WPKS

Financial implications of climate change

Financing Climate Adaptation and Climate Resilience of Public Budgets

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Executive Summary

Climate change poses considerable financial and organisational challenges for Germany. This report analyses the current and future financing requirements for climate adaptation, the fiscal risks for public budgets and the options for prioritising adaptation measures.

Financing needs for climate adaptation (Chapter 2):

Different methods for estimating the financing needs of public budgets – in particular bottom-up analyses based on specific measures and sectors – show that considerable investments are necessary today to address growing climate risks. Bottom-up surveys point to particularly high adaptation costs in flood protection. This finding is consistent with the model-based analyses in this study, which identify coastal and inland flooding as major climate risks and key drivers of financing needs, followed by impacts on energy demand and heat effects on labour productivity and mortality.

The cross-cutting nature of climate adaptation makes it difficult to clearly allocate costs, as many measures address several objectives at once and are often intertwined with other areas of investment. Non-financial barriers such as lengthy planning processes, land use conflicts and administrative hurdles also hinder implementation. Despite considerable uncertainties in the data basis and methodology, it is clear that the investment requirement runs into the billions and will continue to rise. At the same time, there are key research needs: broader model-based coverage of impact channels that have received little attention to date, clearly defined adaptation scenarios with better baseline data, and assessments of packages of measures including ongoing maintenance costs.

Fiscal risks and financing (Chapter 3):

As discussed above, public budgets are under considerable strain due to climate change. This can be broken down into three factors: (1) rising expenditure on repairing damage caused by extreme weather events, (2) high investment requirements for preventive adaptation measures, and (3) potential revenue losses as a result of weakened economic performance – for example, due to damaged infrastructure, loss of income and lower labour productivity.
The existing system of financial equalisation, support programmes and special funds is not sufficient to close the financing gap. Financially weak municipalities in particular are overwhelmed by the complexity and short-term nature of existing programmes. New, innovative financing instruments are being discussed, but their effectiveness and scalability have not yet been sufficiently researched. There is a great need for an advanced, integrated financial architecture that combines existing and new approaches in a meaningful way.

Prioritisation and evaluation of adaptation measures (Chapter 4):

Given limited resources, the prioritisation of adaptation measures is crucial. Ex-ante assessment procedures – in particular cost-benefit analyses, cost-effectiveness analyses and multi-criteria analyses – support a structured and transparent selection process. The selection and weighting of criteria is usually context-specific and participatory. However, practical implementation is hampered by a lack of data, uncertainties in impact assessment and the complexity of the procedures. Practical, low-threshold tools and exchange formats are necessary for broader application; in addition, there is a considerable need for research into the further development of methods, such as for assessing and integrating the costs of inaction or for the comprehensive evaluation of policy mixes.

Conclusion:

Overall, it is clear that adaptation to climate change requires considerable additional investment and a fundamental rethinking of financing and governance mechanisms. The uncertainties in estimating needs and the challenges in implementation make it clear that continuous research, methodological innovation and close integration of policy, administration and practice are essential. Only in this way

can resilience to the consequences of climate change be strengthened and effective, sustainable adaptation be enabled.

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List of abbreviations

ABK	Adjustment requirement component
ABM	Adaptation Benefits Mechanism
ABS	Asset-backed securities
ACCREU	Assessing Climate Change Risk in Europe
AFK	Adaptation to the consequences of climate change
AIIB	Asian Infrastructure Investment Bank
ANK	Action Programme for Natural Climate Protection
APA	Action Plan Adaptation
APA IV	Action Plan Adaptation IV
AP	Work package
ARL	Academy for Spatial Development in the Leibniz Association
BaFin	Federal Financial Supervisory Authority
BAI	Federal Association for Alternative Investments
BBSR	Federal Institute for Research on Building, Urban Affairs and Spatial Development
BCR	Benefit-cost ratio
BEZ	Federal supplementary grants
BMF	Federal Ministry of Finance
BMI	Federal Ministry of the Interior
BMK	Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology (Austria)
BMEL	Federal Ministry of Food and Agriculture
BMUKN	Federal Ministry for the Environment, Climate Protection, Nature Conservation and Nuclear Safety
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
BMV	Federal Ministry of Transport
BMVBS	Federal Ministry of Transport, Building and Urban Development
BMWE	Federal Ministry for Economic Affairs and Energy
BMWK	Federal Ministry for Economic Affairs and Climate Protection
BMWSB	Federal Ministry for Housing, Urban Development and Construction
BNW	Authority network
bpb	Federal Agency for Civic Education
CAT bonds	Catastrophe bonds
CatNat	Catastrophes Naturelles (natural disasters)
CBA	Cost-benefit analysis
CCI	Child Cyclone Index
CCR	Central Reinsurance Fund
CCRIF	Caribbean Catastrophe Risk Insurance Facility
CEA	Cost-effectiveness analysis
CGE	Computable General Equilibrium (model)
CGDD	General Commission for Sustainable Development

CLO	Collateralised Loan Obligation
CMIP6	Coupled Model Intercomparison Project Phase 6
CO2	Carbon dioxide
CRDCs	Climate-Resilient Debt Clauses
DAS	German Adaptation Strategy
Difu	German Institute for Urban Studies
DIVA	Dynamic Interactive Vulnerability Assessment
DM	German mark
DStGB	German Association of Towns and Municipalities
DWD	German Weather Service
EAD	Expected Annual Damage
EBA	European Banking Authority
EBRD	European Bank for Reconstruction and Development
ECB	European Central Bank
EEA	European Environment Agency
ERDF	European Regional Development Fund
EIB	European Investment Bank
EIOPA	European Insurance and Occupational Pensions Authority
EmBArk	Development and climate adaptation: socio-ecological barriers and their significance for climate damage and losses
EnEV	Energy Saving Ordinance
EPA	Environmental Protection Agency
ERI	Economic Resilience Index
ESG	Environmental, Social, and Governance
ECB	European Central Bank
FAG	Financial Equalisation Act
FiFo	Institute for Public Finance Research at the University of Cologne
GAK	Joint Task "Improvement of Agricultural Structures and Coastal Protection"
GBP	Pound sterling
GCM	General Circulation Models
GDP	Gross domestic product
GDV	German Insurance Association
GFG	Local Government Finance Act
GG	Basic Law
GLOFRI S	Global Flood Risk Information System
GRW	Joint Task "Improvement of Regional Economic Structures"
GTAP	Global Trade Analysis Project
GWL	Global Warming Levels
HD35	Annual number of hot days with a maximum temperature above 35 °C
HLNUG	Hessian State Office for Nature Conservation, Environment and Geology
HWS	Flood protection
IAMs	Integrated Assessment Models
IAWAK	Information-based anticipatory water management-based adaptation to climate change

ICMA	International Capital Market Association
IDB	Inter-American Development Bank
IFC	International Finance Corporation
IHK	Chamber of Industry and Commerce
ILS	Insurance-Linked Securities
IMAA	Interministerial Working Group on Adaptation to the Consequences of Climate Change
INSEK	Integrated urban development concept
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
JTF	Just Transition Fund
K-CLOs	Municipal Climate Collateralised Loan Obligations
KAnG	Climate Adaptation Act
KAM	Municipal Climate Adaptation Manager
KF	Cohesion Fund
KfW	Kreditanstalt für Wiederaufbau
KFA	Municipal Financial Equalisation
KPF	Climate forecast factor
KRK	Climate risk component
KTF	Climate and Transformation Fund
KWRA	Climate Impact and Risk Analysis
LANUV	State Agency for Nature, Environment and Consumer Protection North Rhine-Westphalia
LBBW	Baden-Württemberg State Bank
LED	Light Emitting Diode
LISFLOOD	Flood model of the Joint Research Centre (JRC) of the European Commission
LUBW	State Agency for the Environment Baden-Württemberg
MCA	Multi-criteria analysis
MCII	Munich Climate Insurance Initiative
MKUEM	Ministry for Climate Protection, Environment, Energy and Mobility
MRIO	Multi-regional input-output (models)
MU	Ministry for the Environment, Energy and Climate Protection (Lower Saxony)
MWIKE	Ministry for Economic Affairs, Innovation, Climate Protection and Energy (North Rhine-Westphalia)
NAP	National Adaptation Plan
NAS	National Adaptation Strategy
NHWSP	National Flood Protection Programme
NIKO	Lower Saxony Competence Centre for Climate Change
ÖPNV	Local public transport
PACE	Property Assessed Clean Energy
PAGE	Policy Analysis of the Greenhouse Effect (Model)
PIK	Potsdam Institute for Climate Impact Research
PLANAK	Planning Committee for Agricultural Structures and Coastal Protection
RAT	Risk Analysis Tool
RCM	Regional Climate Models

