly winds can increase the inflow from the North Sea into the Baltic Sea. In the German Bight and on west and north-west exposed stretches of coast of the Baltic Sea, there could be an increase in wave heights due to an assumed slight increase in wind events over the North and Baltic Seas and, in particular, the intensification of westerly winds. However, projections of future sea state developments are associated with a high level of uncertainty. Significant changes with regard to the future strength, duration and frequency of storm surges are not yet apparent. However, the rise in sea level will result in higher storm surge peak water levels.

The rise in sea level, higher storm surge peak water levels and the impairment of natural protective functions in the coastal area represent an increasing burden on coastal protection systems. Settlements and infrastructures close to the coast are also increasingly exposed to sea-side loads such as higher extreme water levels during storm surges. However, taking into account the current scenarios, the coastal protection implemented by the federal states seems to guarantee the protection of settlements and infrastructure in the coastal area. Critical drainage situations will occur more frequently in the future due to rising sea levels and low tidal levels, as well as changing precipitation patterns and the resulting increased inland runoff. A severe reduction in sewer capacities is to be expected by the middle of the century at the latest. This will result in an increasing demand for pumping stations, which will require considerable investment.

Climate change also affects natural spatial changes on coasts. The tidal flats and salt marshes are subject to increased changes due to rising sea levels and the effects of storm surges. An increase in the flood duration of the tidal flats is projected by the end of the century; it is assumed that the growth of the tidal flats can partially compensate for these changes up to a certain rate of sea level rise. The coastal areas of the Baltic Sea experience changes in particular due to erosion processes. In the future, the rise in sea level can increase the local transport of sediments and the effects of more frequent heavy precipitation can encourage erosion processes.

Assessment of the climate risks in the action field

Table 13: Climate risks without adaptation in the coastal and marine protection action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Sea temperature and ice cover	Climate risk	medium	high	high	high	high	> 50 years
	Certainty		high		high		
Water quality and groundwater salinization	Climate risk	medium	medium	high	high	high	> 50 years
	Certainty		medium		low		
Sea level	Climate risk	medium	medium	high	high	high	Range from < 10 years to > 50 years depending on the measure
	Certainty		high		medium		
Currents and tidal dynamics	Climate risk	medium	medium	medium	medium	medium	> 50 years
	Certainty		low		low		
Sea state	Climate risk	low	low	medium	low	medium	> 50 years
	Certainty		low		low		
Storm surges	Climate risk	medium	medium	medium	medium	medium	Range from < 10 years to > 50 years depending on the measure
	Certainty		low		low		
Natural spatial changes on coasts	Climate risk	medium	medium	high	medium	high	> 50 years
	Certainty		medium		low		
Increased stress on or failure of coastal protection systems	Climate risk	low	low	medium	medium	medium	Range from 10-50 years to > 50 years depending on the measure
	Certainty		medium		low		
Damage or destruction of settlements and infrastructure on the coast	Climate risk	low	low	medium	medium	high	Range from 10-50 years to > 50 years depending on the measure
	Certainty		low		low		
Overloading of drainage facilities in areas at risk of flooding	Climate risk	medium	medium	high	high	high	10-50 years
	Certainty		medium		medium		

Spatial exposure and sensitivity

Various factors influence the extent to which the seas and German coastal regions are affected by the consequences of climate change. These include the characteristics of the coastal sections, the topographical and morphological structures in the coastal area, the sea topography, the exchange of water with other seas and the input of substances into the sea. The type and condition of the coastal infrastructure, the form of land use and the settlement structures also have an impact on susceptibility to damage. For example, areas with a high population density show higher damage values.

Adaptive capacity

Since coastal protection is primarily the responsibility of the coastal federal states and the municipalities along the German coast, the APAIII+ measures relate mainly to the design of the legal framework and research funding. The general plans and regulations for the coastal protection of the relevant federal states include technical and nature-based coastal protection measures such as building dykes, beach nourishment or building floodplain fields. More far-reaching adaptation can begin in particular in coastal protection or coastal management. The use of natural adaptation instruments can help promote dynamic processes in coastal development. In addition, there are more far-reaching adaptation instruments in technical coastal protection, such as the development and implementation of innovative dike concepts.

With regard to the implementation of the mentioned adaptation options, there are factors that can limit adaptation, including land use and other conflicts of interest (for example with agriculture, nature conservation, the energy and tourism industries), as well as industry and shipping. This can also be limited due to a lack of natural resources, for example for sediment management or for heightening or widening the dike. Given the uncertainties about the height of the sea level rise, measures that enable the continuous readjustment of the adaptation pathway appear particularly worthy of recommendation. Interactions in adaptation arise both within the action field and with many other action fields such as “human health”, “fisheries”, “tourism”, “traffic, transport infrastructure” and “construction”.

Regional planning makes a major contribution to adaptation in the action field, given its control function in land use and development planning. Civil protection makes an important contribution to maintaining the functionality of critical infrastructures on the coast, and the insurance industry contributes to reducing the effects of potential storm surge damage with storm surge insurance.

Assessment of the adaptive capacity and the need for action

In the action field “coastal and marine protection”, the study analysed and assessed the adaptive capacity to the climate impacts “water quality and groundwater salinization”, “natural spatial changes on coasts” and “overloading of drainage facilities in areas at risk of flooding”.

The risk of the climate impact “water quality and groundwater salinization” could be reduced to “medium-high” through the APAIII+ measures and to “medium” (both in the pessimistic case) through more far-reaching adaptation. While the risk of the climatic impact “natural spatial changes on coasts” could remain high through the implementation of the APAIII+ measures, more far-reaching adaptation would reduce this to “medium” (in the pessimistic case). The risk of “overloading the drainage facilities in flood-prone areas” could be reduced to “medium-high” through the APAIII+ measures and even to “low-medium” (in the pessimistic case) through more extensive adaptation (Table 14).

Table 14: Climate risks with adaptation in the coastal and marine protection action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	medium	medium	high	low-medium	low-medium	medium-high	low	medium
Climate risks with and without adaptation at the level of climate impacts								
Water quality and groundwater salinization	medium	medium	high	medium	low-medium	medium-high	low	medium
Natural spatial changes on coasts	medium	medium	high	medium	medium	high	low	medium
Overloading of drainage facilities in areas at risk of flooding	medium	medium	high	low-medium	low-medium	medium-high	low	low-medium
Damage or destruction of settlements and infrastructure on the coast	low	medium	high	*The adaptive capacity was not assessed for this climate impact.*				

There is a very urgent need for action for all three of the climate impacts mentioned, since they were already assessed as having a high climate risk in the pessimistic case for the middle of the century and an assumed adaptation period of several decades. There is also a very urgent need for action for the climate impact “damage to or destruction of settlements and infrastructure on the coast”. However, there was no analysis and assessment of the adaptive capacity for this climate impact. There is an urgent need for action for the climate impact “increased damage to or failure of coastal protection systems”.

6.2.3 Water balance, water management action field

Relevance of the action field and new developments

Water is not only an essential basis of life for humans and important for economic production processes, it also represents habitats for flora and fauna. Both the amount of water available and its quality are important. Changes due to climate change can be expected for both. Hot and dry phases reduce the water supply in the groundwater and in surface waters, which is why conflicts of use are already taking place. Exceptional high and low water events, as they have already occurred in the past, are usually caused by special meteorological situations and also depend on a number of preconditions, such as the level of the water reservoir or the pre-moisture conditions of the soil.

Selected climate impacts in the action field and central analysis results

In the recent past, heat and drought-related low water situations have led to restrictions on inland navigation and the use of cooling water in power plants, as well as the impairment of water quality. In the optimistic case, the modelling mostly shows no worsening of the low water situation. In the pessimistic case, substantial decreases in low water runoff were calculated, especially for the end of the century. The most significant changes are projected for parts of the Rhine.

(Extreme) flood events can cause extensive damage to agriculture and forestry, as well as to buildings and infrastructure. For the RCP8.5 scenario, most of the modelled runoffs indicate an increase in flood runoffs, irrespective of the flood indicator considered, especially in regions with runoff regime types in Germany that are dominated by rain today (low mountain ranges, eastern Germany). The characteristics of extreme and damaging flood events are subject to diverse and, depending on the event, individual influencing factors that can only partially be projected into the future for longer periods of time and are still the subject of research. The dimensioning of technical flood protection measures (e.g. dykes, retention basins or dams) is based on a statistically calculated probability of recurrence. Absolute flood protection is neither technically feasible nor economically sensible. The residual risk is countered with integrated flood risk management. As a result of climate change, it is to be expected that higher peak runoffs will occur and that the recurrence interval of the current design flood will be shortened.

A flash flood is a sudden, locally limited flood with a high potential for damage as a result of convective heavy precipitation. If, for example, the canal network, which in some cases has grown historically in German cities, is overloaded by local heavy rain events, this can result in damage to the settlement area and surface waters. There is a risk of extreme heavy precipitation everywhere in Germany. Statistical analyses suggest that with the increase in air temperature and an increased absorption capacity of water vapour in the atmosphere, an accumulation and intensification of convective heavy precipitation is to be expected. Increased heavy rain events lead to increased overloading of the sewer networks and sewage treatment plants. Higher temperatures are likely to increase the demands on the sewage treatment plants in the future. The introduction of the sewage treatment plant drain into the surface waters at low water levels can lead to more pollution.

The water temperature is a key parameter for the ecological status of water bodies and their tendency towards eutrophication. The ecological status of the lakes and rivers could therefore deteriorate further as the water temperature rises. Rising temperatures will also lead to less ice cover on rivers and stagnant waters, which will result in a change in the mixing dynamics for the lakes. The chemical water quality is determined by the land use, the intensity of use and the toxicity of the substances introduced. The decisive factor is how much the chemical substances can be diluted. The degree of dilution of chemical substances in water depends on the runoff of the water. If the runoff decreases due to increased evaporation caused by warming or changes in precipitation, the concentration of chemical substances increases.

The groundwater level is subject to fluctuations depending on the intensity of use and the climatic situation. Because the groundwater system reacts rather sluggishly to climate changes, forward-looking action must be taken. In some regions, the groundwater is heavily polluted by nitrates and pesticides. The increase in air and soil temperature leads to a long-term rise in the temperature of the groundwater, which has a negative effect on its quality. This is of particular importance for the supply of drinking water, 70 percent of which is obtained from the groundwater. But other sources of drinking water from surface waters and enriched groundwater are also subject to stringent quality criteria, which Germany has complied with to a significant extent. In addition to the mentioned climate risks related to groundwater level and quality, the quality of drinking water sources close to the surface can also be impaired by rising temperatures. Water-borne germs in drinking water pipes are also favoured by the expected warming and can worsen the water quality.

Although the proportion of irrigated agricultural land is currently low, the demand for irrigation water has increased steadily in recent years. Due to climate change, temperatures are rising and dry periods are becoming more frequent. As a result, the need for irrigation will increase noticeably in the future. Currently, the majority of irrigation water is drawn from the groundwater. With an increased need for irrigation water, an increasing competition for groundwater could arise. Only about twenty-five percent of the production water in Germany is used for industrial production. The rest is available for cooling power plants. Since integrated wastewater recycling is expanding and industrial production in Germany has been further reduced in recent years, the future demand for production water depends heavily on political decisions about industrial production in Germany and on the economy.

Assessment of the climate risks in the action field

Table: 15 Climate risks without adaptation in the water balance, water management action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Low tide	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		low		low		
Floods	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		low		low		
Overloading or failure of flood protection systems	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		low		
Flash floods (failure of drainage facilities and flood protection systems)	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		low		
Restrictions on the functionality of sewer networks and receiving waters and sewage treatment plants	Climate risk	low	low	medium	low	medium	10-50 years
	Certainty		low		low		
Water temperature and ice cover and biological water quality	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		medium		
Chemical water quality	Climate risk	medium	medium	medium	medium	medium	< 10 years
	Certainty		low		low		
Groundwater level and groundwater quality	Climate risk	low	low	high	low	high	10-50 years (groundwater level < 10 years in some cases)
	Certainty		medium		high		
Lack of irrigation water	Climate risk	low	low	medium	medium	high	10-50 years
	Certainty		medium		medium		
Drinking water	Climate risk	low	low	medium	low	medium	< 10 years
	Certainty		low		low		
Production water	Climate risk	low	low	medium	low	medium	< 10 years
	Certainty		low		low		

Spatial exposure and sensitivity

The pessimistic scenario projects decreasing low water runoff, especially for the Middle and Lower Rhine including its tributaries Mosel, Neckar, Lippe and Ems. With regard to the average annual flood discharge, most gauges show increases. The increases in the south-west of Germany are lower than in the east.

Regional differences in the sensitivity to high and low water result, among other things, from the extent of water management, for example from the volume of water that can be stored in dams or controlled lakes and drained off in a targeted manner. In the Elbe river basin, the proportion of managed water supply in the total supply is particularly high.

For the groundwater level, the removal of water for irrigation is also relevant during periods of drought. Spatial focus areas for irrigation are located mainly in Lower Saxony, South Hessen, Bavaria, Saxony-Anhalt, the Palatinate and the Upper Rhine.

The expected increase in ground and surface water temperatures will have negative effects on the ecological status of the waters, especially during periods of drought. The rising water temperature is particularly problematic where the water quality is already in a bad state due to the discharge of pollution or soil erosion. The water quality of the lakes will also be affected by rising water temperatures, especially in northeast Germany.

For heavy rain and local flood events, area characteristics such as degree of sealing and land use as well as drainage options play a role. The extent to which heavy rain leads to overloads in settlements is determined by the state of maintenance and the type of sewer network as well as the existence of decentralised drainage infrastructure. A regional differentiation of the occurrence of such overload cases is not possible.

Adaptive capacity

The observed climate impacts of the action field “water balance, water management” are closely linked, which means that adaptation measures for one climate impact can also influence other climate impacts. In addition, due to the mutual dependencies in the use of resources in the nexus “water-energy-land-climate”, there are diverse interactions between the action field “water supply, water management” and almost all others, in particular “soil”, “agriculture” and “biodiversity”, “fisheries”, “transport, transport infrastructure”, “energy sector “, “industry and commerce” and “human health”. The action field therefore requires a high level of coordination at federal and state level.

The APA III provides for technological as well as natural and information-technology adaptation measures. With a view to river floods, for example, the National Flood Protection Program should be mentioned, which contains technical and spatial flood protection measures. The increased implementation of “Natural Water Retention Measures”, which can make a contribution to natural flood protection, is also supported in the renaturation of rivers. Important tools for flood and low water management are high-quality predictions of extreme situations that extend as far into the future as possible. The consistent improvement of water level forecasts is therefore an important APA III IT measure for “water balance, water management”.

In addition to the APAIII+ measures, there are various more far-reaching adaptation options such as greater consideration of heavy rain events and flash floods in laws, ordinances and technical regulations, uniform rules on water abstraction charges or the increased promotion and implementation of multifunctional land use concepts such as the sponge city principle. In particular, the legal framework and the promotion of mutual exchange to increase risk awareness and to avoid possible conflicts of interest or use play an important role in the design and implementation of adaptation measures in the action field. Regional planning contributions to adaptation can be found primarily in relation to water-sensitive and precautionary area planning. Insurance options can help reduce damage in flood or flash flood events.

Assessment of the adaptive capacity and the need for action

In the action field “water balance, water management”, the study analysed and assessed the adaptive capacity for the climate impacts “damage to or failure of flood protection systems”, “flash floods (failure of drainage facilities and flood protection systems)”, “water temperature and ice cover and biological water quality” and “groundwater level and groundwater quality”.