RCP	Representative Concentration Pathways
RegioStaR	Regional statistical spatial typology
SEAR	Solidarity and Emergency Aid Reserve
SEK	Damage experience component
SenMVKU	Berlin Senate Department for Mobility, Transport, Climate Protection and Environment
SFDR	Sustainable Finance Disclosure Regulation
SGB	Social Security Code
SH	Schleswig-Holstein
SoBEZ	Special Needs Federal Supplementary Grants
SPV	Special purpose vehicle
SSP	Shared Socioeconomic Pathways
StA	Standing Committee
StMUV	Bavarian State Ministry for the Environment and Consumer Protection
StMWi	Bavarian State Ministry of Economic Affairs, Regional Development and Energy
TEN-T	Trans-European Transport Network
THW	Federal Agency for Technical Relief
TSI	True Sale International
UBA	Federal Environment Agency
UCITS	Undertakings for Collective Investment in Transferable Securities
UHI	Urban heat island effect
UMK	Conference of Environment Ministers
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
USD	US dollar
VAG	Insurance Supervision Act
VDB	Association of German Guarantee Banks
VKB	Bavarian Insurance Chamber
VKU	Association of Municipal Enterprises
WpHG	Securities Trading Act
WPKS	Science Platform for Climate Protection
WTW	Willis Towers Watson
ZEV	Centre for European Consumer Protection
ZKA	Centre for Climate Adaptation
ZUG	Future-Environment-Society
ZÜRS Geo	Zoning system for flood risk and assessment of environmental risks

1 Introduction

1.1 Background and objectives of the study

The increasing effects of climate change pose considerable challenges for Germany. Extreme weather events such as heat waves, heavy rainfall, droughts and floods are already causing considerable economic damage and require systematic adaptation of key infrastructure, public services and social processes. With the Climate Adaptation Act (KAnG;Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz 2023b) and the German Adaptation Strategy 2.0 (DAS 2.0;Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz 2024), Germany has laid important foundations for a coordinated approach.

Nevertheless, there remains considerable uncertainty regarding the actual financial requirements, sustainable financing and the prioritisation of adaptation measures. Despite clear objectives and commitments, both DAS 2.0 and KAnG leave the question of financing largely unanswered. Empirical studies show that the availability of financial resources for the implementation and maintenance of adaptation measures is considered extremely important. Local authorities that are not among the pioneers in climate policy are particularly dependent on external funding(Friedrich et al. 2024a). A comprehensive survey of local authorities confirms that a lack of human and financial resources are the most significant obstacles to the planning and implementation of climate adaptation measures. Of the 678 local authorities surveyed that are planning or have already implemented measures, 80% and 73% respectively cite these two factors as key barriers(Friedrich et al. 2024b).

The fiscal risks of climate change for public budgets are considerable and complex. They include rising expenditure on climate adaptation, disaster relief and repairing damage after extreme weather events, as well as potential revenue shortfalls due to climate-related economic disruptions. The temporal dimension of these risks makes it difficult to take them into account adequately in current budgetary policy.

To ensure that the limited budgetary resources for climate adaptation measures are used optimally, it is crucial to systematically evaluate existing measures in terms of their effectiveness and, based on this, prioritise promising approaches. Prioritisation does not necessarily mean that the measures and available funds will meet the entire adaptation need, but rather that the available financial resources will be used as effectively as possible. While the number of studies on the costs of climate change for the economy and society in Europe and Germany is steadily increasing, it remains difficult to produce reliable estimates of the investments needed for climate adaptation. Methodological uncertainties in defining and recording adaptation costs – for example, because climate adaptation is cross-sectoral and often embedded in larger investment projects – make it difficult to allocate funds according to effectiveness criteria. Accordingly, financing requirements are currently only available on a selective basis and with limited comparability. Against the backdrop of these challenges, the Science Platform Climate Protection (WPKS) awarded a research project to a consortium consisting of adelphi research gGmbH and the Wegener Centre at the University of Graz. This report presents the results of this research. It analyses the composition of climate adaptation financing needs in Germany, the methodological and practical challenges involved in cost estimation, and how the public sector – especially local authorities – can respond to growing demands. The report evaluates existing estimates of past and future adaptation expenditure in Germany and supplements these by applying international studies to the German context. Various methodological approaches are used: bottom-up

estimates based on the addition of individual measures and top-down models that reflect macroeconomic relationships and interactions.

Another focus is on the question of how existing and future fiscal risks resulting from the consequences of climate change and adaptation measures affect the budgets of the federal, state and local governments. To this end, direct costs for investment and operation are considered, in addition to indirect risks such as loss of revenue or rising expenditure on disaster control and damage repair.

In addition, the report addresses the development and evaluation of innovative financing mechanisms that go beyond traditional support programmes. Among other things, it discusses new instruments such as climate resilience bonds, climate risk insurance, targeted levies and the strengthening of inter-municipal and public-private partnerships. The aim is to identify ways in which the financing of climate adaptation can be made sustainable in the long term in view of limited budgetary resources and growing tasks.

Finally, the report addresses the question of how adaptation measures can be assessed and prioritised in advance, i.e. ex ante. Various methodological approaches are presented and critically discussed, ranging from traditional cost-benefit analyses and multi-criteria assessments to integrative assessment frameworks that also consider non-monetary benefits and social co-benefits. The effectiveness of measures and the efficient allocation of scarce resources are just as much a focus as practical feasibility and consideration of local conditions.

For all areas discussed, the report highlights current obstacles as well as opportunities for improvement and key research needs.

The report begins with a presentation of the estimated adaptation costs for Germany. First, the results from the bottom-up approach are presented, in which the costs are determined by adding up individual measures and sectors. This is followed by an analysis of the adaptation costs based on the top-down approach, which considers macroeconomic relationships and effects. This is followed by a detailed examination of two selected areas: the building sector and flood protection. Specific challenges, investment needs and implementation barriers are analysed in depth for both areas.

The following chapter is devoted to the fiscal risks arising from the effects of climate change on public budgets at various federal levels. In this context, existing financing and compensation mechanisms in the context of climate adaptation are also systematically presented and critically evaluated. Existing gaps are identified and proposals for new, complementary financing instruments are developed.

The concluding chapter examines three key methods for the ex ante assessment of adaptation measures in detail: cost-benefit analyses, cost-effectiveness analyses and multi-criteria analyses. The strengths and weaknesses of each of these methods are critically discussed. The report concludes with recommendations on how these assessment approaches can be further developed methodologically and used more broadly and effectively in practice.

2 Financing requirements for climate adaptation in Germany

Table 1 : Results at a glance

RESULTS AT A GLANCE

- Depending on the method and sector, the annual investment requirements for climate adaptation in Germany are in the order of several billion euros per year. The actual requirements are likely to be significantly higher than the figures currently reported.
- Bottom-up estimates based on individual measures and sectors indicate an annual investment requirement of around EUR 8.6 to EUR 10.6 billion, with building stock and adaptation to heat standing out as particularly cost-intensive areas.
- Top-down approaches based on macroeconomic modelling confirm the considerable scale of the adaptation required and also point to indirect costs and macroeconomic effects that are often overlooked in sectoral analyses. The estimates cover only some of the impact chains and dimensions identified for Germany and should therefore be regarded as conservative estimates of the actual costs of climate change.
- Damage costs from inland and coastal flooding without adaptation increase over time and are particularly pronounced under severe warming (3°C GWL or RCP8.5); for Germany, estimates of EUR 5.3 billion for inland flooding and USD 105 billion for coastal flooding per year towards the end of the century are available.
- The costs of damage with adaptation are consistently significantly lower for all scenarios and time periods. Adaptation costs are low compared to damage costs without adaptation and show a moderate development over time and between scenarios.
- In the building sector, the greatest need for adaptation exists in particular in retrofitting existing buildings to protect them against heat, heavy rainfall and other extreme events. The necessary investments significantly exceed previous expenditure.
- In the area of flood protection, the analyses show that high damage has already occurred in the past and that considerable additional investment will be necessary in the future to limit the risks.
- Sensitivity analyses illustrate that cost estimates are heavily dependent on key assumptions, such as the level of protection, socio-economic developments and the selection of measures. The actual range of requirements is therefore wide.
- Non-financial barriers such as long planning and approval times, land use conflicts, bottlenecks in the construction industry and administrative hurdles can significantly delay implementation and increase costs.
- Distinguishing between specific adaptation costs and general investments in resilience and modernisation remains methodologically challenging and leads to uncertainties in the reported figures.
- Overall, there is a considerable need for research, particularly with regard to the systematic recording of the baseline, further differentiation of costs by sector and region, and the further development of methods for cost estimation and performance monitoring.

2.1 Introduction

Estimating the financing requirements for climate adaptation is an important prerequisite for an effective and forward-looking adaptation policy in Germany. In view of the increasing impacts of climate change and the growing demands on the protection of the population, infrastructure and economy, it is crucial to obtain a realistic picture of the necessary investments and running costs.

The aim of this chapter is to systematically summarise and critically evaluate the current findings on the financing requirements for climate adaptation in Germany. Existing estimates from different methodological approaches and international comparative values are used for this purpose. The focus is particularly on the differences between bottom-up and top-down approaches, which offer different perspectives and insights into the amount and composition of adaptation costs.