The risk of the climate impact “damage to or failure of flood protection systems” could be reduced to “low-medium” (pessimistic case) through the APAIII+ measures as well as through more far-reaching adaptation. The reason for this optimistic assessment by the experts is the extensive preparatory work and specific bundles of measures on the subjects of flood prevention (in the area) and flood protection (on waterways; for example through the National Flood Protection Program). The assessment was based on the premise that many of these measures can be implemented.

The risk of the climate impacts “flash floods (failure of drainage facilities and flood protection systems)” as well as “water temperature and ice cover and biological water quality” could remain unchanged through the implementation of the APAIII+ measures. However, more far-reaching adaptation could reduce the risk to a medium-high level for the former and a medium level for the latter (pessimistic case). In the pessimistic case, a reduction in the risk of the climate impact “groundwater level and groundwater quality” would not be possible either through the implementation of APAIII+ measures or more far-reaching adaptation (Table 16).

Table 16: Climate risks with adaptation in the water balance, water management action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	medium	medium	high	low-medium	low-medium	medium-high	low	medium
Climate risks with and without adaptation at the level of climate impacts								
Overloading or failure of flood protection systems	medium	medium	high	low-medium	low	low-medium	low	low-medium
Flash floods (failure of drainage facilities and flood protection systems)	medium	medium	high	medium	medium	high	low-medium	medium-high
Water temperature and ice cover and biological water quality	medium	medium	high	medium	low-medium	high	low	medium
Groundwater level and quality	low	low	high	low	low	high	low	high

There are very urgent needs for action for the climate impacts “damage to or failure of flood protection systems”, “flash floods (failure of drainage facilities and flood protection systems)”, “water temperature and ice cover and biological water quality” as well as “groundwater level and groundwater quality", since they were assessed as having a high risk by the middle of the century (in the pessimistic case) and require an adaptation period of several decades. There is an urgent need for action for the climate impacts "lack of irrigation water", "chemical water quality" and "restrictions on the functionality of sewer networks and receiving waters and sewage treatment plants".

6.3 Infrastructure cluster

6.3.1 Construction action field

Relevance of the action field and new developments

The focus of the action field "construction" is protecting people and property from the risks caused by climate change. The basic principle both in the creation and in the modification of existing structures is damage prevention. In addition to the consequences of climate change, demographic development plays a central role in the "construction industry". Since the beginning of the 21st century, (re-)urbanisation has led to continuously high levels of development pressure in cities. As a result, the supply of recreational areas in large cities (with over 500,000 inhabitants) has declined accordingly in recent years. The preservation and improvement of urban green spaces due to the increasing risks of climate change (e.g. heat waves and heavy rain) are becoming more important. Natural hazards such as storms, hail, heavy rain and river floods are already causing considerable damage to buildings and placing new demands on building stability/resistance.

Selected climate impacts in the action field and central analysis results

Damage to buildings can occur both directly from heavy rain, in particular extreme summer precipitation of short duration, and from flood events. Spatially differentiated projections of the future frequency and intensity of heavy rain are currently not possible due to the limitations of climate models, but an intensification of heavy rain due to climate change can generally be expected. Depending on the type of event, numerous factors in different combinations are decisive for damage to buildings caused by river floods. This subjects projections of extreme floods to a high level of uncertainty. Without additional adaptation measures, they could increase in the future due to climate change. For the middle of the century, the projected changes in the south and west are smaller than in the middle and east of Germany, while for the end of the century, further, more pronounced changes are evident, especially in the east of Germany.

As a result of climate change, the vegetation in settlements is likely to be exposed to additional stresses, in particular from more frequent, more intensive or longer-lasting drought and/or heat, storms as well as pests and diseases. In most regions of Germany, drought can both increase and decrease by the middle and end of the century, while increases are expected for heat across the board over the course of the century.

Increasing urbanization leads to an expansion of urban heat islands, which can be expected to increase the heat load for people in urban agglomerations. It is not yet possible to clearly predict the influence of climate change on the intensity of the heat islands, as this also depends on regional factors such as wind speed and the degree of cloud cover. The structural densification and higher population concentrations are expected to increase the intensity, especially if the urban development does not make use of greening potential.

Due to the increasing number and duration of hot spells without structural adaptation measures, climate change will increasingly lead to high indoor temperatures. In metropolitan areas, these are additionally reinforced by the urban heat island effect. In addition to increasing heat exposure, rising indoor temperatures could also have a negative impact on air quality and indoor hygiene by promoting the release of hazardous substances and mould growth.

Projections of temperature and precipitation show a decrease in the number of days with difficult construction activity ("bad weather days") by around half by the end of the century. Strong winds, heavy rain, heat and exposure to ultraviolet radiation, on the other hand, can increase the risk of accidents and health risks on construction sites and, as a result, limit the performance of employees, especially outdoors, or lead to construction interruptions for reasons of occupational safety.

Assessment of the climate risks in the action field

Table: 17 Climate risks without adaptation in the construction action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Damage to buildings due to heavy rain	Climate risk	medium	medium	medium	medium	medium	10-50 years
	Certainty		medium		low		
Damage to buildings due to river flooding	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		low		
Vegetation in settlements	Climate risk	low	medium	medium	medium	high	> 50 years
	Certainty		high		high		
Urban climate / heat islands	Climate risk	medium	medium	high	high	high	10-50 years
	Certainty		medium		medium		
Indoor climate	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		medium		
Times for construction work	Climate risk	low	low	low	low	low	< 10 years
	Certainty		medium		medium		

Spatial exposure and sensitivity

The spatial exposure in the action field "construction" depends largely on the climatic impact under consideration. For damage to buildings due to river floods, the relative position of buildings to rivers and their basins is decisive. Factors that influence the sensitivity of buildings to changes linked to climate are the size and cubature of the building, the material used and, in some cases, elements of the building technology. At the same time, these are factors influencing sensitivity for the "urban climate/heat islands" climate impact. In addition, the sensitivity depends on urban structural factors such as urban surface sealing, area-related expansion, vegetation cover and green volume, existing air ducts or the degree of structural use. Factors influencing the sensitivity of the vegetation in settlements are not only the type of vegetation and the species composition, but also the air quality, pollutant inputs such as road salt and the degree of sealing and soil compaction.

Adaptive capacity

Efforts are already underway to adapt to climate change in the construction industry, including the adaptation of technical regulations and standards, the creation of structures for the institutionalisation of adaptation, and the expansion of the scope for action for municipalities through amendments to the building code. The number and range of APAIII+ measures and more far-reaching options are comparatively large and broad. Measures to adapt to the increased risk of damage to buildings relate to both building renovations and the construction of new buildings and require the creation of legal requirements and their specification through standards and technical regulations. The APAIII+ measures to adapt the vegetation in settlements relate, for example, to the drought tolerance of newly planted species and the promotion of surface desealing. The latter can also counteract the impact of the increasing heat island effect, as can facade and roof greening, the integration of blue and green structures in urban settlement areas, polycentric concepts of urban development and the structural and technical regulation of the indoor climate.

The possibilities for more far-reaching adaptation in the action field include flood-adapted construction and decisions about location, which require momentum from building planning and construction regulations. Furthermore, more far-reaching adaptation can be implemented in the form of updated training and continuing education options for actors in the construction sector or the expansion and improvement of green infrastructure in settlement areas. In the latter, the introduction of standards and the assessment (and monetisation) of ecosystem services could prove helpful. More far-reaching adaptation to the heat island effect, primarily vegetation-based approaches, are already being tested; for application on a larger scale, however, they require the creation of legally binding requirements and possibly financial incentives. The availability of water is also decisive to the implementation of such approaches, especially for the irrigation of urban green spaces. Barriers to adaptation in the action field “construction” can, for example, stem from the limited influence of the public sector on privately owned buildings, regulations related to the protection of historical buildings and monuments, or the high costs of flood-adapted construction. Ideas about transformative adaptation tend, for example, to keep areas at risk of flooding clear and generally limit the (per capita) use of built-up areas.

While all three cross-sectional action fields (spatial planning, civil protection, financial management) contribute to the adaptive capacity in the action field “construction”, spatial planning instruments for dealing with the risk of damage caused by floods or heavy rain, regulating both the urban and building climates, and increasing vegetation in the urban environment are of particular importance.

Assessment of the adaptive capacity and the need for action

Since the climate impacts “damage to buildings due to river floods”, “vegetation in settlements”, “urban climate/heat islands” and “indoor climate” were already classified as high climate risks for the middle of the century in the pessimistic case and require an adaptation period of ten to 50 years (damage to buildings, urban climate) or more than 50 years (vegetation in settlements, indoor climate), they are associated with very urgent needs for action. While “vegetation in settlements” can be reduced to a medium risk by means of the APAIII+ measures (and even to a low-medium risk through more far-reaching adaptation), the climate risks “damage to buildings due to river floods” and “urban climate/heat islands” cannot be reduced to a medium risk by the APAIII+ measures, but by more far-reaching adaptation (Table 18).

Table 18: Climate risks with adaptation in the construction action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	medium	medium	medium-high	low-medium	low-medium	medium	low	low-medium
Climate risks with and without adaptation at the level of climate impacts								
Damage to buildings due to river flooding	medium	medium	high	medium	low-medium	medium-high	low	medium
Vegetation in settlements	low	medium	medium	low	low-medium	medium	low	low-medium
Urban climate/ heat islands	medium	medium	high	low-medium	low	medium-high	low	medium
Indoor climate	medium	medium	high	*The adaptive capacity was not assessed for this climate impact.*				

6.3.2 Energy industry action field

Relevance of the action field and new developments

The action field “energy industry” is of high relevance for the economy and society and has numerous interactions with many other action fields. The energy industry is influenced by politics, technical developments and socio-economic processes. But climate change also plays a major role in many ways. This affects almost all parts of the value chain in the energy industry. Renewable energies are influenced, for example, by weather events that change in their frequency or intensity, while nuclear and coal energy depend on the availability of cooling water, which can be limited during periods of low water. Climate also influences transmission and supply networks and their expansion. Climate change also has a major impact on energy demand. This is shown, for example, by an expected reduction in heating requirements and an increase in cooling requirements due to milder winters and hotter summers, although demand is also influenced by many other factors. For example, the observed increase in energy efficiency is essential for heat consumption, one of the largest energy consumers in Germany, especially in private households. Overall, it is expected that energy demand will increase in the future due to both population and economic growth.

Selected climate impacts in the action field and central analysis results

The need for cooling energy is essential to changes in energy demand due to climate change. In addition to climatic influencing factors (rising average temperatures, heat and increased air humidity), other factors play a role here, including building types and behaviour-related aspects. As a result, projections of the future cooling energy demand are subject to a high level of uncertainty. In principle, however, an increasing demand can be assumed for both the middle and the end of the century. However, the air conditioning requirement still only represents a small proportion of the total energy consumption; no electricity deficits are to be expected as a result of this increase in the future. A clear reduction in the need for heating energy can be expected both by the middle and by the end of the century; the need will continue to be highest at high altitudes in Germany. While projections show a total reduction of up to 30 percent by the end of the century, cold winters may also occasionally occur in the future, especially due to shifts in the polar jet stream. This will lead to periods with higher heating requirements.

On the energy supply side, there may be climate effects on regional supply chains for fossil fuels. For example, the transport of coal and oil via waterways can be affected by more frequent low water events. The future increase in hot days and rising temperatures, especially in summer, can furthermore reduce the availability of cooling water, since the cooling water withdrawal and discharge can be restricted to protect the water ecology. This can lead to a throttling or temporary cessation of the electricity production of thermal power plants. The relevance of both climate impacts will decrease with the energy transition and will be of less importance for the future energy supply.

The generation capacity of renewable energy sources is also affected by the effects of climate change. For example, high temperatures and hot periods reduce the efficiency of photovoltaic systems, and high wind speeds can require the temporary deactivation of wind turbines. In both cases, projections suggest only minor changes, but there are very high uncertainties in the projections with regard to wind speeds and wind energy yield. Extreme weather events such as heat waves, heavy precipitation, storms and severe weather can ultimately cause interruptions and network fluctuations in the energy supply as a whole. The expected increases in the first two event types can impair the reliability of the supply, together with the network expansion necessary for the energy transition (by the middle of the century). Due to the high density of connections in the German power grid, however, only rare interruptions are to be expected.

Assessment of the climate risks in the action field

Table 19: Climate risks without adaptation in the energy industry action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Cooling energy requirements	Climate risk	low	low	low	medium	medium	10-50 years
	Certainty		low		low		
Heating energy requirements	*see below*						
Interruption of the regional supply chains for energy sources	Climate risk	low	low	low	low	low	< 10 years
	Certainty		medium		medium		
Insufficient cooling water for thermal power plants	Climate risk	low	low	low	low	low	10-50 years
	Certainty		medium		medium		
Reduction / increase in yield in photovoltaic systems and in wind energy systems on land and at sea	Climate risk	low	low	low	low	low	10-50 years
	Certainty		low		low		
Lack of reliability of the energy supply	Climate risk	low	low	low	low	low	10-50 years
	Certainty		low		low		

Table 20: Opportunities of climate change in the energy industry action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			high chance	low chance	high chance	low chance	
Heating energy requirements	Climate risk	low	low	low	medium	low	< 10 years
	Certainty		low		low		

Spatial exposure and sensitivity

Both the exposure and the sensitivity factors in the action field "energy industry" tend to be climate-impact specific. On the supplier side, for example, location factors such as proximity to coastal or inland waters are relevant. For the transport of fossil fuels, the dependence on the navigability of inland waterways and the associated upstream exposure and sensitivity factors also play a role. On the demand side, for example, the whole of Germany is affected by increases in cooling energy requirements, while southern Germany is particularly exposed to this climate impact. The heat island effect also suggests differences in exposure between urban and rural areas.

Adaptive capacity

With regard to the potential for adaptation in the action field "energy industry", the picture is quite heterogeneous; the APAIII+ measures and more far-reaching adaptation relate mainly to the use of technical measures and natural resources. On the energy supply side, the autonomous adaptation of the respective actors in the energy sector plays a relatively large role compared to adaptation through state and regulatory action. The adaptability of the energy infrastructure can be increased by investing in decentralized energy supply structures and establishing smart grids. Planning and approval procedures as well as a potential lack of social acceptance and financial costs, on the other hand, can represent obstacles to adaptation. The integration of the topic of climate adaptation in standardization procedures also appears to make sense. Transformative, cross-system adaptation measures such as relocation are more conceivable after other means have been exhausted.

It should also be emphasized that the measures and targets adopted as part of the energy transition do not have a negative effect on future adaptation potential, and that adaptation measures in the action field do not lead to increased energy consumption and emissions. On the demand side, for example, alternative cooling technologies are preferable to conventional air conditioning systems. There is also great potential here for measures that seem to make economic sense even without the consequences of climate change (so-called "no-regret" measures), for example energy-efficient construction to regulate energy consumption. There are numerous other interactions with adaptation options in other action fields, such as water management, construction and human health. The adaptive capacity in the action field "energy industry" is strengthened by contributions from all three cross-sectional action fields. Civil protection contributes to the adaptation with efforts to protect and maintain critical infrastructure and, with it, energy supply facilities. The financial sector can support the expansion of renewable energies through targeted investments, and regional planning makes a contribution in planning for the expansion of renewable energies.