First, the current estimates of adaptation costs in Germany are presented. The results of the bottom-up approach, in which costs are determined by aggregating individual measures and sectors, are presented first. This is followed by a presentation of the results from the top-down approach, which is based on macroeconomic modelling and macroeconomic analyses.

Two selected areas are then examined in more detail in separate sections: the building sector and the flood protection sector. Specific challenges, investment requirements and implementation barriers are analysed in detail for both sectors. Another section is devoted to sensitivity analysis and examines the extent to which the results depend on key assumptions – for example, regarding the level of protection, socio-economic developments or the selection of measures. Finally, the most important methodological and content-related uncertainties and the resulting research needs are identified, and recommendations for the further development of cost and demand estimation are made.

2.2 Macro-level analysis

2.2.1 Bottom-up analysis

The bottom-up approach focuses on the detailed analysis of specific adaptation measures and their costs. The costs are calculated by adding up the individual cost elements required to implement each measure. These may include costs related to study, infrastructure, operating and training.

A key advantage of the bottom-up method is its flexibility and adaptability. It can be applied to a wide range of adaptation measures and requires less data than more complex economic models. A prominent example of the bottom-up approach is the cost estimate for the National Adaptation Plan (NAP) of the Government of Fiji. This plan uses an Excel-based tool that enables specialist departments in ministries and subordinate authorities to enter resource and cost data in order to calculate the costs of the NAP's 160 adaptation measures(Government of Fiji 2020). However, the absolute figures cannot be transferred to Germany due to differences in economic structure and infrastructure. Nevertheless, the methodological approach – that is, the systematic recording and addition of the costs of individual measures – could in principle be used for the German context.

Determining the financing requirements for climate adaptation in Germany using bottom-up approaches presents various challenges. Unlike clearly definable individual projects, such as the planning of a wind farm to achieve emission targets, climate adaptation is a cross-cutting issue that permeates almost all areas of public and private activity, from urban development and water management to forestry and agriculture. Adaptation measures are rarely isolated but are often considered and implemented as part of more comprehensive investments, renovations or modernisations. This makes it difficult to clearly allocate and precisely quantify the actual costs incurred.

This problem is also reflected in the results of the interviews conducted as part of this study[1]: experts and practitioners unanimously emphasise that in practice, climate adaptation is usually an integral part of other measures and is rarely reported as a separate cost factor. Existing bottom-up estimates are therefore often based on assumptions, projections and the delineation of cost components that can be explicitly attributed to climate change adaptation. Despite these methodological uncertainties, the available studies and surveys provide important indications of current and future financing needs.

This chapter presents the available results of bottom-up estimates for Germany. It considers both nationwide estimates and sectoral analyses before delving deeper into the key findings from interviews with stakeholders from government, business and civil society. This provides a comprehensive picture of the financial challenges, but also of the existing gaps and uncertainties in the financing of climate adaptation in Germany.

2.2.1.1 Review of existing estimates

The bottom-up estimates of the financing requirements for climate adaptation in Germany available to date provide an informative but by no means complete picture. The range of the sums reported illustrates how strongly the results depend on the methods used, the periods considered and the respective sectoral boundaries. The 2022 survey conducted by the Conference of Environment Ministers (UMK) provides a key reference point. It estimates that by 2030, around EUR 55 billion in investment will be required at the state and municipal level for climate adaptation, nature conservation and natural climate protection, of which around EUR 38 billion is explicitly earmarked for climate adaptation measures(Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2022). The data basis for this estimate is a bottom-up survey in which the individual federal states reported and aggregated their requirements. It should be noted that these figures are to be understood as conservative minimum requirements, as many indirect costs and long-term measures were not fully captured.

The study byHeilmann et al. 2024 takes up this estimate and specifies the annual financing requirement for climate adaptation at around EUR 5.6 billion for the period 2024 to 2030. Here, too, it is emphasised that the actual requirements are likely to be significantly higher, as numerous cost areas and long-term measures have not yet been adequately taken into account. The study also attributes around 75% of investments to local authorities, underscoring the central role of the local level in implementing adaptation measures.

The KfW Municipal Panel 2023 provides further important guidance for the municipal level. According to the panel, German municipalities spent around EUR 1 billion on climate adaptation in 2021, with the estimated annual investment requirement for climate protection and climate adaptation together amounting to around EUR 5.8 billion(Raffer 2023). The survey is based on a nationwide questionnaire and extrapolation that systematically records the expenditure and plans of local authorities.

In addition, the analysis of the federal government's adaptation expenditure(Hölscher et al. 2025b) provides an initial overview of the funds actually made available at the federal level. For 2022, the federal government's adaptation expenditure is estimated at between EUR 2.07 and EUR 3.41 billion. This expenditure is spread across numerous departments and funding areas and has often not been clearly identified as adaptation funding to date.

[1] The evaluation is based on confidential, guideline-based individual interviews conducted in a protected setting. Local stakeholders, representatives of state and federal institutions, and scientists were interviewed. An anonymised overview can be found in Appendix B.

Note: In a press release, the BMUV estimated the total financing requirement for climate adaptation until 2030 at EUR 38 billion(Die Zeit 2024). However, the exact data basis and methodology of this estimate are not transparently traceable, which is why this figure should be interpreted with appropriate caution.

2.2.1.1.1 Approximation based on the transfer of research results from France

The results of a recent study from France are used in this section to provide an initial approximation of the investment costs for climate adaptation in the building sector. These figures serve as a frame of reference before the investment requirements for Germany are examined in greater detail later in the report, particularly in the detailed analysis in Section 2.2.1.1.3.1 and in Section 2.3.1.

The French study was conducted by I4CE and other partners on behalf of the Commissariat général au développement durable (CGDD). The aim of the study was to present, for the first time, reliable estimates of future investment requirements for climate adaptation in France. The focus was on three sectors that are particularly affected: buildings, land-based transport infrastructure and agricultural crop production. The main question tackled was what costs can be expected in these areas up to the year 2100 under different adaptation pathways, which differ primarily in terms of ambition level and strategic preparation – particularly under a +4°C warming scenario (Dépoues et al. 2024).

Methodologically, the analysis is based on a combination of literature review, sectoral expert workshops and the evaluation of existing technical and economic data. For each sector, the most important climate risks were first identified and then various adaptation options – from reactive measures to proactive investments – were assessed in terms of their costs and effectiveness. The study emphasises that it is currently not possible to provide an exact estimate of the total costs of adaptation, but it does provide robust estimates and a methodological framework that can also be applied to the German context.

In order to make the results of the French study usable for the German context, a pragmatic transfer approach was chosen. The investment requirements for climate adaptation determined in France were first related to the French population in order to obtain sectoral per capita values. These values were then extrapolated to the German population in order to enable an initial estimate of the order of magnitude of the adaptation investments required in Germany.

It should be noted that France differs from Germany in terms of urbanisation, infrastructure and geographical conditions and is exposed to different climate change impacts in some areas. In addition, the financing requirements for many adaptation measures do not depend exclusively on the population size. For instance, infrastructure measures such as dyke construction or adaption of transport infrastructure are particularly influenced by regional and sectoral factors. Nevertheless, extrapolation based on per capita values appears reasonable here, as the results of the French study are significantly influenced by the building sector and other areas were not included in the projection.

Table 2 : Overview of sectoral adaptation costs in France and transfer to Germany, based on Depoues et al. 2024

Sector	Type of measure	Cost estimate for France (EUR per year)	Extrapolation of costs for Germany (EUR per year)
Buildings	Adaptation to heat new buildings	EUR 1 to 2.5 billion	EUR 1.22 to 3.24 billion

Buildings	Adaptation to heat in existing buildings	EUR 4.4 billion	EUR 5.37 billion
Buildings	Organisational measures for adaptation to heat [2]	EUR 31 million	EUR 38 million
Buildings	Organisational measures for adaptation to flooding	EUR 125 million	EUR 153 million
Transport	Adaptation of rail and road infrastructure	No usable information available ('hundreds of millions or even billions')	No transfer made
Transport	Organisational measures	Several tens of millions of EUR per year	No transfer made
Agricultural crop production	Technological adaptation measures	EUR 1.5 billion	EUR 1.83 billion
Total			**8.6 billion to 10.6 billion EUR**

As the study did not provide any specific usable figures for the transport sector, no calculations were made for Germany in this case. Applying the results for the other two sectors shows that the annual investment required for climate adaptation measures amounts to approximately EUR 8.6 to 10.6 billion. Particularly noteworthy is the high need for adaptation in existing buildings, especially in regard to protection against increasing heat. These figures illustrate that substantial and continuous investment is necessary to ensure the long-term resilience of key infrastructure and sectors to the effects of climate change.