Assessment of the adaptive capacity and the need for action

No climate impacts were selected for the analysis of the adaptive capacity for the action field "energy industry". Therefore, only the adaptive capacity at the level of the action field was assessed (Table 21).

Table 21: Climate risks with adaptation in the energy industry action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	low	low	low	low	low	low	low	low

There are no very urgent or urgent requirements for action in the action field.

6.3.3 Transport, transport infrastructure action field

Relevance of the action field and new developments

An efficient transport sector is of major importance to the economy and society in Germany and is closely linked to other action fields. Interruptions and impairments to transport systems can affect not only transport safety and performance, but also business processes and productivity.

Negative impacts on critical infrastructure can disrupt the personal organisation of everyday life, cause supply bottlenecks or impair of public safety. At the same time, the transport sector is vulnerable to damage as a result of extreme weather events.

The action field “transport, transport infrastructure” is therefore potentially severely affected by climate change. For example, a future increase in floods, storms, landslides and extreme heat spells can have negative consequences for road and rail transport, and both low and high water events can affect the inland navigation operations and the companies that depend on it.

Apart from climate change, the transport sector is subject to constant change in economic, environmental and technical conditions. Predictions about transportation indicate an increase in traffic in the future. Efforts are underway to implement environmentally friendly and flexible transport concepts (for example, shifting transport from road to rail, as well as the combined and flexible use of different types of transport, both in freight and passenger transport). At the same time, technological developments must be taken into account, in particular advancing electrification, digitisation and automation in road, rail and waterway traffic.

Selected climate impacts in the action field and central analysis results

The navigability of inland waterways can be affected by both low and high water events. Both of these can occur more intensely in the future due to climate change. The seasonal reduction in transport capacities caused by low water events can have significant economic effects under severe climate change. In the optimistic case, projections show only very moderate changes up to the end of the 21st century. In the pessimistic case, water levels in the Rhine, Moselle and sections of the Neckar could fall below the low-water threshold up to 35 days a year by the middle of the century (the current value is 20 days per year). In this scenario, more intense and frequent low water situations are projected for most inland waterways by the end of the century. On the Rhine and Danube waterways, which are particularly important from a transport perspective, values of over 40 days could occur in some sections if no adaptation measures take place.

The shipping restrictions caused by floods are of shorter duration and have less economic significance than the low water events. In the optimistic case, only insignificant changes are expected in both periods (middle and end of the century compared to the reference period 1971 to 2000) with regard to the number of exceedances of the upper threshold values relevant to shipping. In the pessimistic case, the number of exceedance days increases for almost all waterways towards the middle of the century. However, by the end of the century, most of the waterways will see no further changes.

The navigability of shipping lanes is also affected by the impacts of climate change, in particular the accelerated rise in sea levels. Sea waterways, ports and maritime infrastructures will be exposed to higher peak water levels due to storm surges in the future. An increase in the dominance of the tide currents caused by the rise in sea level can lead to an increased upstream sediment transport and, as a result, increased expenditures for maintenance dredging in the estuaries. All in all, the study considers the effort required to maintain the functionality of the waterway and port infrastructure up to 2050 as a rather minor challenge – that challenge will continue to increase up until the end of the century, however.

Roads and railways can be affected by climate change-related damage or obstacles as a result of extreme river floods, flash floods, storms, gravitational mass movements or extreme heat. As of yet, the impact of these events on transportation can only be modelled with a high degree of uncertainty.

With regard to the effect of river floods, there are no significant changes compared to today in the optimistic case for the middle and the end of the century; there are more frequent restrictions in the pessimistic case. In the case of gravitational mass movements, climatic drivers can modify the major engineering-geological factors and possibly trigger events; the length of endangered sections of the federal motorway and rail networks could double by the end of the century, taking into account the climatic drivers.

Climate change can also affect the risk of damage to traffic control systems, overhead lines and power systems. The rise in temperature and the increase in hot days amplify the effects of heat-related damage, while the projected decrease in the number of frost days would reduce the damage caused by snow and ice loads. Given the available information, there are no effects of climate change on damage caused by wind breakage (e.g. overhead lines), since the projections of wind fields do not show any clear trends regarding changes.

Assessment of the climate risks in the action field

Table 22: Climate risks without adaptation in the transport, transport infrastructure action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Navigability of inland waterways (low water)	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		low		
Navigability of inland waterways (flooding)	Climate risk	low	low	low	low	medium	10-50 years
	Certainty		medium		low		
Navigability of the sea waterways	Climate risk	low	low	low	low	medium	10-50 years
	Certainty		medium		low		
Damage / obstacles to roads and railways (flooding)	Climate risk	low	low	medium	low	medium	10-50 years
	Certainty		medium		low		
Damage / obstacles to roads and railways (gravitational mass movements)	Climate risk	low	low	medium	low	medium	10-50 years
	Certainty		medium		low		
Damage to traffic control systems, overhead lines and power supply systems	Climate risk	low	low	medium	low	medium	10-50 years
	Certainty		low		low		
Damage to inland and maritime waterways, ports and maritime infrastructures	Climate risk	low	low	low	low	medium	10-50 years
	Certainty		medium		low		

Spatial exposure and sensitivity

In the action field "transport, transport infrastructure", various factors influence the extent to which climate change impacts the modes and means of transport. Significant factors include the condition of the respective transport infrastructure as well as the traffic and transport volume. The sensitivity of the rail and road sections to flooding depends on the height of the tracks or the lanes near the river (river floods) and on the availability and volume of retention and drainage systems (flash floods). The sensitivity to wind breakage depends on the vegetation near the route (trees) and their management and infrastructure parameters (overhead lines). The sensitivity of inland navigation to restrictions caused by high and low water is influenced, among other things, by the characteristics of the river basin (including the management measures installed) and the characteristics of the waterway (depth and width, waterway management, bridge heights).

Adaptive capacity

The APA III contains a comparatively large number of measures for the action field "transport, transport infrastructure". For example, research projects such as topic 1 "adapting transport and infrastructure to climate change and extreme weather events" create a good knowledge base in the BMVI expert network with regard to the diverse climate effects, the need for adaptation and selected adaptation measures in the transport sector.

With a view to adapting the navigability of inland waterways to low water events, the "Rhine Low Water Action Plan" contains a bundle of different measures. This includes, among other things, the further development of forecast systems.

Given the existing uncertainties, as in other action fields, so-called "low-regret" measures are also recommended with regard to possible, more far-reaching adaptation measures. This includes measures to increase flexibility both in river engineering (flexible elements) and in logistics (e.g. simplification of intermodal transport). When it comes to adaptation, "transport, traffic infrastructure" has interactions with the action fields "industry and commerce" and "water balance, water management". The cross-sectional action field of spatial planning, regional and urban land-use planning makes a significant contribution to improving the adaptive capacity in the action field.

Assessment of the adaptive capacity and the need for action

The study analysed and assessed the adaptive capacity of the action field "transport, transport infrastructure" for the climate impact "navigability of inland waterways (low water)". The participating experts conclude that the many measures in APA III could be sufficient to reduce the climate risk of the climate impact "navigability of inland waterways (low water)" from "high" to "medium", even in the pessimistic case. A reduction to a climate risk of "low" could be possible through more far-reaching adaptation (Table 23).

Table 23: Climate risks with adaptation in the transport, transport infrastructure action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	low-medium	low	medium	low	low	low-medium	low	low
Climate risks with and without adaptation at the level of climate impacts								
Navigability of inland waterways (low water)	medium	medium	high	low	low	medium	low	low

The need for action is classified as very urgent for the climate impact “navigability of inland waterways (low water)”, since the climate risk was rated as “high” in the pessimistic case for the middle of the century and many measures could require a significant lead time (up to 50 years). Urgent needs for action arise for the climate impacts “damage/obstacles to roads and railways (flood)”, “damages/obstacles to roads and railways (gravitational mass movements)” and “damage to traffic control systems, overhead lines and power supply systems”.

6.4 Economy cluster

6.4.1 Industry and commerce action field

Relevance of the action field and new developments

The German economy has grown steadily over the past ten years. Industry is responsible for a high share of gross value added and the share of manufacturing in gross value added is comparatively high across the EU. In addition, as an export nation, Germany is heavily involved in international value chains. As a result, the impact of climate change both at home and abroad affects this action field. Possible risks due to climate change relate to various areas of the industrial and commercial value chain, such as input logistics (availability of raw materials and intermediate products, conditions for the transport of goods), production (employee performance, availability of production-related resources such as energy and water) or the market.

Selected climate impacts in the action field and central analysis results

The impact of climatic drivers in climate-vulnerable mining and cultivation countries could impair the future supply of German companies with raw materials and intermediate products. Raw materials such as cocoa, coffee, tea, mate, rubber and cotton show high vulnerabilities. Intermediate products have lower vulnerability values, but a higher market concentration compared to raw materials. If several supplier countries are affected by the impacts of climate change at once, this can increase the overall impairment of the supply of raw materials and intermediate products.

Trading with climate-vulnerable countries also has risks for German companies, such as changes in demand and shifts in future sales markets. Medium to high vulnerability values were determined for various branches of the mechanical engineering industry. Due to the lower market concentration values of the sales markets, changes in demand will probably only affect small sales volumes per country. There are opportunities due to the development of new sales markets, particularly in the construction and chemical industries. Strong market growth is expected for innovative environmental technologies until 2025. Small and medium-sized German companies in particular have high innovation potential in this area.

Climate change-related impairments to the transport of goods can occur both at home and abroad. Increasing risks arise for international shipping traffic, which dominates global trade. International air, road and rail traffic can be increasingly affected by extreme weather events. In the domestic movement of goods via waterways, extremely low water levels can lead to a reduction in the transport volume, delivery delays or reloading to other modes of transport. Projections for the Rhine show that the average loading levels will decrease by the end of the century. This can lead to increased costs for the transport of goods. Finally, in land-based goods transport, an increase in heavy precipitation and hot days can result in brief interruptions in the transport infrastructure.

Climate change also affects the demand and availability of production-related resources. The energy supply of German companies can be viewed as largely stable in the future. However, there is a possibility that fluctuations in the price of electricity triggered by extreme weather events can lead to higher energy costs, especially for energy-intensive industries. Uncertainties arise from the planned network expansion as part of the energy transition, which can lead to an increased susceptibility to failure in the network. It can be assumed that the demand for cooling water for thermal power plants, which currently accounts for a significant proportion of the water demand, will continue to decrease in the future as a result of the energy transition. In some industries with water-based products, such as food and beverage production, rising temperatures could lead to an increased demand for water that cannot be replaced by efficiency improvements.

Chemical and sewage treatment plants are affected by increasing heavy precipitation and on the coasts by the consequences of rising sea levels from increased risks of the release of dangerous substances through flooding. In built-up areas, sewage systems that are overloaded by heavy rainfall can escape or run off on the surface and get into bodies of water. Long periods of heat can lead to increased heating of system parts. If there are thermally sensitive substances in these components, they can begin to react and trigger the release of substances.

As a result of the increasing average air temperatures and more frequent heat waves, an increase in the performance losses of employees who work indoors is to be expected. More frequent and stronger extreme weather events can increase performance losses due to accidents or the health problems of outdoor workers.

The mentioned effects of climate change on industrial value chains can lead to the impairment of production processes and an increase in the effort required for operational planning.

Assessment of the climate risks in the action field

Table 24: Climate risks without adaptation in the industry and commerce action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Impairment of the supply of raw materials and intermediate products (international)	Climate risk	medium	medium	high	medium	high	< 10 years
	Certainty		low		low		
Restrictions in sales markets (international)	Climate risk	low	low	medium	low	medium	< 10 years
	Certainty		low		low		
Competitive advantage in innovative environmental technologies	*see below*						
Impairment of the international transport of goods	Climate risk	low	low	medium	medium	medium	10-50 years
	Certainty		medium		low		
Impairment of the movement of goods via waterways (inland)	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		low		
Impairment of the land-based movement of goods	Climate risk	low	low	medium	low	medium	< 10 years
	Certainty		low		low		
Energy consumption and impairment in energy supply	Climate risk	low	low	low	low	low	< 10 years
	Certainty		medium		medium		
Water requirements	Climate risk	medium	low	medium	low	medium	< 10 years
	Certainty		low		low		
Release of dangerous substances	Climate risk	low	medium	medium	medium	medium	< 10 years
	Certainty		medium		medium		
Reduced employee productivity	Climate risk	medium	low	medium	medium	high	< 10 years
	Certainty		medium		medium		
Impairment of production processes	Climate risk	low	low	low	low	medium	< 10 years
	Certainty		low		low		
Operational planning expense	Climate risk	low	low	low	low	low	< 10 years
	Certainty		low		low		

Table 25: Opportunities of climate change in the industry and commerce action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			high chance	low chance	high chance	low chance	
Competitive advantage in innovative environmental technologies	Potential	medium	medium	low	medium	low	< 10 years
	Certainty		low		low		

Spatial exposure and sensitivity

The extent to which German companies are affected by climate change depends on various factors. The branch of the economy, the size of the company, the company's international orientation or the ability to innovate all play a role. At the same time, they represent critical starting points for adaptation and for improving adaptive capacity. With regard to the impairment of the domestic movement of goods via waterways, the conditions of the federal waterways and their catchment area characteristics as well as the location of large industrial sites are critical factors of spatial exposure. The sensitivity of inland navigation to restrictions caused by high and low water is influenced, among other things, by the characteristics of the river basin (including the management measures installed) and the characteristics of the waterway (depth and width, waterway management, bridge heights). With regard to the supply of international raw materials and intermediate products, for example, the proportion of imports from climate-vulnerable countries, the proportion of raw materials and/or intermediate products with few substitution options, and the market concentration of imports are relevant factors to sensitivity.

Adaptive capacity

When it comes to adaptation, the action field shows diverse potential; APA III lists a comparatively large number of measures. These are related to measures in the action field "transport, transport infrastructure" or to weather-related extreme events and their effects on industrial sites and buildings, occupational health and safety, plant safety and the safeguarding of hazardous substances.

Due to the high degree of heterogeneity in German industry and commerce and the associated climate impacts examined in the action field, there is also a broad field of possible, more far-reaching adaptation options. It should be noted here that adaptation by the federal government in the context of state trade is considered in particular. Autonomous adaptation by the companies themselves can be triggered by these measures and the framework conditions for adaptation can be improved. Examples of this include information campaigns, advisory services, adaptation bonuses or targeted funding. Regulatory market changes, such as safety standards in the context of building regulations, also create a framework for adaptation. In addition to the measures mentioned, adaptation guidelines for industry and commerce can serve as guidelines for adaptation and play a role in the success of implementation. Although smaller companies can often react more flexibly to changes than large companies with complex organisational structures, small and medium-sized companies can face more financial obstacles to implementation. Another obstacle to the adaptation in the action field can be the different time horizons for companies and for government action, since measures may not be implemented at the required time. Adaptation in the action field can reach its limits if government measures lead to the creation of market imbalances or if adaptations are no longer profitable for companies. The cross-sectional action field of the financial sector in particular contributes to strengthening the adaptive capacity by arranging insurance for physical climate risks. Incentives for adaptation can also be set through guidelines for granting loans or investments. Regional planning in particular can support spatial adaptation processes that require a change in land use.

Assessment of the adaptive capacity and the need for action

In the action field “industry and commerce”, the study analysed and assessed the adaptive capacity to the climate impacts “impairment of the supply of raw materials and intermediate products (international)” and “impairment of the movement of goods via waterways (inland)”.