2.2.1.1.2 Cost estimate of the BaumEntscheid initiative

The civil society initiative BaumEntscheid has drafted a bill for the state of Berlin that provides for comprehensive greening of the city, the BäumePlus Act. The aim of this law is to make Berlin heat-resilient and climate-adapted by 2040. Among other things, it provides for the planting of new street trees, the creation of numerous green spaces and the efficient use of rainwater(Initiative Volksentscheid Baum et al. 2024). The initiative has provided a cost estimate for the measures contained in the law. According to this estimate, the total cost will amount to EUR 7.2 billion, which corresponds to approximately EUR 500 million per year(Initiative Volksentscheid Baum et al. 2024).

[2] Organisational measures example: heatwave measures package for knowledge transfer and stakeholder involvement, research and testing of existing solutions.

From this figure, an annual per capita cost of approximately EUR 130 can be extrapolated. To illustrate possible cost structures for urban climate adaptation measures, this value was applied to the five largest German cities:

Table 3 : Extrapolation of adaptation costs for German cities based on per capita cost estimates

City	Population (2022)	Estimated annual costs
Berlin	3,755,251	Approx. EUR 488 million
Hamburg	1,892,122	approx. EUR 246 million
Munich	1,512,491	approx. EUR 197 million
Cologne	1,084,831	approx. EUR 141 million
Frankfurt	773,068	approx. EUR 100 million

The calculations are based on a flat-rate per capita cost assumption from Berlin. They do not take into account local differences in land availability, tree species, care and maintenance costs, or synergy effects with existing programmes. Furthermore, greening costs depend much more on the urban structure and the degree of soil sealing than on the pure number of inhabitants. The significance of a per capita projection is therefore limited and cannot reflect differences in urban structures. For this reason, the projection was applied exclusively to other urban areas and not to the total population of Germany. The figures should therefore not be understood as exact budget targets, but merely serve to illustrate the magnitude of potential investments in German cities.

2.2.1.1.3 Estimates for individual sectors

A comprehensive study commissioned by the Federal Ministry for Economic Affairs and Climate Protection provides an important framework for sectoral analysis (Bundesministerium für Wirtschaft und Klimaschutz 2023). It analyses both the costs of climate change impacts to date and the future investment needs for adaptation measures to extreme weather events in Germany. This is an independent study whose sectoral cost estimates are not explicitly included in the total costs mentioned above. The costs reported include investments made in both the public sector (federal and local authorities) and the private sector. A brief explanation of the respective allocation is provided in the following sections.

For future investments in adaptation measures, a cumulative requirement of around EUR 190 billion is reported for the period 2022 to 2050. Particularly high investments are estimated in the construction industry (EUR 69 billion), agriculture (EUR 24 billion), water supply (EUR 16 billion) and wastewater and waste management (EUR 16 billion). Other relevant sectors include research and development, architecture and engineering firms, public administration, forestry, mechanical engineering, rubber and plastic products manufacturing, and other economic sectors.

The study is based on the PANTA RHEI macroeconometric model, which quantitatively analyses sectoral and macroeconomic effects according to different scenarios. The modelling combines values from the literature, expert estimates and the evaluation of past investments. The results should be interpreted as conservative lower limits, as numerous indirect and difficult-to-quantify effects – such as long-term follow-up costs or interactions between sectors – cannot be fully represented.

The sectoral differentiation of investment requirements shows that the building sector in particular faces considerable challenges. The study identifies the construction industry as one of the areas with

the greatest need for adaptation. An in-depth analysis of the investments required in the building sector is provided in a recent study commissioned by industry associations (see Section 2.2.1.1.3.1) and a specific detailed analysis in this report (see Section 2.3.1).

2.2.1.1.3.1 Building sector and construction industry

Climate adaptation in the building sector is central to the future security and resilience of the German construction industry. A recent study commissioned by industry associations estimates that adapting buildings to climate change-related risks – such as heat, heavy rain, flooding, storms and hail – will require an investment of EUR 137 billion by 2035 in a scenario of mild climate change(Sander et al. 2025). In a scenario of more severe climate change, the requirement rises to EUR 237 billion. This corresponds to an annual investment requirement of EUR 12.5 to 21.5 billion, depending on the development of climate risks.

It is noteworthy that the majority of the investments (approx. 86%) will be spent on retrofitting existing buildings, while new construction will account for only a comparatively small share. Adaptation to heavy rainfall events and heat waves represents the largest cost blocks (e.g. EUR 65 billion for heavy rainfall and EUR 44 billion for heat in the mild scenario). The study is based on detailed modelling, a comprehensive literature and market analysis and expert workshops. It considers single-family homes, multi-family homes and non-residential buildings, and differentiates between various climate signals.

The study also shows that the implementation of adaptation measures requires considerable human resources: in the mild climate change scenario, around 7,700 additional full-time equivalents will be needed annually by 2035, and in the severe scenario, more than twice as many. The transformation of the building sector towards greater climate adaptation is therefore not only a technical challenge, but also a challenge for the labour market and structural policy.

2.2.1.1.3.2 Water management

In addition to the building sector, water supply and wastewater disposal are among the key areas of climate adaptation in Germany. Adapting water management infrastructure is essential to ensure security of supply and environmental standards even under changing climatic conditions. The modernisation and adaptation of water supply and wastewater infrastructure represents a significant investment item in the area of climate adaptation. According to a recent study commissioned by the Association of Municipal Companies (VKU), the general investment requirement for this sector for the period 2025 to 2044 is around EUR 800 billion, which corresponds to an average annual requirement of EUR 40 billion(VKU 2025). This figure includes both the maintenance and renewal of existing infrastructure and the necessary adjustments to changing climatic conditions.

Feedback from the water industry and the analyses in the study show that, on average, around 10 to 15% of the total investment is explicitly attributable to climate change adaptation measures. Based on conservative estimates, this corresponds to EUR 80 to 120 billion by 2044, or around EUR 4 to 6 billion per year. However, it is difficult to determine in practice the proportion that is directly attributable to climate change adaptation, as the expected effects of climate change are already taken into account in every renewal and pipeline construction projects are designed to last for many decades.

The study primarily covers the incremental adaptation of existing systems – i.e. the additional investments necessary to fulfil the core tasks of drinking water supply and wastewater disposal even under changed climatic conditions. Transformative or large-scale infrastructure projects (such as new long-distance pipelines or seawater desalination) are not yet included in the estimate. Requirements also vary greatly from region to region, depending on water resources, demand trends and the local effects of climate change.

Climate adaptation costs in the water sector account for a relevant but by no means dominant share of total investment requirements. At the same time, the figures make it clear that financing these measures – in view of rising costs and limited fee-bearing capacity – is a key social and political task.

2.2.1.1.3.3 Forestry

Forestry in Germany has been particularly hard hit by extreme weather events in recent years. Storms, drought and bark beetles caused economic damage of around EUR 13 billion in the years 2018 to 2020 alone(Deutscher Forstwirtschaftsrat 2021). This sum includes lost revenue and additional costs due to calamity felling, losses due to immaturity, losses in value, unsaleable damaged timber and additional costs for administration and, in particular, for the reforestation of damaged areas. The volume of damaged timber during this period was around 177 million cubic metres, and the damaged area requiring reforestation was 284,500 hectares.

The additional costs for reforestation of the disaster areas alone are estimated at around EUR 1.36 billion for these three years – equivalent to around EUR 450 million per year. However, according to estimates by the German Forestry Council, funds of this magnitude will be needed not only in the short term, but annually, in order to preserve the forest and adapt it to climate change in the long term. It should be noted that not all damage and the associated investment requirements arise in the public sector; a considerable proportion must also be borne by private forest owners.

The emergency aid programmes provided by the federal and state governments to date amount to around EUR 1.6 billion. With a minimum annual requirement of EUR 450 million, this sum is sufficient for around three and a half years – but only on the assumption that all damage and associated investment requirements arise in the public sector and are also covered in full by public funds.

For the period up to 2030 – i.e. the next seven years – this results in an additional financing requirement of around EUR 1.55 billion to cover the minimum requirements for reforestation alone, assuming that all costs are borne by the public sector. This sum represents a conservative lower limit, as additional measures such as conversion to more climate-resilient mixed forests, prevention, research and consulting have not yet been taken into account.

Private forests, which account for around half of Germany's forest area, are particularly affected due to their fragmented structure and are in need of additional support. The study makes it clear that adapting forests to climate change is a long-term, intergenerational task that requires ongoing social and political support, given the total costs and the financial capabilities of forestry operations. However, the figures cited do not immediately reveal the proportion of damage to the forestry industry's turnover or profits.

2.2.1.1.3.4 Administrative costs of implementing the Federal Climate Adaptation Act (KAnG)

In addition to the investment requirements for specific climate adaptation measures, the administrative costs associated with implementing the Federal Climate Adaptation Act (KAnG) at various levels must also be taken into account. The budget of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) includes explicit funds for this purpose, which are required exclusively for the fulfilment of the legal requirements. These include, in particular, personnel costs at federal, state and local level, as well as the costs of developing climate adaptation concepts, climate risk analyses, monitoring, reporting and the development of strategies and indicators.

The annual administrative costs are estimated at around EUR 2.75 million for the federal government and between EUR 830,000 and EUR 1.67 million for the federal states(Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz 2023b). In addition, there are one-off costs of

between EUR 66 million and EUR 1.9 billion at federal state level, depending on the specific design. Particularly noteworthy are the one-off costs for the development of climate adaptation concepts at the municipal level. Assuming an average of EUR 100,000 per concept, this results in a total requirement of up to EUR 956 million, depending on the number of concepts to be developed; if the estimate is doubled to EUR 200,000 per plan, the financing requirement also doubles accordingly. These expenses cover administrative costs only – investments in specific measures, such as flood protection or urban greenery, are not included.

These administrative expenses are a necessary prerequisite for enabling a strategic, data-based and coordinated climate adaptation policy at all levels of government. Only based on these concepts and administrative structures can concrete adaptation measures be planned, financed and implemented in a second step.

2.2.2 Top-down analysis

In contrast to the bottom-up analysis described above, the top-down analysis used here does not directly assess financing requirements, but estimates them based on various modelling approaches. These top-down studies therefore only yield financing requirements indirectly: on the one hand, the economic costs of climate change impacts (GDP losses) can be used as an approximation for financing requirements. On the other hand, the comparison of adaptation costs with the economic damage avoided as a result can be used to identify cost-effective adaptation options. Top-down approaches range from sectoral to macroeconomic methods that integrate different approaches and simulate complex interactions. Depending on the model type, this results in varying degrees of detail and insights into the extent of economic climate damage. For this reason, section 2.2.2.1 first presents the different modelling approaches for quantifying climate change impacts and adaptation in section 2.2.2.1.2, followed by a presentation of the methodological approach used to synthesise the results from the available studies in section 2.2.2.1.3. The results of the evaluation are then presented in sections 2.2.2.2 (consequential costs) and 2.2.2.3 (adaptation costs).

2.2.2.1 Overview of existing modelling approaches for assessing the impacts of climate change and adaptation to climate change

Climate change causes a wide range of economic and social costs. These costs include both direct and indirect costs resulting from physical damage (e.g. flooding, heat damage, crop losses) or resulting consequences (e.g. production losses, supply chain disruptions, failure of critical infrastructure) (Kousky 2014). Some of these damages may be market-related, meaning they can be valued using observable prices, or they may be non-market-related (e.g. loss of quality of life, ecosystem services), which makes valuation much more difficult but no less important(Boyd and Markandya 2021). Unlike direct costs, indirect costs often extend over longer periods of time and affect a larger geographical area than the immediate location of the physical climate damage(Hallegatte et al. 2013).

Due to economic interdependencies, direct and indirect market damage also has repercussions throughout the entire economy and beyond. If these effects are large enough, macroeconomic indicators such as GDP, employment or inflation may be affected. However, aggregate indicators such as GDP cannot reflect the often-considerable distribution problems associated with climate change. Furthermore, local losses may be barely visible in national statistics but can have serious consequences for those affected. Ultimately, welfare losses should be taken into account as a fundamental decision variable. However, these are difficult to measure. GDP serves as an imperfect proxy here, as it does not fully capture the loss of consumption or the decline in individual utility (consumer surplus) – and because in some cases it may even increase due to repair investments, even though the quality of life declines. For this reason, the decline in consumption is often considered a more appropriate approximation of welfare losses.

2.2.2.1.1 Effects of climate change in modelling approaches

Roughly speaking, three approaches can be distinguished for capturing or modelling the types of costs described above. The first approach comprises process-based or biophysical models. Biophysical models are models that quantitatively represent physical, chemical and biological processes in natural or managed ecosystems, in particular to assess the effects of climate change on, for example, plant growth, soil functions and water balance. Compared to purely economic or social science approaches, biophysical models provide the scientific basis for climate impact scenarios: For example, they can calculate how a change in temperature or a period of drought affects biomass production, soil erosion or the spread of pests. In order for the results of these biophysical simulations to be used as input for economic or integrated models and their macroeconomic consequences to be assessed, a monetary evaluation of the respective damage is carried out. Depending on the sector under consideration, a statistical approach can be used (e.g. value of statistical life to assess premature deaths) or the assessment can be based on a partial equilibrium model that already links the physical variables with part of the economy. Individual sectoral climate impacts can then be added together to calculate the total economic damage. There are no interactions between the sectors.

The second approach is based on statistical or econometric methods to estimate climate-economy relationships at the macroeconomic level. Historical data and time series are used to analyse how climate variables – such as temperature changes, precipitation patterns or extreme weather frequency – affect macroeconomic indicators such as GDP. Typical methods include regression analyses, panel data models and econometric time series models, which isolate the influence of climatic factors by controlling for other influencing factors such as population growth, capital stock and technological development. This makes it possible to examine, for example, how a one-degree Celsius increase in average temperature correlates statistically with changes in the annual GDP growth rate. In this way, the economic effects of climate change are quantified for the entire economy without first modelling individual sectors separately. This approach therefore draws on observed historical correlations to make projections for the future.

The third approach combines information from one or both of the first two approaches and simulates it in a macroeconomic model. This allows several sectors to be considered simultaneously, taking into account economic feedback and the long-term climate impacts on the entire economy. By mapping complex interactions and structural changes, this approach enables a comprehensive assessment of the overall economic damage caused by climate change. Typical examples of such models are computable general equilibrium (CGE) models, multi-regional input-output (MRIO) models and integrated assessment models (IAMs). Compared to IAMs such as DICE or PAGE, which simulate the integrated relationship between climate effects and economic development on a global scale over long periods of time, CGE and MRIO models have higher spatial and sectoral resolution and are therefore better suited to investigating climate change impacts and adaptation for individual countries and regions.Figure 1 shows how climate change impacts can be represented in CGE and MRIO models.

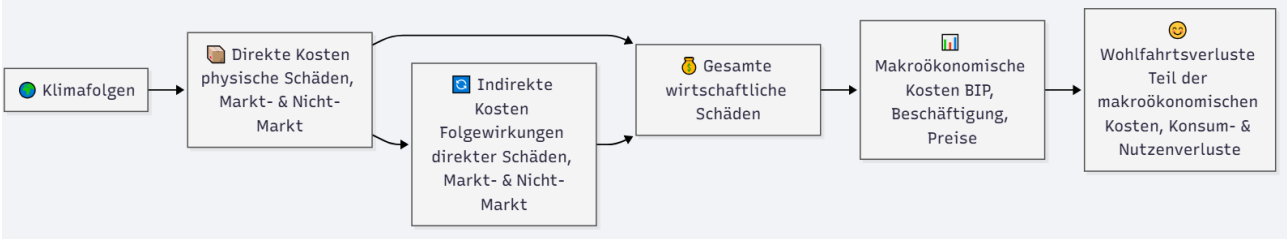

Figure 1 : Modelling steps in macroeconomic models, in particular CGE and MRIO models

The economic assessment of climate damage poses a major methodological challenge, as the effects of climate change are complex, cross-sectoral and spread over long periods of time. Each approach has its

strengths and weaknesses. Process-based or biophysical models capture individual physical damages in detail and translate them into monetary values, but often neglect cross-sectoral interactions. Top-down econometric models are based on historical data and statistical methods to directly estimate macroeconomic climate effects, but offer less insight into individual damage processes and rely on past correlations. Integrated models combine information from both approaches and simulate complex economic interactions and long-term structural changes. This enables them to provide a comprehensive and holistic assessment of the economic impacts of climate change, but they are complex and data-intensive. A detailed discussion and description of the different approaches, their limitations and areas of application can be found inPiontek et al. (2021).

Most models use combinations of climate scenarios (Regional Concentration Pathways, RCPs) and socio-economic scenarios (Shared Socio-economic Pathways, SSPs) to investigate the effects of future climate change. Projections from different climate models (General Circulation Models, GCMs; usually broken down regionally by Regional Climate Models, RCMs) are typically used to illuminate the uncertainty space. These different realisations are then examined in more detail for different time periods, for example, a period in the near future (around 2030), the medium future (around 2050) and the end of the century (2080 or 2100). The effects thus represent average changes in the climate (average over 20-30 years).

Increasingly, final results are presented for different levels of global warming (Global Warming Levels, GWL). This transfer of results can be done in two different ways: Variant 1 takes the level of global warming at the end of the century; for example, in this approach, RCP 2.6 corresponds to global warming of slightly above 1.5°C in 2100, RCP4.5 to global warming of slightly above 2°C in 2100, and RCP8.5 to warming of 4°C in 2100. All results of the respective RCP scenario are then presented at different points in time (e.g. 2030, 2050, 2080) and all results of an RCP scenario are assigned to the same GWL. The advantage of this approach is that the time dimension is retained, which is important for socio-economic issues. The disadvantage is that the warming achieved in the earlier periods does not correspond to the GWL, but is usually lower. Thus, damage costs in a 3°C scenario may be the same or even lower than in a 2°C or 1.5°C scenario. Variant 2 evaluates each GCM run individually with regard to the question of when 1.5°C, 2°C or 3°C will be exceeded globally. The results are then reported for that year. This means that results from different RCPs and different years are compared for a given level of warming. The advantage of this approach is that the GWLs are reached exactly, the disadvantage is that this occurs at different points in time and the economic structure (population, sectoral composition) can vary greatly, meaning that the comparison only makes limited sense in economic terms.