The risk of the climate impact “impairment of the supply of raw materials and intermediate products (international)” could be reduced to “medium-high” in the pessimistic case by implementing more far-reaching adjustments.

While the APAIII+ measures could reduce the climate risk of the climate impact “impairment of the movement of goods via waterways (inland)” to “medium-high” in the pessimistic case, a reduction to a medium climate risk could be achieved with more extensive adaptation (Table 26).

Table 26: Climate risks with adaptation in the industry and commerce action field

	Climate risks without adaptation			Climate risks with adaptation: APAIII+ measures			Climate risks with adaptation: More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	medium	low	medium	low-medium	low	medium	low	low
Climate risks with and without adaptation at the level of climate impacts								
Impairment of the supply of raw materials and intermediate products (international)	medium	medium	high	medium	medium	high	low	medium-high
Impairment of the movement of goods via waterways (inland)	medium	medium	high	low	low	medium-high	low	medium

The climate impact “impairment of the movement of goods via waterways (inland)” is classified as a very urgent need for action, since the pessimistic case rates it as “high” by the middle of the century and many measures could require a significant lead time (up to 50 years).

Urgent needs for action arise for the climate impacts “impairment of the supply of raw materials and intermediate products (international)”, “impairment of the international transport of goods”, “water demand” and “performance losses of employees”.

6.4.2 Tourism action field

Relevance of the action field and new developments

Since a large number of tourist activities take place in the open air, the tourism sector in Germany[17] (both supply and demand side) is largely dependent on the weather and, accordingly, is also influenced by climatic changes. Certain tourist activities are also based on natural features or the scenic attractiveness of a region. In this way, climate-related changes that affect the appearance of a landscape or visibly change the characteristics of certain natural areas can also have an impact on the tourism sector. Depending on the type of tourism and region, the air temperature and the associated occurrence of snow as well as the frequency and intensity of extreme events such as heat waves, drought, heavy rain or floods, have an influence here. In addition, changes in the natural environment (for example on the coasts), impairment of bathing water quality or air quality or similar processes, some of which are caused by climate change, can limit tourist activities and/or reduce tourist demand. However, in addition to risks from climatic changes, there can also be opportunities for the tourism sector, for example through the extension of the swimming and hiking season. Overall, the influence of climate change on the tourism industry can be seen as one of many factors that affect demand, supply and the labour market situation in the tourism sector. In particular, socio-demographic and socio-economic circumstances, such as age, educational and household structure as well as household income, explain the multi-causality of tourist demand.

Selected climate impacts in the action field and central analysis results

The following picture emerges for winter tourism: both periods with a winter atmosphere and the natural probability of snow in the (currently) critical period for winter tourism are clearly decreasing across the board. The areas in which the probability of snow remains the same (high) are already very limited by the middle of the century (especially in the German Alps). The tourism industry is particularly affected when regional/local travel providers are very specialised and the total added value from tourism is very high.

Major damage to tourist infrastructures and businesses in coastal areas can be caused by stronger storm surges, rising sea levels and coastal erosion. In addition, the increasing frequency and intensity of heavy precipitation, storms, dry periods or high and low water caused by climate change can lead to interruptions in tourist use, for example hiking, cycling, forest trails, ski slopes or bodies of water.

Economic opportunities and risks for tourism providers arise from the periods/duration of seasonal activities that are influenced by climate change. The extension of the cycling, hiking and bathing season could have a positive effect – although the latter could be impaired by a deterioration in the quality of the bathing water. At the same time, changes in the natural environment, for example in ski areas, lead to operational risks due to the shortening or absence of the winter tourism season.

The effects of the rise in air temperature as a result of climate change on the different types of health tourism reveal spatial differences: while changes in the bio-climate can have negative effects on health tourism, changes in temperature can also have a positive effect.

In addition to climatic changes, demographic change and socio-economic trends have a decisive impact on the development of demand in the tourism sector. The influence of climate change on

[17] All statements relate to vacation and leisure tourism in Germany by both residents and foreign travellers, and only trips that include overnight stays; travel from Germany to other countries is not taken into account.

travel decisions will continue to play a subordinate role in the overall context of the numerous factors that influence tourist demand.

Assessment of the climate risks in the action field

Table 27: Climate risks without adaptation in the tourism action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Restriction of tourism options: effects of a lack of guaranteed snow on winter tourism	Climate risk	low	medium	medium	high	high	< 10 years
	Certainty		medium		medium		
Restriction of tourism options: effects of heat on health-based tourism	Climate risk	low	low	medium	medium	medium	< 10 years
	Certainty		low		low		
Damage to tourist infrastructure and business interruptions	Climate risk	low	medium	medium	medium	high	< 10 years
	Certainty		medium		low		
Shift in demand	Climate risk	low	low	medium	low	medium	< 10 years
	Certainty		low		low		
Economic opportunities and risks for tourism	Climate risk	medium	medium	medium	high	high	< 10 years
	Certainty		medium		low		

Spatial exposure and sensitivity

Depending on the type of tourism, the altitude ("classic" winter tourism destinations: low mountain ranges, Alps, Alpine foothills) or the relative distance to waters/proximity to the coast are factors of spatial exposure in the tourism sector. On the supply and demand side, sensitivity is linked to socio-demographic and socio-economic characteristics. The degree of specification or diversification also plays a decisive role on the supply side. For example, unpredictable winter sports conditions have long been dealt with in low mountain ranges, so that a certain amount diversification has been achieved in terms of tourist activities; in the alpine ski regions, however, quite a few providers live almost exclusively from ski tourism.

Adaptive capacity

The multi-causality of travel decisions makes it difficult to forecast and control demand-side adaptation to climate change; adaptation options exist mainly on the supply side. Tried and tested risk management mechanisms are relevant here. Certain strategies and individual measures are already in use, for example the education and sensitisation of tourism stakeholders as well as the structured preparation for extreme events and disasters. Selected measures are primarily aimed at generating and providing knowledge as well as raising awareness. This includes the provision of guidelines for the implementation of adaptation measures, online information portals (such as the regional climate atlas) as well as the provision of meteorological data and climate adaptation advice from the "Climate Data Center" of the German Weather Service.

More far-reaching adaptation can be made both at the destination management organisation (DMO) level and at the operational level. Diversification of the available activities can be a helpful strategy. In winter tourism destinations in German low mountain ranges, this is already being pursued with an expansion to include summer outdoor activities, which could also prove useful for the German Alps instead of or in addition to technical adaptation measures such as snow management. The same applies to coastal regions (due to the rise in sea levels) or destinations specialising in hiking tourism (e.g. heat and drought damage). Diversification can also include expanding the cultural activities or marketing regional products. Flexibility seems to be particularly important in addition to a variety of activities, given the heterogeneity of travel decisions. While the DMO can provide critical momentum for the conception and implementation of adaptation, adaptation processes are based on the interaction of various actors and require coordination and cooperation. Overall, organisational and knowledge-generating measures are essential components of adaptation strategies (including on the demand side), but financial resources are also critical.

The cross-sectional action field of "spatial planning" through regulations on land use contributes to improving the adaptive capacity in the action field; the financial sector could also play a role by expanding the available insurance options, for example.

Assessment of the adaptive capacity and the need for action

No climate impacts were selected for the analysis of adaptive capacity for the action field "tourism". As a result, only the adaptive capacity at the level of the action field was assessed (Table 28).

Table 28: Climate risks with adaptation in the tourism action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	low	low	medium	low	low	medium	low	low-medium

There are no very urgent needs for action here. There is an urgent need for action for the climate impact "economic opportunities and risks for the tourism industry".

6.5 Health cluster

6.5.1 Human health action field

Relevance of the action field and new developments

Human well-being and health are influenced by weather and climatic conditions. They can affect both the body and the psyche and, in extreme cases, lead directly or indirectly to death. As a climatic driver, rising temperatures in particular play an essential role in people's health. Heat puts a strain on the cardiovascular system and can lead to aggressive behaviour. Other weather extremes that can endanger human health are frost, strong winds, and flooding due to high water or heavy rain. Climate change can have indirect effects on human health by promoting allergies and pathogens or their carriers, or by increasing exposure to UV radiation.

Selected climate impacts in the action field and central analysis results

The heat load will increase. The reason for this is not only the increasing number of heat waves during the year and their longer duration. The densification of inner cities and the increasing concentration of the population into larger agglomerations also contribute to this. The densification of inner cities will intensify the heat island effect, while the growth of cities in the surrounding area will increase the area of the heat islands. At the same time, the population's sensitivity is increasing in the course of demographic change: people aged 75 and over are considered to be particularly sensitive to heat, as are people with a wide variety of existing illnesses. Other extreme events that could become more frequent and intense are heavy rain and hail. The projections are still ambiguous for individual weather extremes such as storms. Overall, however, the increasing frequency and intensity of extreme weather events increases the risk of people being injured or killed.

As a result of climate change, the pollen season starts earlier and lasts longer. In some years, one pollen season goes straight to the next; pollen allergy sufferers do not have an allergy-free break. The alder, examined in more detail in the KWRA 2021, opens the pollen season together with the hazel as an early bloomer. At the end of the century, it could bloom around two weeks earlier on average across Germany. The shift in the beginning of flowering would be particularly clear at higher altitudes. It is also expected that plants will release more and stronger allergenic pollen in the future. The shifting vegetation zones can also shift the pollen spectrum.

The increasing temperatures favour certain microorganisms and algae in their growth and spread. As with other living beings, different protozoa, bacterial strains, algae or fungus species have different requirements in terms of temperature and humidity. Often, however, a warmer environment promotes growth or reproduction. As an example of microorganisms favoured by heat, the KWRA 2021 describes the bacterial genus Vibrio. Vibrions occur naturally in brackish and marine water and can cause deadly infections. Their infection potential depends on the water temperature. As the oceans warm, the number of infections from vibrions could increase. In addition, the population as a whole is getting older and therefore potentially more sensitive.

Weather and climate not only influence microorganisms, but also pathogens such as mosquitoes, ticks and mice in their distribution, abundance and activity. Among the native vectors, ticks in particular could benefit from climate change. This would manifest, among other things, in an extension of their active period or in the increased abundance of previously less common species. The increasing spread of previously non-indigenous vectors could also be relevant. Their introduction into Germany is often due to the international movement of people and goods. Host animals also introduce vectors. With climate change, the favourable areas for non-native species can expand, promoting the spread of those species.

UV radiation is carcinogenic and the main cause of skin cancer. The incidence of skin cancer has been rising for decades. With climate change, the situation could worsen as the number of hours of sunshine increases or the cloud cover decreases (although the future development of the cloud cover is uncertain). This increases the population's potential exposure to UV radiation. A changing climate can also have an impact on people's behaviour, which could lead to increased exposure to the open air and with it an increase in UV radiation exposure. In addition, the complex interactions between greenhouse gases, climate change and the stratospheric ozone layer influence the recovery of this ozone layer. Low ozone events have increased in the northern hemisphere over the past two decades. They can result in a significantly increased exposure of the population to UV radiation.

The local concentration of pollutants in the air is also influenced by the weather. Projections assume that the emission of air pollutants and precursors for ground-level ozone will decrease by the middle of the century. Nevertheless, the concentration of ground-level ozone could increase with increasing temperatures and duration of sunshine. Exposure to air pollutants could generally also increase due to the higher number of hot days and the associated lower air circulation.

The climate impacts described show that the number of weather-related illnesses could increase. In addition, extreme weather events could more often lead to temporary overloads in healthcare facilities or the failure of the required infrastructure. Climate change requires investments in the health system, especially in training and education for employees, prevention campaigns, research and the reliability of infrastructures.

Assessment of the climate risks in the action field

Table 29: Climate risks without adaptation in the human health action field

Climate impact		Present	Middle of the century		End of the century		Adaptation period
			optimistic	pessimistic	optimistic	pessimistic	
Heat stress	Climate risk	high	medium	high	medium	high	10-50 years
	Certainty		high		medium		
Allergic reactions due to plant-based aeroallergens	Climate risk	low	medium	high	medium	high	10-50 years
	Certainty		medium		medium		
Potentially harmful microorganisms and algae	Climate risk	low	low	medium	medium	medium	< 10 years
	Certainty		high		medium		
UV-related health damage	Climate risk	medium	medium	high	medium	high	10-50 years
	Certainty		medium		very low		
Distribution and change in abundance of possible vectors	Climate risk	low	low	medium	medium	medium	< 10 years
	Certainty		high		low		
Respiratory issues (due to air pollution)	Climate risk	medium	medium	medium	medium	high	< 10 years
	Certainty		medium		low		
Injuries and deaths as a result of extreme events	Climate risk	low	low	low	low	medium	< 10 years
	Certainty		medium		low		
Effects on the healthcare system	Climate risk	medium	medium	medium	medium	high	< 10 years
	Certainty		medium		very low		

Spatial exposure and sensitivity

In principle, every person can be affected by weather- and climate-related diseases. Nevertheless, there are population groups that are more sensitive to the health consequences of climate change. These are people who are immunocompromised due to age or illness. In addition, there are portions of the population that are exposed to health-threatening situations longer and more frequently than others, for example people who spend a lot of time outdoors. People are also at risk when they lack a functioning, easily accessible health system in the event of problems. This is itself facing new challenges in the course of climate change.

Adaptive capacity

In the action field "human health" there is a comparatively large number and variety of options for climate change adaptation; the essential elements include education, monitoring of environmental influences as well as standards for rules of conduct and technical equipment. The federal government's Adaptation Action Plan (APA III) makes significant contributions to the high-level climate risks "heat exposure", "UV-related damage to health (especially skin cancer)" and "allergic reactions due to aeroallergens of plant origin" in the areas of education, research and monitoring, information and awareness-raising. Adaptation to the increasing exposure to heat and UV radiation can also include regulations on occupational safety and the provision of information material to specific target groups. The adaptation of the information and early warning systems also contributes to better handling of increasing heat exposure. Adaptation measures for the climate impact "allergic reactions through aeroallergens of plant origin" aim to promote awareness monitoring and the investigation of the mechanisms of action of new allergens. Adaptation to the spread of possible pathogens and potentially harmful microorganisms and algae can primarily take place through research, monitoring activities and warning the population or the designation of risk areas.

While more far-reaching adaptation in the area of human health is primarily linked to the mobilisation of financial resources and the creation of a legal framework, significant changes in consumption and eating habits as well as interventions in settlement and building design can have a transformative influence on adaptation (mitigation the release of pollutants and greenhouse gases, consideration of the allergenicity of urban trees/urban greenery). Conflicts of goals between adaptation-related measures exist, for example, with regard to the planting of potentially allergenic species or the expansion of blue infrastructures, which can serve as potential places of distribution for vectors or harmful microorganisms.

The time horizon for the measures in the field of "human health" is most often estimated at less than ten years and in a few cases several decades.

Assessment of the adaptive capacity and the need for action

There is a very urgent need for action for the climate impacts "heat stress" and "UV-related damage to health", given that the climate risks are rated as "high". While the APAIII+ measures could reduce the climate risk to "medium-high", it could be reduced to "medium" through more far-reaching adaptation. Another very urgent need for action is the climate impact "allergic reactions due to aeroallergens of plant origin". Both the APAIII+ measures and more far-reaching adaptation could reduce the climate risk from "high" to "medium" (in the pessimistic case) (Table 30).

Table 30: Climate risks with adaptation in the human health action field

	Climate risks without adaptation			Climate risks with adaptation				
				APAIII+ measures			More far-reaching adaptation	
	Present	2031-2060		2020-2030	2031-2060			
		optimistic	pessimistic		optimistic	pessimistic	optimistic	pessimistic
Climate risk in the action field (with and without adaptation)	medium	medium	high	low-medium	low	medium	low	medium
Climate risks with and without adaptation at the level of climate impacts								
Heat stress	high	medium	high	medium-high	low	medium-high	low	medium
UV-related damage (especially skin cancer)	medium	medium	high	low-medium	low-medium	medium-high	low	medium
Allergic reactions due to plant-based aeroallergens (e.g. pollen)	low	medium	high	low	low	medium	low	medium

There is an urgent need for action for the climate risks “breathing difficulties (due to air pollution)” and “effects on the health system”.

7. Integrated assessment

In the integrated assessment, the results of all action fields were evaluated across the board in order to identify particularly affected regions, action fields and climate impacts as well as patterns of adaptive capacities and action requirements.

Overall view of climate risks without adaptation

At the level of climate impacts, a significant increase in climate risks is expected by the end of the century. For example, by the middle of the century (in the pessimistic case), more than a third of all climate impacts examined could show high climate risks. At the end of the century (in the pessimistic case), more than half of the climate impacts could have high climate risks. In the optimistic case (favourable scenario combination of climate and socio-economic projections) the climate risks are rated significantly lower: by the middle of the century, only two climate impacts show a high climate risk. By the end of the century, however, high risks are estimated for over a quarter of all climate impacts, even in the optimistic case.

The climate risks, assessed at the level of the action fields as a whole, could increase significantly by the end of the century, for the most part. Until then, almost all action fields can have medium-high or high climate risks in the pessimistic case. A particularly large number of climate impacts with a high climate risk are found in the action fields “biodiversity”, “forestry”, “water balance, water management” and “coastal and marine protection”, “construction” and “human health”. The action fields “energy industry” and “industry and commerce” are assessed as less severely impaired.

Table 31: Overview of climate risks without adaptation at the level of the action fields

	Present	Middle of century, optimistic case	Middle of century, pessimistic case	End of century, optimistic case	End of century, pessimistic case
Biodiversity	low	medium	medium-high	medium	high
Soil	low-medium	low-medium	medium-high	low-medium	medium-high
Agriculture	medium	medium	high	medium	high
Forestry	medium	medium	high	medium	high
Fisheries	low-medium	medium	high	medium	high
Coastal and marine protection	medium	medium	high	high	high
Water management, water balance	medium	medium	high	medium	high
Construction	medium	medium	medium-high	medium	high
Energy industry	low	low	low	low	low
Transport, transport infrastructure	low-medium	low	medium	low-medium	medium-high
Industry and commerce	medium	low	medium	low	medium
Tourism	low	low	medium	medium	high

The identified climate risks were also evaluated in relation to the four protected assets and resources: human beings, the economy, the environment and cultural heritage. The assessment reveals that a comparatively large number of climate impacts for the environment were rated as high in the pessimistic case for the middle and end of the century. This shows how much aquatic and land-based ecosystems are impacted and includes, for example, climate impacts in the areas of soil erosion, loss of genetic diversity or decline in species populations, damage to ecosystems such as forests, or changes in natural areas. The climate impacts that have been assigned to the cultural heritage category can also often have an above-average climate risk, especially for the end of the century. These are mostly climate risks related to cultural landscapes, landscaped gardens and architectural cultural assets.

The temporal dynamics in the action fields are different and should be taken into account when planning adaptation: comparatively low climate risks in the present combined with a high increase in climate risks by the end of the century (action fields “biodiversity”, “fisheries”, “tourism”) could lead to an underestimation of the long-term risks. Climate risk assessments that are high at an early stage could hide the fact that the risk development is still progressing and will increase sharply by the end of the century.

A comparison of the results of the KWRA 2021 with those of the VA 2015 shows that the climate risk profiles for each action field and also for most of the climate impacts are similar. This indicates the robustness of the foundational methodology. The increase in knowledge between the VA 2015 and the KWRA 2021 has enabled a much more differentiated view of the climate impacts, i.e. a higher number of analysed climate impacts.

In a comparison between the VA 2015 and the KWRA 2021, the assessed risk has increased for almost half of the climate impacts and the action fields. In the KWRA 2021, the climate risk for the action fields “agriculture”, “forestry”, fisheries”, “water balance, water management” and “human health” was rated high instead of medium or medium-high; the action fields “tourism” and “industry and commerce” were rated medium instead of low-medium (each related to the near future/mid-century and the pessimistic case). With regards to the climate impacts, the VA 2015 and the KWRA 2021 reveal strong deviations in the assessment of the risk of loss of yields (action field “agriculture”), which was still low for the pessimistic case (near future/mid-century) in the VA 2015, but is rated as high in the KWRA 2021. The risk of “heat and drought stress” in the action field “forestry” was rated one level higher across all time dimensions and projections. The same also applies to the climate impact “water temperature and ice cover and biological water quality” in the action field “water balance, water management”. The reasons for the higher rating in the KWRA 2021 compared to the VA 2015 are presumably the evaluation period (shifted further into the future), the less favourable climate projections, the better level of knowledge and the heightened awareness of climate change. The assessment did not change for about one third of the climate impacts and action fields.

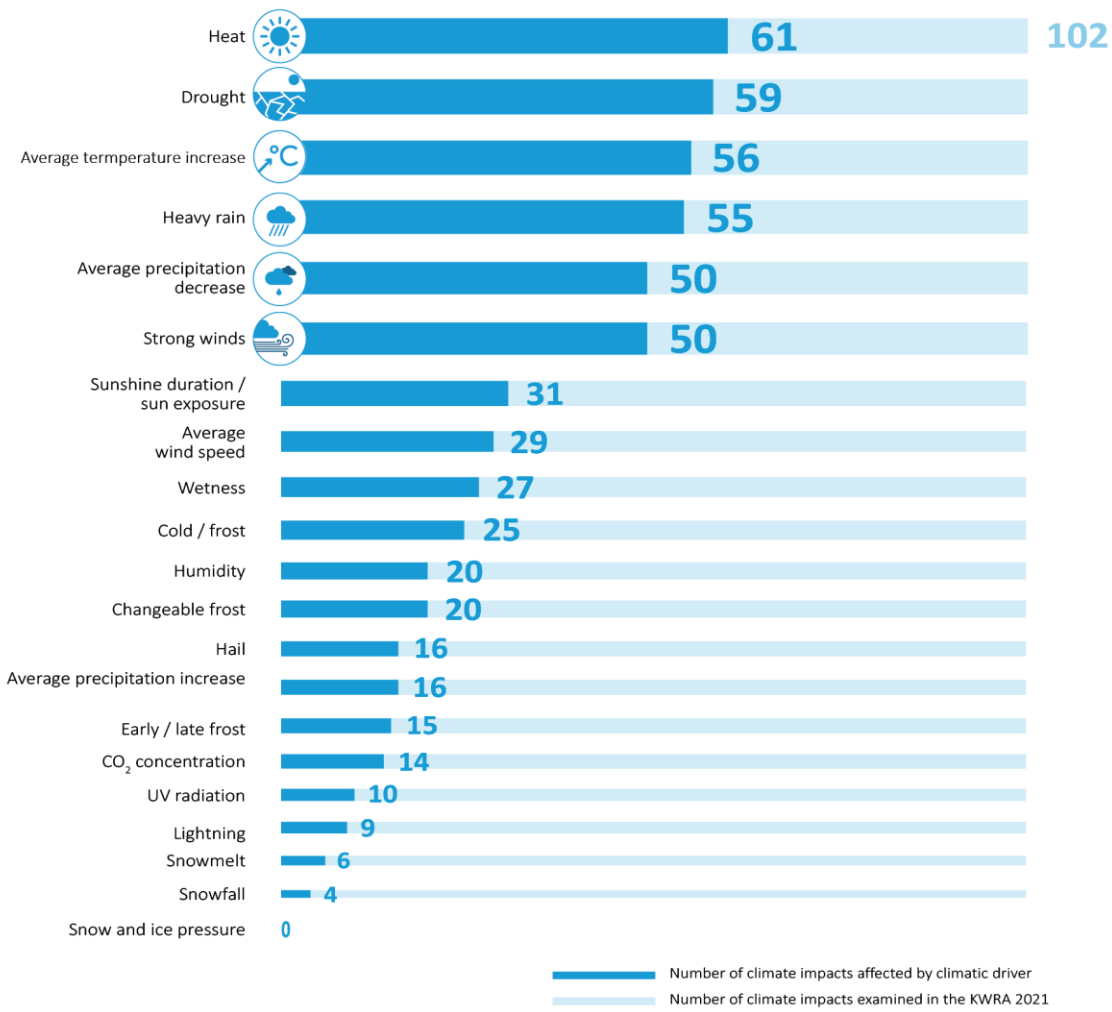
Cross-field assessment

In addition to the overall consideration of the climate risks without adaptation, a cross-field assessment of the climate drivers, sensitivity factors, certainties and interactions of the climate impacts of the 13 action fields was carried out.

The aim of the evaluation of the climate drivers was to identify those drivers that influence a particularly large number of climatic impacts, climatic impacts with high climatic risks, or certain groups of climatic impacts (e.g. climatic impacts closely related to the economy or natural systems).

The assessment revealed that the six climate drivers – average rise in temperature, heat, drought, heavy rain, average decrease in precipitation and strong wind – influence a majority of the 102 examined climate impacts. This identification of the primary climate drivers seems robust, as it does not change even when considering various sub-aspects such as climate impacts with high climate risks or protected assets. When looking at the high climate risks, however, there is a higher relevance of the climate drivers drought and average decrease in precipitation compared to the consideration of the total amount of all climate impacts.

Figure 6: Number of all negatively influenced climate impacts per climatic driver



Source: adelphi

Climate impacts in the environment category are particularly often influenced by drought. They are also exposed to an above-average number of climate drivers and are therefore often affected by climate change. The results of the assessment also show that gradually changing climate elements, such as the rise in temperature, are just as relevant for climate effects as extreme events.

In addition to climate drivers, sensitivity factors such as the intensity of use of soils, the degree of sealing, the species composition of ecosystems or socio-demographic structures are usually the most important components for the development of climate impacts. In the KWRA 2021, a cross-comparison took place in order to identify which sensitivity factors or groups of sensitivity factors are particularly relevant and what can be derived from the consideration of sensitivity factors for adaptation to climate change.

The results show that the sensitivity of the systems affected by climate change is very heterogeneous and depends on the system itself and on the climatic driver. There are therefore a large number of different sensitivity factors. Certain sensitivity factors, especially those that can be assigned to land and water use, occur more frequently in some action fields. They will play a larger role in the success of adaptation to climate change. Cross-field approaches are potentially important here.

Most of the sensitivity factors relate to the use of and stress on natural resources, especially water and land. With a view to adapting to climate change, increased protection of natural resources from anthropogenic overloading or overuse is central.

The cross-field assessment of the certainty highlights climate impacts and action fields with particularly high or low certainty as well as changes to the level of certainty between the observed time periods. This made it possible to identify climate impacts and action fields in which there is still a need for further research due to the low level of certainty or in which the identified climate risks are still subject to high uncertainties and should therefore be interpreted carefully.

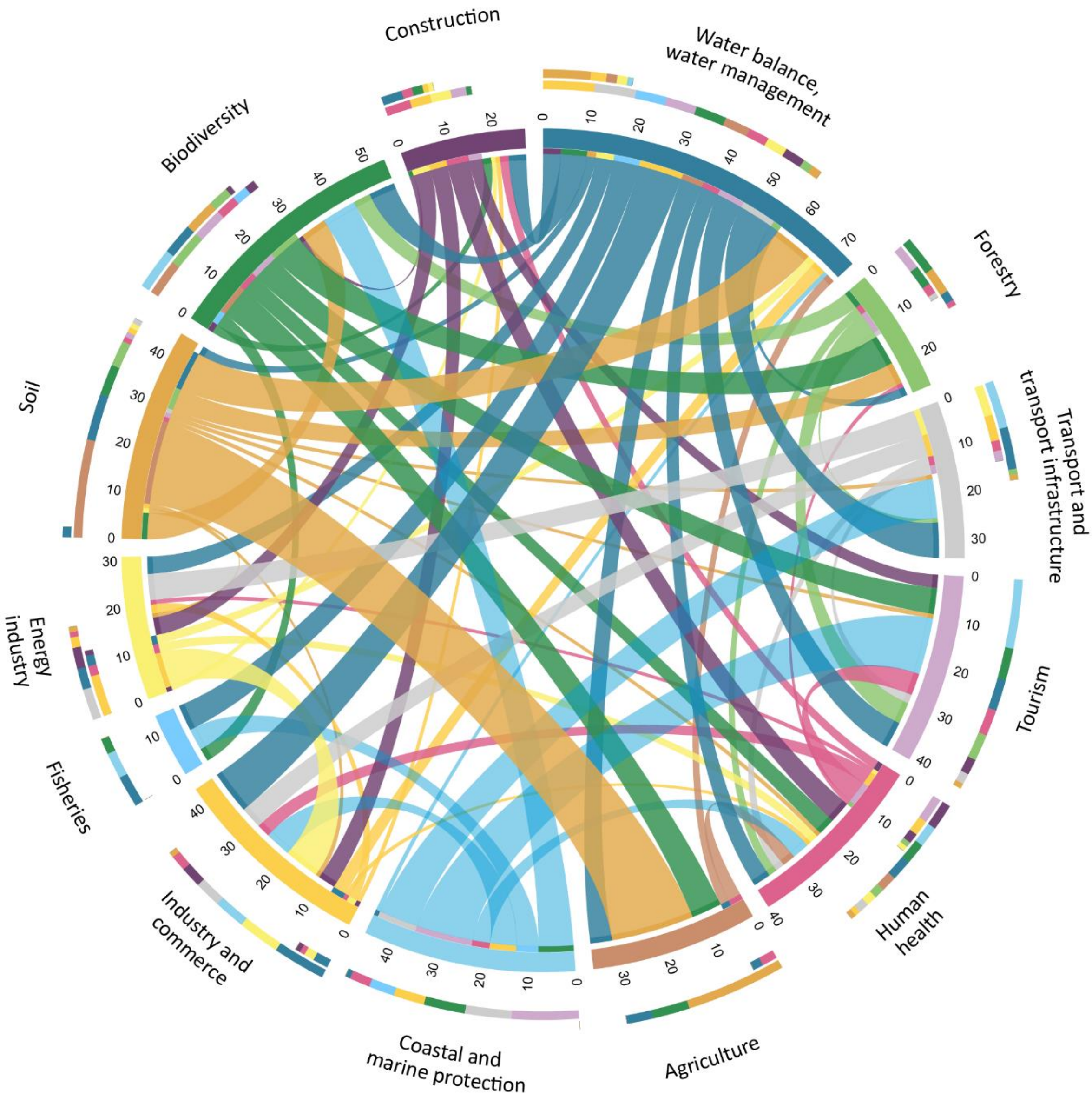
The average degree of certainty in the assessment of the climate risks is, based on the "mid-century" period, medium and, based on the "end of the century" period, low. The assessments of climate risks in this way appear to be more robust for the near future, although there are also uncertainties here.

Very little too little certainty in the assessment can mostly be found in the case of climate risks with complex causal relationships and/or a high number of socio-economic influencing factors. There is a particular need for further research here. Climate risks in the action fields "soil" and "water balance, water management" show, on average, comparatively low levels of certainty, as they are often characterised by many influencing factors and complex, sometimes very dynamic interrelationships. This increases the uncertainties in the assessments of the climate risks in these action fields.