2.2.2.1.2 Climate change adaptation in modelling approaches

Although numerous studies have already quantified the consequences of climate change, reliable assessments of adaptation measures are still relatively rare. Adaptation strategies can take many different forms, and their effectiveness depends heavily on the specific context and region. The models described in Section 2.2.2.1.1 can map different adaptation activities and thus estimate their damage prevention potential. This allows the direct costs and benefits of adaptation to be identified. Estimating the economic repercussions resulting from reduced damage and the implementation of adaptation measures requires a model that depicts the entire economy and is capable of modelling adaptation.

In model-based analysis of adaptation, it is also important to distinguish between two adaptation mechanisms. On the one hand, there are autonomous adaptation processes, which are often understood as spontaneous and market-based and tend to be undertaken by private actors. On the other hand, there are planned adaptation activities, which are targeted and strategic and tend to be undertaken by public actors, but not exclusively so. Autonomous adaptation processes can be controlled by model-specific parameters, which implicitly facilitates adaptation. For example, higher

substitution elasticities allow producers or consumers to switch more easily between different input factors or consumer goods when climate change makes certain factors or goods more expensive, but not others. Planned adaptation processes require explicit modelling using exogenous data on costs and direct damage reduction through adaptation. This means that data on both the implementation costs and the benefits of adaptation must already be known in order to estimate the economic effects.

In model-based analysis, the degree of adaptation is either determined endogenously or specified exogenously. Endogenous determination is usually based on cost-benefit analyses: if the ratio of adaptation benefits (damage avoided) to adaptation costs (investments, maintenance costs) is greater than 1, the measure is cost-effective and is examined in the macroeconomic analysis for its cross-sectoral effects. In some models, mostly sectoral ones, the sum of adaptation costs (investments) and residual damage (damage taking adaptation into account) is also minimised, thus determining the cost-effective level of adaptation.

Alternatively, the degree of adaptation is specified exogenously in the models, for example by stipulating that the current adaptation target, such as protection against a 100-year flood event, will also be maintained in the future. If scenarios involve an expansion of settlement, this standard is also applied to this area. A higher warming scenario also changes the required degree of adaptation in these models. Some models also make the adaptation target dynamic based on observed increases in the level of protection as a result of the increase in per capita income or the exposed population. Which of the two approaches – exogenous or endogenous determination of the degree of adaptation – is preferable is, to a certain extent, a matter of taste.

Despite the growing relevance of climate adaptation, research on adaptation in the context of macroeconomic models lags far behind what is needed.Wei and Aaheim (2023) show that to date only 97 studies worldwide have analysed adaptation measures using CGE models to date. Of these, only 37 explicitly consider planned adaptation, and European countries are only sporadically included in the study – Germany remains completely unconsidered. These figures illustrate how large the scientific gap remains, particularly for national economies and their adaptation strategies. Since then, however, two studies have been undertaken in Germany, which we discuss in Section 2.2.2.3.2.

2.2.2.1.3 Approach: synthesis of different results

The selection of studies evaluated is based on the IPCC's Sixth Assessment Report, Working Group II, Chapter 13(Bednar-Friedl et al. 2022), in particular the studies underlying Figure 13.33 on the economic consequences of climate change in Europe. This database was supplemented by publications that have since been published in scientific journals or as publications of the European Publications Office (e.g. the PESETA studies of the Joint Research Centre), and by studies that were conducted explicitly for Germany and commissioned, for example, by the Federal Environment Agency.

In order to make the results from the various studies comparable, information on scenarios was standardised. On the one hand, the time periods were aligned: the results for the short term up to 2030 include all results for the period 2020-2030; for the medium term (mid-century around 2050), the period 2040-2065; long term (end of the century; until 2100) the period 2070-2100. In accordance with the information in the publications, results reported in RCPs were converted into GWL according to variant 1 or variant 2, depending on the availability of results. Where information on exceedance times was available, this information was also used to specify time periods.

The primary economic comparison variable is damage costs expressed as percentage reductions in GDP or welfare, whereby welfare effects can take into account not only sectoral effects but also non-market effects such as mortality. Most studies use a delta approach, i.e. the effects are calculated relative to a baseline scenario without climate change. The advantage of this approach is that results from model calculations with different base years can be compared and that a conversion of the base

year (valorisation) is not necessary. Another advantage is that results from different studies remain comparable even with differing baseline developments, e.g. regarding the development of the CO_2 price or demographic and structural changes.

The collection of relevant literature on the economic costs of climate change impacts for Germany or a larger region that includes Germany comprises 23 peer-reviewed articles or reports, which provide a total of over 380 values for different time periods and warming levels. These estimates are distributed across more than 14 climate-related damage categories (sectors), and the models take into account different climate scenarios and socio-economic developments. For better comparability,Table 4 shows the distribution of the results across three warming levels, andTable 5 shows the distribution across three time periods. 317 of the data points evaluated are damage costs without adjustment, 66 data points are with adjustment. The majority of data points (346) are generated using CGE models, followed by MRIO models (29) and econometric studies (10). The larger number of available data points from CGE models results not only from the higher number of publications, but also from the typically greater variety of scenario combinations analysed in CGE studies.

Overall, most estimates are available for damage to infrastructure due to coastal flooding and changes in labour productivity. In third place are estimates of cross-sectoral damage, which take into account a range of different climate change impacts or are based on aggregated damage functions. With regard to the three warming scenarios, there are more modelling results for stronger warming scenarios. There are around twice as many estimates for the middle of the century as there are for the short and long term (end of the century), which is also due to the fact that most macroeconomic studies are less suitable for the long term.

Table 4 : Overview of evaluated literature by global warming level (GWL): number of data points and number of literature sources

Sector	Data points per GWL			Number of sources
	1.5	2	3°C	
Damage to infrastructure due to inland flooding	15	38	26	6
Damage to infrastructure caused by coastal flooding	11	19	27	8
Damage to the transport sector	10	10	10	2
Change in labour productivity	10	9	35	7
Change in mortality due to heat	1	1	3	3
Change in energy supply	9	9	9	3
Change in energy demand	6	7	8	3
Change in agricultural yields	7	8	10	5
Change in forestry yields	6	6	6	1
Change in fishery yields	6	6	6	1
Damage caused by water scarcity and drought	1	1	1	1

Extreme weather events			3	2
Tourism			1	1
Cross-sector damage	11	13	18	8
Number of data points	**93**	**127**	**163**	

Table 5 : Overview of evaluated literature by observation period (number of data points per period)

Sector	Short term (2030)	Medium term (2050)	Long term (2080)
Damage to infrastructure due to inland flooding	9	62	8
Damage to infrastructure due to coastal flooding	16	30	11
Damage to the transport sector	12	12	6
Change in labour productivity	13	23	18
Change in mortality due to heat	1		2
Change in energy supply	10	10	7
Change in energy demand	6	8	7
Change in agricultural yields	7	9	9
Change in forestry yields	6	6	6
Change in fishery yields	6	6	6
Economic damage caused by water scarcity and drought	1	1	1
Extreme weather events		3	
Tourism			1
Cross-sector damage	11	13	18
Number of data points	**98**	**185**	**100**

2.2.2.2 Identified economic costs of climate change for Germany

The economic costs of climate change can best be approximated using studies on cross-sectoral damage (Figure 2). Estimates vary considerably depending on the study, but both the median and the results within a study increase with the GWL. At 1.5°C warming, the average effect is a GDP loss of 0.11%, rising to 0.25% at 2°C and 0.61% at 3°C warming. However, the confidence intervals are very wide, and a macroeconometric study finds GDP losses of 11%(Kotz et al. 2024b)[3]. A model variant of a CGE model run with high investment mobility also yields similarly high effects, leading to GDP losses for Germany of up to 19%, compared to a maximum of 3.7% with low investment mobility, which is the standard assumption in CGE models(Parrado et al. 2021). A much-discussed macroeconometric study projects GDP increases of 63% for Germany by the end of the century(Burke et al. 2015). However, this study only considers the effect of higher annual average temperatures, but not changes in precipitation and extreme events, and contradicts most studies in terms of the direction of the effect and, above all, the strength of the effect, which is why the study was excluded from further analysis as an outlier.

In summary, three conclusions can be drawn regarding cross-sectoral damage:

1. Estimates of the economic costs of damage caused by climate change increase with the level of warming and over time.
2. The estimates cover only part of the impact chains and dimensions identified for Germany and should therefore be understood as conservative estimates of the actual costs of climate change.
3. More recent estimates tend to be higher than earlier ones, which is why damage costs of at least 1% of GDP (average annual GDP losses) and damage costs in excess of 10% of GDP cannot be ruled out.