On the other hand, there is a high degree of certainty with regard to the assessments of the climate risks in the action fields "agriculture" and "construction", because a comparatively good level of knowledge exists with regard to possible climate impacts. Climate impacts with high-rated climate risks tend to have a higher degree of certainty in the assessment. This indicates, especially for the middle of the century, a solid knowledge base as a basis for possible adaptation.

In addition to the previously listed cross-field aspects, the links between the action fields and climate impacts were also examined. If the consequences of climate change have negative effects on a climate impact, this often has an indirect effect on other downstream climate impacts as well. The evaluation of the interactions shows which climate impacts and aggregated action fields have an impact on a particularly large number of other climate impacts or action fields (outgoing interactions) or which, conversely, are influenced by a particularly large number (incoming interactions). A total of 257 interactions were identified between the 102 climate impacts of the 13 action fields (Figure 7).

Figure 7: Interactions between the action fields



Note: the graphic shows the outgoing and incoming interactions between the 13 action fields. The coloured bars of the innermost circle show the colour of the outgoing interactions of the respective action field (for example light brown for the soil action field). The thickness of the connections within the innermost circle stands for the number of interactions which, starting from one action field, have an effect on another action field. The exact number of incoming impacts for an action field is shown in the outermost bar. The inner bars next to it show the number of outgoing effects of the respective action field, for example the "coastal and marine protection" action field only has outgoing interactions and the "tourism" action field only has incoming interactions.
Source: adelphi

Outgoing interactions can be found above all in natural systems and resources in the action fields "water balance, water management", "coastal and marine protection", "soil" and "biodiversity". The climate impact "flood" shows the most outgoing interactions. Incoming interactions relate in particular to economic systems that use nature, infrastructures and buildings as well as people and social systems ("tourism", "industry and commerce", "agriculture" and "human health"). The climate impact "damage to tourist infrastructures and business interruptions" is influenced by most other climate impacts, which illustrates their dependence on activities in other action fields, including adaptation.

The action fields with a relatively large number of outgoing interactions are part of the water and land clusters, which will be particularly hard hit by climate change in the future. Under certain circumstances, this can trigger cascading effects in a large number of the associated climate impacts and action fields in the economy, infrastructure and health clusters.

If one considers the high climate risks alone, most of the interactions exist in the field of "biodiversity". The many incoming interactions here indicate the broad threat posed by climate change. The climate impact "shift of areas and decline of stocks" occupies a central position with many outgoing and incoming interactions.

In urban areas, there seems to be a close link among the interactions between the climate impacts "heat load", "demand for cooling energy" and "urban climate/heat islands" and, as a result, even a self-reinforcing feedback loop.

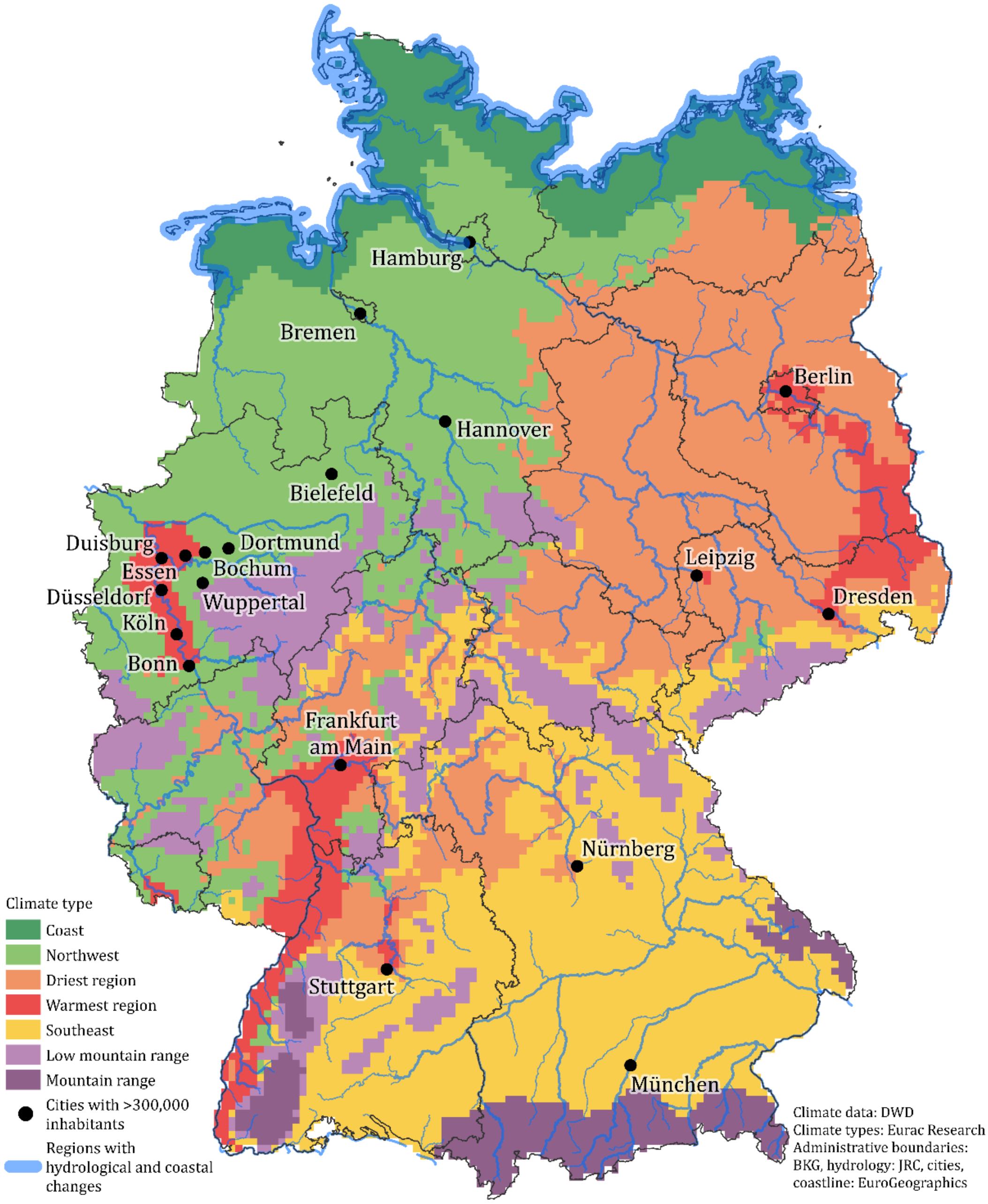
Evaluation of spatial patterns

As part of the evaluation of spatial patterns, maps were generated that divide Germany into homogeneous climate areas and show how the climate can change across multiple climate indicators in the future. For this purpose, climate area types[18] were calculated for the reference period (1971 to 2000), the middle of the century (2031 to 2060) and the end of the century (2071 to 2100).

The calculation of the climatic area types using cluster analysis resulted in the subdivision into seven climate area types (Figure 8). In order to describe the climate of the reference period for each cluster and identify the most relevant indicators for each cluster, the average value of all grid cells within a cluster was determined for each indicator. According to the average values of the indicators, the geographical location and the topography, names were assigned to the seven clusters:

[18] With regard to their climate, climate area types are relatively homogeneous, separate areas that have been identified by means of a cluster analysis.

Figure 8: Map of the seven climate area types as a result of the k-means cluster analysis of the 14 climate indicators for the reference period (1971 to 2000)



Source: Eurac Research

- For the climate of the "coasts", a comparatively small rise in temperature is to be expected – which will lead to fewer frost days, and low average changes in precipitation – but significantly more days of heavy rain, with a tendency towards wetter winters.
- Even in the moderate climate of the "northwest" there will be a comparatively moderate rise in temperature and fewer days of frost, but with significantly more frequent temperature extremes than on the coast. As on the coast, the number of frost days decreases and the number of heavy rain days increases.
- The "driest region", to which large parts of eastern Germany and parts of central Germany belong, will remain the driest in Germany in the future. Nevertheless, the days of heavy rain increase. The warming and change in precipitation are within the German

average. The number of hot days and tropical nights are increasing at an above-average rate.

- The "warmest region", mainly to be found in the west and the far east of Germany, has the highest average temperatures and most hot days and tropical nights in Germany. For this region, the greatest increase is to be expected on hot days and tropical nights. At the same time, the average precipitation there can increase relatively sharply in winter.
- The climate of the "southeast", which stretches from Baden-Württemberg to Saxony, is expected to warm up the most in the future; there will be significantly more hot days. In summer, decreasing precipitation and more frequent dry periods can also be expected.
- In the area of the cool, temperate climate of the "low mountain range", precipitation in winter and year-round heavy rain days may increase significantly in the future, while precipitation drops off sharply in summer and the number of dry days increases.
- For the climate of the "mountain range", an increase in dry days in summer and an increase winter precipitation is forecast, which will then increasingly fall as rain due to the higher temperatures, not as snow. Heavy rain days can also increase at an above average rate, while frost days decrease at an above average rate. The absolute average warming and the relative increase in hot days are likely to be greatest here.

The greatest changes across all climatic area types towards the middle of the century (absolute values and relative changes) can be found in the average precipitation in winter, in the number of hot days, tropical nights and frost days. As in the middle of the century, the greatest overall change values for the end of the century can be found in the number of hot days and tropical nights as well as frost days.

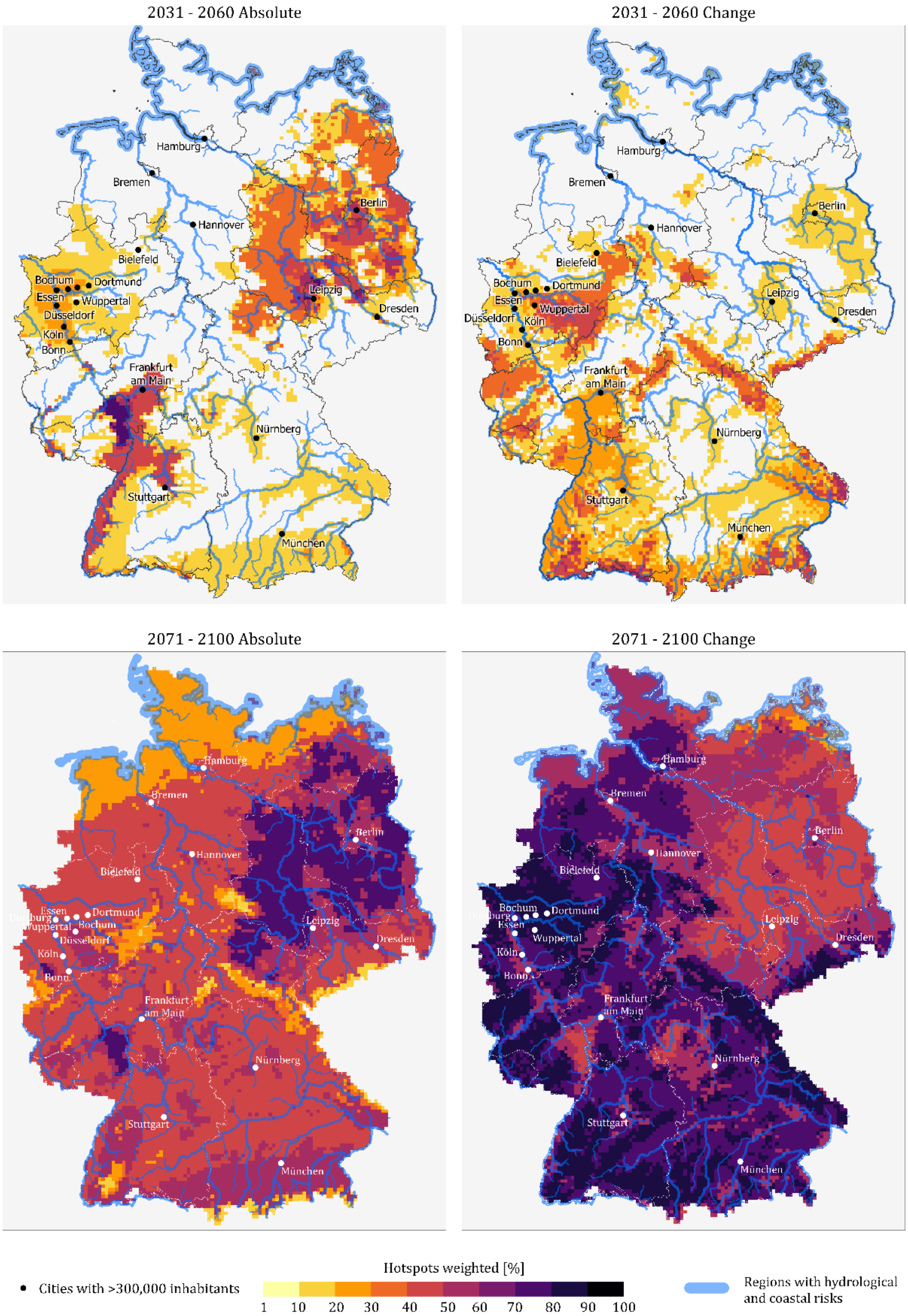
In addition to the analysis of the climate area types, so-called climatic hotspot maps were created. These map the areas in Germany in which individual climate indicators show particularly high values or particularly strong changes. Weighted, aggregated climatic hotspot maps show the regions in Germany that are particularly affected by climate change as a result of high climatic extremes or major climatic changes. It should be emphasized that only meteorological variables were included in these analyses. In addition, the river valleys can be affected by floods, and the dangers on the coast from rising sea levels will increase significantly in the second half of the 21st century.

In accordance with the cross-field assessment, the hotspot analysis used those climate drivers that occur particularly frequently in the case of high climate risks, with the exception of strong winds, as there are no climate projections for these that reveal a robust change signal. The other five main climate drivers (heat, drought, average temperature rise, average decrease in precipitation, heavy rain) were analysed based on indicators for which the corresponding calculations by the German Meteorological Service were available.

In order to identify hotspots across all selected climate drivers, hotspot maps of the individual climate drivers were aggregated and weighted. For this purpose, the climate drivers were weighted according to the averaged evaluations of the influenced climate risks for the three time periods, present, middle and end of the century.

The results show that climatic hotspots are located in the south, south-west and east of Germany (Figure 9). Various urban agglomeration areas are clearly affected. Towards the end of the century, the climatic hotspots become much more intense and expand considerably. A particularly large number of climatic hotspot regions can then be found in southern Germany and in the west, but in fact the entire federal territory is affected.

Figure 9: Weighted aggregated climatic hotspots of the six climate indicators for the middle and end of the century; absolute and change values



Left (absolute values): regions that could be affected by a particularly large number of climatic extremes; right (change values): regions that could be affected by particularly high changes in climate parameters. 100 percent means maximum applicability, i.e. exceeding the threshold values for all climatic parameters considered. The climate parameters high average annual temperature, number of hot days, number of tropical nights, low annual precipitation, number of dry days, days with heavy rain as well as the significance that these climate parameters have for all investigated climate effects were taken into account. Data basis: 85th percentile of the prepared DWD reference ensemble (Brienen et al. 2020) for the RCP8.5 scenario of the IPCC AR5 (IPCC 2013).