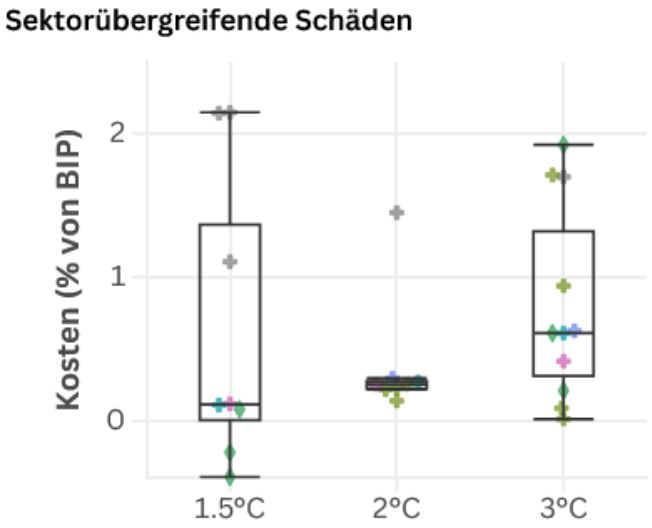

Figure 2 : Cross-sector damage as a percentage of GDP by warming level (GWL)
The box plot covers the 25th and 75th percentiles. Online link: https://public.flourish.studio/visualisation/23898568/;
Sources considered:Kahn et al. (2021) ;Szewczyk et al. (2020) ;Kompas et al. (2018) ;Parrado et al. (2021) ;Aaheim et al. (2017) ;Kotz et al. (2024b) ;Ciscar et al. (2018)

[3] Damage at the state level as a median value is provided by the authors here: pik-potsdam.de/~wenz/KotzLevermannWenz24_NAT_numbers.csv

Another reason why cross-sector damage costs are comparatively low is the underlying sectoral damage, the economic effects of which partially cancel each other out. For example, coastal flooding and inland flooding lead to significant GDP losses, as do losses in labour productivity and, to a lesser extent, GDP losses in energy supply and transport infrastructure. On the other hand, the majority of model calculations show GDP increases in agriculture, forestry and fisheries (Figure 6), at least when longer growing seasons and higher temperatures are taken into account.

The economic damage per damage area (sector) is described in more detail below. Compared to cross-sectoral damage, the trend in warming levels for sectoral damage, particularly from coastal flooding and inland flooding (Figure 3), is less clear. This is partly because precipitation and thus flood projections are subject to greater uncertainty than projections of temperature rise. On the other hand, the level of flood protection in Germany is above average compared to other European countries. Thirdly, these model calculations take into account average annual damage, but not the damage caused by a once-in-a-century event, for example.

Two opposing effects play a role in the change in energy demand (Figure 4): while the effect of the decrease in heating degree days initially dominates, leading to a drop in energy demand, a significant increase in cooling degree days and thus an increase in energy demand will occur later or at a higher degree of warming. In terms of energy supply, there are minor GDP losses due to a decrease in hydropower potential and variability in solar radiation and wind.

Labour productivity declines with increasing warming, at least according to the studies in question (Figure 5). However, there is considerable heterogeneity between the studies in terms of the strength of the effect, which is why the median GDP loss does not increase clearly with the degree of warming. The same conclusion can be drawn for heat-related excess mortality based on the few macroeconomic estimates available, but this needs to be further substantiated by additional studies.

There are insufficient studies for a comparative evaluation of damage to tourism caused by extreme weather events and economic damage caused by drought. Additional research projects are needed in this area.

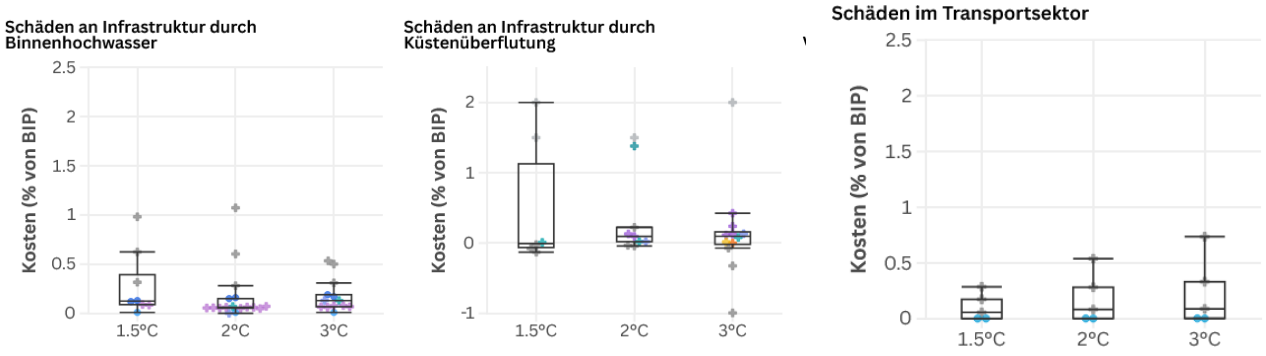

Figure 3: Sectoral effects of flooding as a percentage of GDP by warming level (GWL)
The box plot covers the 25th and 75th percentiles. Online link: https://public.flourish.studio/visualisation/23898568/
Sources considered: Inland flooding:Ciscar et al. (2018);Dottori et al. (2023); Knittel et al. (2024); Koks et al. (2019); Parrado et al. (2021) ;Szewczyk et al. (2020) ; Coastal flooding: Bachner et al. (2022); Ciscar et al. (2018); Dellink et al. (2019); Parrado et al. Pycroft et al.(2020); Pycroft et al. (2016); Roson and Sartori (2016);Szewczyk et al. (2020); Transport sector:Parrado et al. (2021); Flaute et al. (2024)

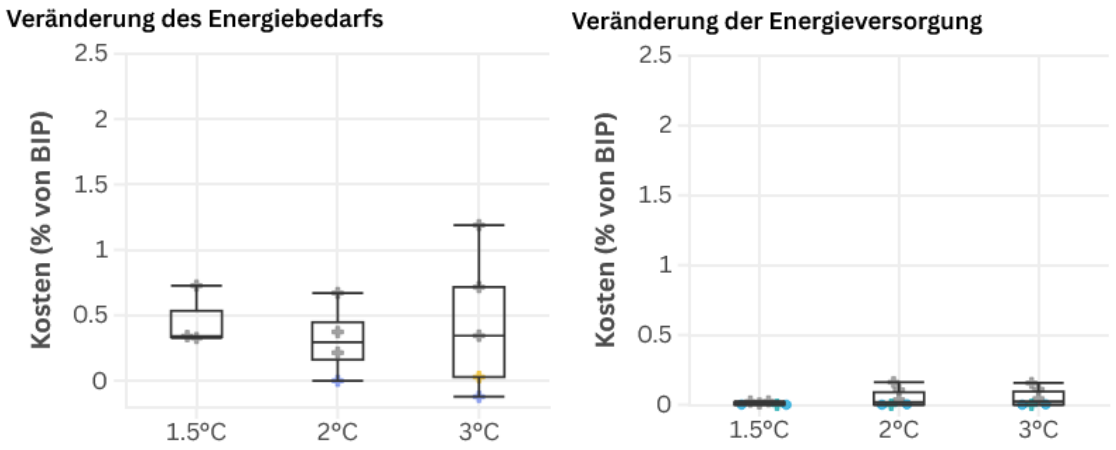

Figure 4: Sectoral effects of changes in energy demand and energy supply as a percentage of GDP by warming level (GWL)
The box plot covers the 25th and 75th percentiles. Online link: https://public.flourish.studio/visualisation/23898568/
Sources considered: Energy demand:Parrado et al. (2021);Ciscar et al. (2018);Dellink et al. (2019); Energy supply:Flaute et al. (2024);Parrado et al. (2021); Szewczyk et al. (2020)

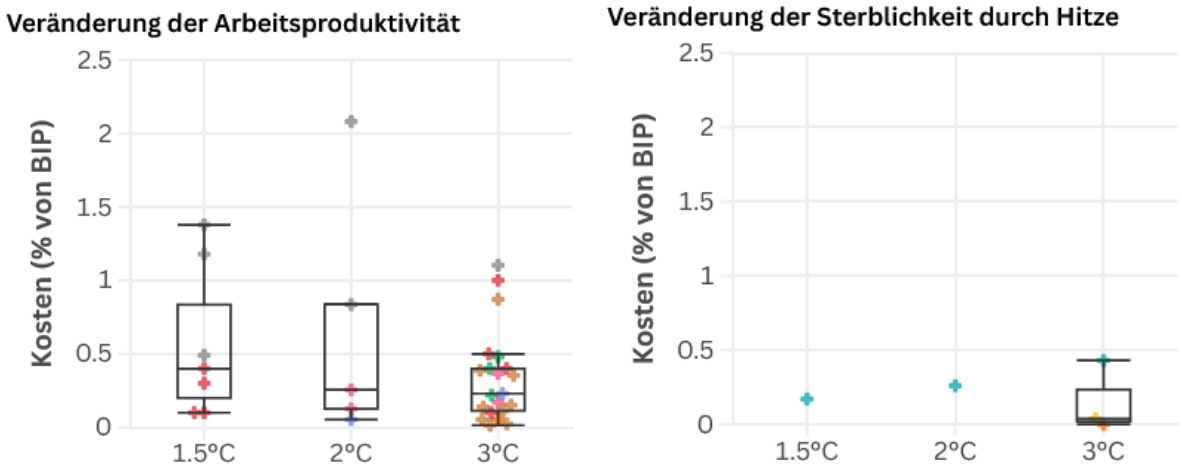

Figure 5: Sectoral effects due to labour productivity losses and heat-related mortality as a percentage of GDP by warming level (GWL)
The box plot covers the 25th and 75th percentiles. Online link: https://public.flourish.studio/visualisation/23898568/
Sources considered: Labour productivity:Ciscar et al. (2018);García-León et al. (2021); Knittel et al. (2024); Orlov et al. Parrado et al.(2020); Parrado et al. (2020); Roson and SartoriSzewczyk et al. (2016); Szewczyk et al. (2021); Mortality:Dellink et al. (2019);Szewczyk et al. (2020); Roson and Sartori (2016)