Source: Eurac Research

Overall view of climate risks with adaptation

The technical analysis of the adaptive capacity was carried out for 33 selected climate risks and for all 13 action fields based on the assessment of the effectiveness of the selected adaptation measures (APA III) and the more far-reaching adaptation. The analysis shows how much individual climate risks can be reduced by the APAIII+ measures, where there is a need for more far-reaching adaptation and where there are still high climate risks even with more far-reaching adaptation.

In the period from 2020 to 2030 and also in the period thereafter, the APAIII+ measures, which take into account the adaptation instruments of the federal government formulated in APA III and some other planned adaptation measures, only have a low potential for reducing climate risks without adaptation in some cases. There are several reasons for this:

1. The adaptation period for the selected climate risks is almost always classified as medium to long, which means that it will take significantly more than ten years to effectively reduce the climate risks over a large area in Germany.
2. Climate adaptation is a joint task that requires coordinated action at all governmental and non-governmental levels in order to achieve a climate-resilient society. In the case of many climate impacts, the federal government is only responsible for setting the political framework. The main actors and essential levels for implementation are the federal states, municipalities and civil society.
3. The adaptation measures selected by the federal government often include soft instruments and measures (e.g. for research, communication and cooperation); these provide a critical foundation for effective adaptation, but are insufficient for an effective reduction of the climate risk and must be taken up by other actors.
4. Given the advances in knowledge, the KWRA 2021 analyses more climate impacts and assigns a higher risk in some cases than the vulnerability analysis from 2015. This progress in knowledge is not yet reflected in the APA III, as the APAIII+ measures there were – logically – linked to the VA 2015. Therefore, some of the selected climate risks were hardly addressed in the APA III.

There was no consideration of the overall adaptation potential for the reduction of climate risks through measures already adopted or planned by the federal states and municipalities.

In the optimistic case at the action field level, the assessment results for the middle of the century after implementation of the APAIII+ measures show low or low-medium residual risks and, assuming more far-reaching adaptation in all action fields, low residual risks.

In the optimistic case, it is almost always expected at the level of the individual climate impacts that, by 2060, the climate risks will either not increase compared to the present without adaptation or that the increase can be compensated for by the APAIII+ measures so that the residual risks are not higher than the climate risks without adaptation in the current period. In many cases, once the APAIII+ measures take effect, the situation may even be better than the current one (overcompensation through APAIII+ measures). This can be justified by the longer period until the selected adaptation measures take effect, as well as a higher risk reduction than in the period from 2020 to 2030. If more extensive adaptation by 2060 is taken into account, largely low climate risks are expected in the optimistic case.

In the pessimistic case, higher residual risks are expected than in the optimistic case in almost all action fields after the APAIII+ measures have been implemented. As early as the middle of the century, the climate risks could remain high after the adaptation measures in the action fields "agriculture" and "forestry". Medium-high residual risks may remain in the "biodiversity" action field and in the "fisheries", "water balance, water management" and "coastal and marine protection" action fields. These relatively high residual risks show that natural systems or systems that use natural resources would not only be particularly negatively affected by a pessimistic combination of scenarios, but that more far-reaching adaptation would also be necessary. In almost all action fields, the residual risks can be reduced through more far-reaching measures. As a result of more far-reaching adaptation, the residual risks can be significantly reduced in the pessimistic case, especially in the action fields "agriculture" and "industry and commerce". On the other hand, in the action fields "fisheries" and "forestry", medium-high residual risks are expected even after more far-reaching adaptation in the pessimistic case

Table 32: Climate risks with adaptation at the level of the action fields

Action field	Climate risks without Adaptation			Climate risks with adaptation					Certainty of evaluation (climate risks with adaptation)	
				with APAIII+ measures			with more far-reaching adaptation			
	Present	Middle of the century		2020-2030	Middle of the century				2020-2030	Middle of the century
		Optimistic	Pessimistic		Optimistic	Pessimistic	Optimistic	Pessimistic		
Biodiversity	low	medium	medium-high	low	low-medium	medium-high	low	medium	medium	low
Soil	low medium	low-medium	medium-high	low-medium	low	medium	low	low-medium	medium	low
Agriculture	medium	medium	high	medium	low-medium	high	low	medium	medium	medium
Forestry	medium	medium	high	medium	low-medium	high	low	medium-high	medium	low
Fisheries	low medium	medium	high	low-medium	low-medium	medium-high	low	medium-high	medium	low
Coastal and marine protection	medium	medium	high	low-medium	low-medium	medium-high	low	medium	medium	medium
Water balance, water management	medium	medium	high	low-medium	low-medium	medium-high	low	medium	medium	low
Construction	medium	medium	medium-high	low-medium	low-medium	medium	low	low-medium	medium	low
Energy industry	low	low	low	low	low	low	low	low	medium	medium
Transport, transport infrastructure	low medium	low	medium	low	low	low-medium	low	low	medium	low
Industry and commerce	medium	low	medium	low-medium	low	medium	low	low	medium	low
Tourism	low	low	medium	low	low	medium	low	low-medium	low	very low
Human health	medium	medium	high	low-medium	low	medium	low	medium	medium	low

In the pessimistic case, it is also evident that, at the level of the climate impacts for the period up to 2060, the APAIII+ measures can reduce many climate risks (in some cases significantly). Nevertheless, the majority of the expert assessments result in medium-high and high climate risks after implementation of the selected adaptation measures. One reason for this is the significant increase in climate risks assumed for the pessimistic case without adaptation as a result of stronger climate change (compared to the current period). Another reason is that, at the same time, this stronger climate change limits the effectiveness of adaptation measures in many cases. The effectiveness of adaptation measures therefore also depends on the severity of climate change that the measure encounters.

In the pessimistic case, more far-reaching adaptation could often reduce the climate risks more strongly than adaptation through the APAIII+ measures. Particularly in the action fields “agriculture” and “coastal and marine protection”, with individual climate impacts in the action field “soil” (wind erosion, water shortage in the soil) as well as with almost all climate impacts related to infrastructure and in the action field “human health”, the climate risks that can be reduced through more far-reaching adaptation can be significantly lower than the climate risks without adaptation. In contrast, high residual risks are expected in spite of more far-reaching adaptation for climate impacts in which heat and drought damage play a role (for example pests in forestry) or for climate impacts in complex natural systems (for example in the action field “fisheries”, for climate impacts “groundwater level and groundwater quality” and “spread of invasive species”). In the case of these climate impacts, adaptation measures, including more far-reaching action, can only be applied to subsystems or areas. They cannot fully affect the entire dynamics of the system. The medium-high to high residual risks of many climate impacts, even after adaptation in the pessimistic case, indicate that adaptation is more effective in the case of weak climate change, as in the optimistic case, than in the case of strong climate change. In this way, they indicate the need for climate protection measures for effective adaptation.

In the case of three climate impacts in the action fields “biodiversity” and “soil”, adaptation can come up against absolute limits of adaptation due to a lack of possibilities or the physical load limits of organisms. In the case of other climate impacts in the land and water clusters, transformative approaches are likely to be required in the pessimistic case in order to be able to reduce the climate risks to medium or lower after adaptation.

Particularly in areas in which climate risks cannot or can hardly be reduced even through more far-reaching adaptation, for example in natural systems such as forests, soils, terrestrial or aquatic ecosystems, it is advisable to minimise their impairment as a result of anthropogenic (over)use to increase the resilience of these systems.

Identification and characterisation of the needs for action

Determining a need for action shows where action is required in the future and what that need might look like.[19] No specific adaptation measures are proposed, but statements are made about the potential for action with regard to adaptation dimensions or instrument categories.

In order to analyse the needs for action – similar to the VA 2015 – the first step was to prioritise on the basis of the statements on the climate risks without adaptation and the statements on the urgency of the adaptation based on the assessment of the adaptation period.

There is a very urgent need for action (Table 33) when the climate risk is already high. The need for action is also very urgent if the climate risk is high in the middle of the century and adaptation measures must start now due to a medium or long adaptation period. The same applies to the end of the century (high climate risk at the end of the century and long adaptation period).

[19] No adaptation options are seen in the so-called purely upstream climate impacts at the level of physical changes in natural systems. This includes, for example, the rise in sea level itself. The purely upstream climate impacts were therefore only assessed with regard to the climate risk without adaptation.

A total of 31 climate impacts with a very urgent need for action were identified. In the event of severe climate change, there is a threat of high climate risks for these impacts, since the adaptation of the threatened systems takes a long time. They can be summarised in the following areas:

- Consequences of extreme heat on health, especially in cities, primarily along the Rhine and Spree, the warmest regions in Germany.
- Consequences of drought and low water (often combined with heat) on all water-using and water-dependent systems; rural regions are particularly affected, primarily in the dry regions in the east and in the western centre of Germany, but also industrial locations.
- Consequences of heavy rain, flash floods and floods, especially for infrastructures and buildings, regions that are primarily affected are settlements near bodies of water and in narrow valleys in the low mountain range.
- Consequences of the gradual rise in temperature, such as the rise in sea level, on natural and nature-utilising systems, especially on the coasts, in the waterways, in rural areas and in the mountains.

In addition, urgent action requirements are taken into account (Table 34): There is an urgent need for action if the climate risk in the present is medium or if it will be either medium by the middle of the century and a medium or long adaptation period is to be expected, or if it will be high and a short adaptation period is to be expected. There is also an urgent need for action if, with a view to the end of the century, a medium climate risk and a long adaptation period are expected or if a high climate risk and a medium adaptation period are expected.

Table 33: Very urgent need for action (31)

Action field	Climate impact
Biodiversity	Spread of invasive species
	Damage to water-bound habitats and wetlands
	Damage to forests
Soil	Soil erosion by water
	Lack of water in the soil
	Wind erosion
	Production function
Agriculture	Abiotic stress (plants)
	Loss of yields
Forestry	Heat and drought stress
	Pest/disease stress
	Forest fire risk
	Utility: Timber yield
Fisheries	Distribution of fish species in rivers
Coastal and marine protection	Water quality and groundwater salinization
	Natural spatial changes on coasts
	Damage or destruction of settlements and infrastructure on the coast
	Overloading of drainage facilities in areas at risk of flooding
Water balance, water management	Water temperature and ice cover and biological water quality
	Overloading or failure of flood protection systems

Action field	Climate impact
	Flash floods (failure of drainage facilities and flood protection systems)
	Groundwater level and groundwater quality
Construction	Damage to buildings due to river flooding
	Vegetation in settlements
	Urban climate/heat islands
	Indoor climate
Transport, transport infra-structure	Navigability of inland waterways (low water)
Industry and commerce	Impairment of the movement of goods via waterways (inland)
Human health	Heat stress
	Allergic reactions due to aeroallergens of plant origin
	UV-related damage to health (especially skin cancer)

Table 34: Urgent need for action (23)

Action field	Climate impact
Biodiversity	Damage to coastal ecosystems
	Ecosystem services
	Shift in areas and decline in numbers
	Loss of genetic diversity
Soil	Landslides and mudslides
Forestry	Damage from windthrow
	Utility: recreation
Fisheries	Decoupling of food relationships in the Baltic Sea
Coastal and marine pro-tection	Increased stress on or failure of coastal protection systems
Water balance, water management	Lack of irrigation water
	Chemical water quality
	Restrictions on the functionality of sewer networks and receiving waters and sewage treatment plants
Construction	Damage to buildings due to heavy rain
Transport, transport infra-structure	Damage/obstacles to roads and railways (flood)
	Damage/obstacles to roads and railways (gravitational mass movements)
	Damage to traffic control systems, overhead lines and power supply systems
Industry and commerce	Impairment of the supply of raw materials and intermediate products (interna-tional)
	Impairment of the international transport of goods
	Water requirements
	Reduced performance of employees
Tourism	Economic opportunities and risks for the tourism industry
Human health	Respiratory issues (due to air pollution)
	Effects on the healthcare system

The adaptation capacities and the residual risks were only examined for the very urgent needs for action, which vary depending on the optimistic and pessimistic case and the extent of the ad-aptation (adopted measures/more far-reaching measures). On this basis as well as the further analysis of the adaptive capacities and the statements on certainties in the assessments, additional statements can be made about the very urgent needs for action that address the following questions:

- In the optimistic and in the pessimistic cases, are the APAIII+ measures sufficient to reduce the residual risk to a specific, set level?
- In the optimistic and in the pessimistic cases, are the more far-reaching measures sufficient to reduce the residual risk to a specific, set level?
- How certain are the statements?

On the basis of these questions, the climate impacts with very urgent needs for action can be divided into five groups:

I. **Implementation:** In this category, the APAIII+ measures are sufficient to reduce the climate risk by adapting to a previously determined residual risk. In the case of climate impacts in this group, it is particularly important to ensure that existing plans are implemented. This can aim, for example, at ensuring the financing of the measures, carrying out ongoing monitoring or clarifying that actors beyond the federal level are sufficiently involved in the implementation of the measures.

II. **Development:** In this category, the APAIII+ measures are not sufficient to achieve the targeted residual risk; additional, more far-reaching measures must be considered. In addition to implementing the APAIII+ measures, this is primarily a matter of developing and implementing new measures. The more far-reaching measures should be taken into account in adaptation planning, even if they may be linked to (significant) additional costs and only bring benefits in the event of climate change (i.e. high regret).

III. **Development under uncertainty:** In this group of climate impacts with very urgent needs for action, the certainty in the assessment of the residual risk is low; further research is recommended for the development and before taking more far-reaching measures. At the same time, it is necessary to ensure that the APAIII+ measures are implemented.

IV. **Innovation:** In the case of climate impacts with very urgent needs for action from this group, it is relatively certain that the goal of adaptation, i.e. reducing the residual risk to a specific, predetermined level, will not be achieved even with the APAIII+ measures or more far-reaching action. As far as possible, more extensive adaptation should be considered here. To this end, it is necessary to advance research on adaptation and to start a professional and, if necessary, social discourse on the necessity of such extensive adaptation measures and the necessary changes in the framework conditions.

V. **Innovation under uncertainty:** There is still little knowledge available for climate impacts with very urgent action requirements that can be assigned to this category. However, it appears that the goal of adaptation cannot be achieved. Further intensive research, both with a view to possible more far-reaching adaptation measures and with a view to extensive adaptation, appears to make sense. It is also advisable to implement the APAIII+ measures and include more far-reaching measures in the adaptation planning.

Which climate impact is classified into which group depends on which residual risk is to be accepted in the optimistic or in the pessimistic case, as well as the degree of certainty that is accepted in order to implement the adaptation measures without further research. As part of the investigation, the following (normatively set) specifications were used for classification purposes as an example:

- In the optimistic case, a low-medium residual risk should not be exceeded.
- In the pessimistic case, a medium residual risk should not be exceeded and
- The overall confidence threshold is set to medium. Climate impacts for which the value is higher fall into the groups with uncertainty.

On the basis of these specifications, four climate impacts from different action fields are assigned to the "Implementation" category, i.e. only a small proportion of all climate impacts with very urgent action requirements. Most of the climate impacts with very urgent needs for action can then be assigned to the "development" group; the more far-reaching adaptation has the potential to reduce the residual risks in accordance with the normative setting. However, a relatively high number of climate impacts (13) are also attributable to the groups "with uncertainty". Given the requirement set for overall certainty, there is still an obvious need for research here.

The more detailed analysis showed that the classification of the climate impacts is highly sensitive to changes in the accepted residual risk and the determination of the desired certainty.

In addition to this type of characterisation of the needs for action, there is a further qualification with a view to the potential for action in the six adaptation dimensions (knowledge; motivation and acceptance; technology and natural resources; financial resources; institutional structure and human resources; and legal framework and political strategies). The assessment of the adaptive capacity included an analysis of which adaptation dimensions come into play or can in principle come into play in the APAIII+ measures and in the more far-reaching adaptation.

The evaluation of this information reveals that the APAIII+ measures have a strong expression in the knowledge dimension (i.e. the generation of knowledge makes a contribution to the reduction of climate risks). Additional potential for action for more far-reaching adaptation exists above all in the dimensions of "motivation and acceptance", "legal framework and political strategies" and (partially) "technology and natural resources". With regard to technology and natural resources, there is potential for action primarily in the provision of natural resources and, in addition to the availability of water, the availability of land areas in particular is an important factor for adaptation. However, this also implies potential conflicts in the future implementation of adaptation measures.

Cross-sector analysis of the system areas

In order to gain further knowledge for adaptation planning, a cross-sector analysis of the climate impacts took place with a view to system areas. For this purpose, the individual climate impacts were assigned to five system areas.

- Natural systems and resources

"Natural systems and resources" such as groundwater, soils or ecosystems are very directly affected by climate change. The 30 climate impacts that can be assigned here are found primarily in the action fields "soil", "biodiversity", "water balance, water management" and "coastal and marine protection".

For a large number of natural systems – 60 percent of the climate impacts examined – we expect high climate risks by the middle of the century; the number will rise to 70 percent by the end of the century (Figure 10). In particular, the gradual rise in temperature, but also extremes such as heat and drought as well as potentially strong winds threaten the natural systems.

The selected adaptation measures are less effective with these systems than with the climate impacts of other systems. More far-reaching adaptation is therefore needed more. The adaptation period is mostly more than ten and sometimes more than 50 years, and is on average significantly longer than in the other system areas.

In the case of four investigated climate impacts from this area, the limits of adaptation are foreseeably exceeded because adaptation measures are generally not available. The need for more and more extensive adaptation is great, especially for the preservation of biodiversity and in the area of water and soil protection.

The combination of a long period of adaptation and high climate risks results in a large number (11) of very urgent needs for action in relative and absolute terms. There are also five urgent needs for action. If one subtracts the climate impacts for which there is no possibility of adaptation, it becomes apparent that, for almost all climate impacts for which adaptation would be possible, there are also needs action.

- Economic systems that use nature

“Economic systems that use nature” is the largest overarching area, with 31 climate impacts. Most of the climate impacts of this group originate from the action fields “agriculture”, “forestry” and “fisheries”, but there are also various other action fields.

The climate risks without adaptation are noticeably lower in this area than for the natural systems and resources, across all time periods and for both the optimistic and the pessimistic cases. Nevertheless, they are by no means insignificant. Almost a third of the climate impacts can have a high climate risk in the pessimistic case by the middle of the century; this number can rise to a good half by the end of the century. Drought stress, but also the gradual rise in temperature, play a role here.

Adaptation measures have already been initiated many times in this system area. The selected adaptation measures are likely to be significantly more effective than with “natural systems and resources”. The potential for more far-reaching adaptation measures is also fundamentally higher, but not above average when all system areas are considered as a whole. The average period of adaptation in this system area is the average of all climate impacts, but it varies widely.

With ten climate impacts that have very urgent needs for action, there are a particularly large number of instances in this system area, but in relative terms there are no more than in other system areas. There are also six climate impacts with urgent needs for action.

- Infrastructure and buildings

The 23 climate impacts in the “infrastructure and buildings” system area are primarily assigned to the action fields “transport, transport infrastructure”, “construction”, “energy industry” and “industry and commerce”. There are also others from different action fields, such as water management or coastal and marine protection.

The climate risks without adaptation in this area are significantly lower than the average of all climate impacts – across all time periods and for both cases (optimistic and pessimistic). Climate risks often arise in connection with heavy rain, floods and inundations and the associated undercutting and landslides. In addition, the heat and the rise in sea levels come into play here.

The trend towards lower climate risks is offset by a particularly high effectiveness of adaptation; whether climate change is stronger or weaker has very little influence here. For the present as well as for the middle of the century, and with a view to selected as well as more far-reaching measures in the pessimistic and in the optimistic cases, the possibilities of climate adaptation are relatively high compared to the other system areas.

With its seven very urgent needs for action, the area is in the average of all areas. The seven urgent needs for action, on the other hand, represent an above-average number.

- Economic systems remote from nature

"Economic systems remote from nature" form a relatively small area with seven climate impacts. Essentially, these come from the action field "industry and commerce"; in addition, there are climate impacts from "tourism" and "construction". Particularly relevant climate drivers include the gradual rise in temperature and climatic extremes (e.g. heat, heavy rain).

Overall, the climate risks in this system area are significantly lower than in the "infrastructures and buildings" system area and by far the lowest of all system areas. This applies across all time periods and in both of the cases under consideration (pessimistic and optimistic). Only one climate impact appears to be at high risk in the middle of the century with severe climate change and only two at the end of the century. No statement can be made on the adaptation potential for this system area, as only one climate impact was examined.

In view of the short adaptation period and the relatively low climate risks without adaptation, the need for action in this area is also low: there are no very urgent needs for action, and only two urgent ones.

- People and social systems

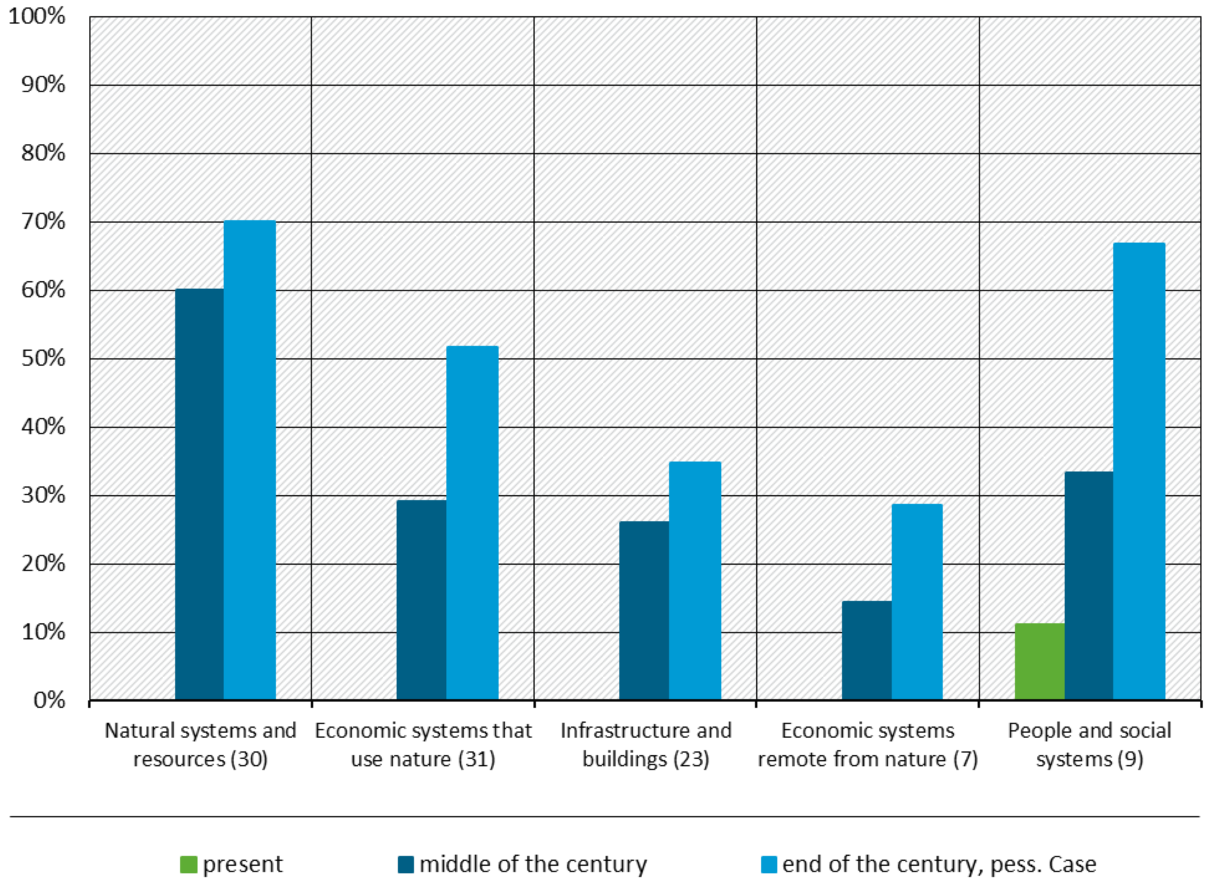
In addition to all ecological, technological and economic systems, climate change ultimately has direct effects on humans and the healthcare system. The corresponding system area has nine climate impacts, almost all of which belong to the "human health" action field.

By far the most significant climatic driver for this system area is heat. Other extreme weather events, in particular flash floods caused by heavy rain or storms, also play a role, as does the gradual rise in temperature.

The climate risk situation without adaptation appears to be unfavourable overall. Currently, the area has the highest risks of all system areas. Of all the climate impacts considered, "heat stress" is the only one rated as high for the present time. By the middle of the century, in the event of severe climate change, one third of the climate impacts in the system area can be associated with high risk. Towards the end of the century the number may rise sharply, to two thirds.

In view of only a few, appropriately examined climate effects, no valid statements can be made about the adaptation options in the entire system area. With three very urgent needs for action, the system area is within the average; the addition of three urgent needs for action, however, rates it significantly higher than the intersection of all system areas.

Figure 10: Percentage of the climate risks rated as high for the present time and the pessimistic case for the middle and end of the century based on the five systems



Note: the information in brackets corresponds to the number of climate impacts assigned to each system.

Source: adelphi

The analysis based on the different system areas enables various conclusions relevant to adaptation planning:

As can be seen from the previous statements, the system area “natural systems and resources” is more affected by climate change than the other system areas. At the same time, the adaptation period tends to be significantly longer and the effectiveness of adaptation measures is comparatively low. This situation is inherently unfavourable. It requires special attention due to the interdependence of the individual systems.

As is already visible from the analysis of the interactions, there is a relatively close connection between the individual climate impacts, and as a result, between action fields and system areas. These links are not consistent. The sorting according to system areas provides a very clear picture here: climate impacts from the system area “natural systems and resources” have outgoing interactions much more often; that is, they are upstream and act on downstream climate impacts in other system areas. This system area accounts for more than half of all outgoing interactions.

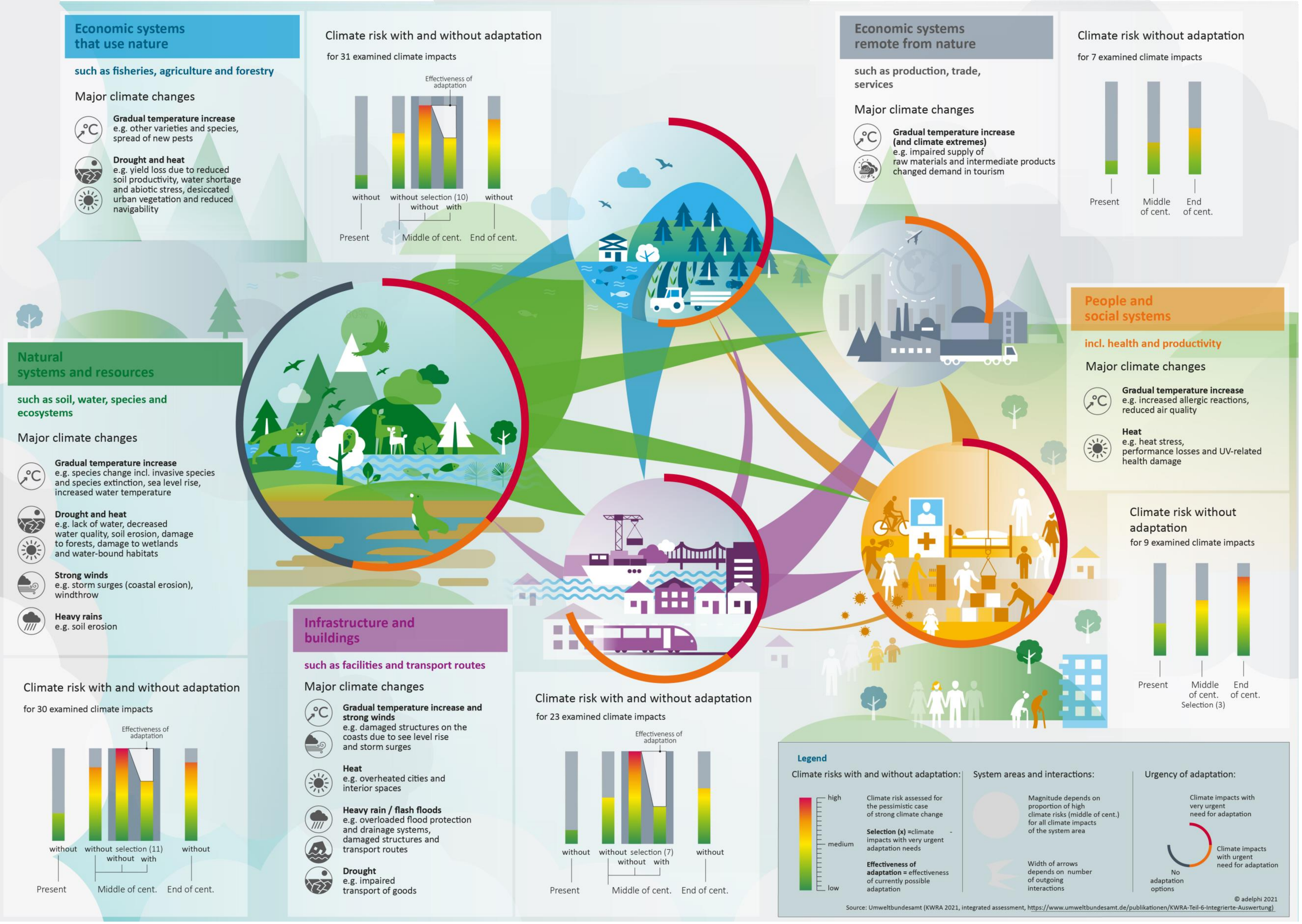
In some cases, the outgoing interactions are immediately noticeable for the downstream systems; in others cases, the corresponding effects will only really take effect after a delay, possibly many years later. If it is possible to limit the effects of climate change in the area of “natural systems and resources”; this can have positive effects on many climate impacts in other system areas and noticeably further the success of adaptation in those areas.

This statement is supported by the studies of the sensitivity factors. Here, too, it was shown that natural factors, such as land use or water use, are particularly important for the sensitivity of the affected systems in various action fields and with many climate impacts. The protection of these sensitivity factors or their positive influence in the direction of greater climate resilience has a positive effect in many ways.

For this reason, it appears to be significant to the adaptability of many affected systems to prevent future conflicts of objectives, especially in the use of water and land resources. In the course of climate change, both resources will be subject to increasing use in the future. This is already evident for water, but it will become even more apparent in the case of land resources in the future. Spatial planning will play an even more significant role here in the future.

Due to the effects described, there is a greater need for action in the area of “natural systems and resources”. This system area seems to play a central role when it comes to the successful implementation of climate adaptation. In addition to climate protection, the best option seems to be to strengthen the autonomous adaptability and the functional capabilities of the corresponding systems and to reduce their limitations. This requires relieving these systems from their current overuse by humans.

Figure 11: Climate risks of affected systems, interactions and urgency of adaptation



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