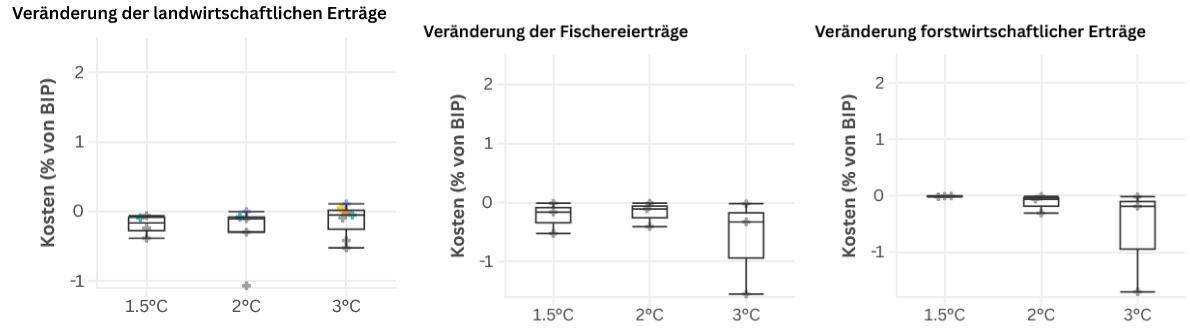

Figure 6: Sectoral effects of agriculture, forestry and fisheries as a percentage of GDP by warming level (GWL)
The box plot covers the 25th and 75th percentiles. Online link: https://public.flourish.studio/visualisation/23898568/
Sources considered: Agriculture:Parrado et al. (2021);Dellink et al. (2019); Roson and Sartori (2016);Ciscar et al. (2018);Szewczyk et al. (2020); Fisheries:Parrado et al. (2021); Forestry:Parrado et al. (2021)

2.2.2.3 Adaptation costs

Estimates of adaptation costs for Germany from modelling studies are available from sectoral and biophysical models for the areas of infrastructure damage caused by river flooding(Dottori et al. 2023) and coastal flooding (sea level rise)(Hinkel et al. 2014). Economic analyses that model adaptation options in addition to climate change impacts are equally rare. To date, only six publications for Germany or a larger region encompassing Germany have been found in the scientific literature that explicitly consider adaptation measures(Bachner et al. 2022; Flaute et al. 2024; Knittel et al. 2024; Lutz et al. 2025b; Parrado et al. 2020; Szewczyk et al. 2021). The results of the two sectoral models and the six macroeconomic studies are presented here.

2.2.2.3.1 Sectoral studies

A comprehensive assessment of adaptation measures to damage caused by river flooding is provided inDottori et al. Dottori et al. (2023) using the widely used LISFLOOD flood model, which was developed by the European Commission's Joint Research Centre (JRC) and is publicly available.Dottori et al. (2023) evaluate four key adaptation strategies for reducing future flood risk in Europe using model calculations and cost-benefit analyses. They project up to the year 2100 under three different global warming scenarios (1.5°C, 2°C, 3°C). For each of the four adaptation strategies (dyke raising, retention areas and basins, flood proofing and resettlement), they simulate the effects on future flood damage and population exposure.

The cost-benefit analysis optimises the benefits (economic damage avoided) and the costs of implementation and maintenance over the lifetime of the measures. For all measures except flood protection for buildings (flood proofing), the investment costs were calculated assuming a distribution of construction costs between 2020 and 2050, while maintenance costs were taken into account from 2050 to 2100. Flood protection measures on buildings have a limited service life compared to other measures, so additional construction costs for replacement measures are estimated for the period 2060–2090. Maintenance costs amount to 1% of the total construction costs. This calculation results in a cost-optimised level of protection. The effect of the measures applied (level of protection for dyke heightening and retention areas or damage reduction rate for flood protection on buildings and resettlement) increases linearly from 2020 (no effect) to the target value for 2050 and remains constant thereafter. Future costs and benefits are then discounted to present values, using a discount rate of 3% in the case of Germany.

Dike raising means raising or extending existing river dikes in order to increase the maximum amount of river water that can be absorbed by the water body and drained away without causing damage. Depending on the regional context, the measure involves the construction of new permanent dams or the raising of existing ones along the river network. The costs are calculated on the basis of the additional dyke height required and the total length of the extended dyke line(Dottori et al. 2023).

Flood retention areas and basins (detention areas) are areas created along river courses that serve to temporarily retain flood water during extreme flood events. This reduces peak discharges and delays them. These areas are usually surrounded by a dyke and collect flood water above a defined level via control structures such as pipes or overflows. The water is returned to the river channel in a controlled manner via appropriate outlet structures. In contrast to retention basins, which store water permanently, flood retention basins store water temporarily – even if permanent storage may be possible in individual cases. Retention areas, detention areas and detention basins are all considered nature-based solutions, as they utilise the natural retention capacity of floodplains and supplement it with technical facilities to ensure the safe absorption, storage and drainage of floodwater. In(Dottori et al. 2023), only flood detention areas and detention basins are modelled.

Flood protection measures for buildings include structural and non-structural adaptations aimed at preventing or minimising damage to the building fabric and contents caused by flooding. Dry flood proofing makes buildings watertight up to an expected water level, for example by sealing basement rooms. Wet flood proofing allows controlled water ingress into buildings and reduces damage through flood-adapted use and equipment, e.g. waterproof building materials and furniture(Dottori et al. 2023).

Resettlement is understood as an adaptation measure in which buildings and populations are relocated from flood-prone areas to safe zones. Model assumptions are based on a linear relationship between reduced building area and costs, which include construction, land purchase, demolition and higher costs for multi-storey buildings. Infrastructure and agricultural land are not taken into account. Resettlement destinations and social acceptance are not modelled.

The cost-benefit analysis calculates the discounted net value for each strategy from the total implementation costs (investment and maintenance) and the economic damage saved (flood losses avoided) over the lifetime of the measures. This allows damage to be presented once with and once without adaptation.Figure 7 illustrates the annual costs of various climate change adaptation strategies for temperature increases of 1.5°C, 2°C and 3°C (Table 6 contains the detailed data). The blue bars in Figure 7: Expected annual damage (EAD) and adaptation costs for four adaptation options: retention areas, dyke reinforcement, building protection and resettlement, in million EUR per year for three global warming levels (1.5°C, 2°C and 3°C); own representation based onDottori et al. (2023)show the expected annual damage (EAD), while the orange additional bars indicate the annual adaptation costs. The results presented here correspond to the median of multiple scenario combinations. The ranges of the results are discussed in Section 2.2.3.1.1.

The results show that the expected damage costs increase significantly as temperatures rise. In the "no adaptation" scenario, the amount of damage rises from around EUR 2,800 million per year (1.5°C) to approximately EUR 5,300 million per year (3°C). The implementation of adaptation measures such as retention areas or dyke reinforcements offers a significant reduction in EAD in all warming scenarios. At the same time, these measures result in additional annual costs, which are moderate compared to the damage costs saved by not adapting. The options of retention areas and dyke heightening appear to be particularly efficient, as both damage costs and adaptation costs remain relatively low in all temperature scenarios. In contrast, flood protection measures on buildings or resettlement lead to a reduction in damage, but due to the relatively low damage reduction potential and despite the low adaptation costs, they result in approximately the same total costs – especially in the case of severe warming. The analysis shows that adaptation can significantly reduce damage costs, but residual damage still increases with rising temperatures. The cost-effectiveness of all adaptation measures increases with the degree of global warming. This is because the benefits (damage avoided) are expected to grow faster than the implementation costs, due to the increasing frequency of floods and the associated exposure. One limitation of this study is that the combination of different measures was not considered in this modelling study.

Table 6 : Damage and adaptation costs for river flooding in millions of euros for Germany (own calculation based on data fromDottori et al. (2023)

		1.5°C		2		3	
		EAD	Adaptation costs	EAD	Adjustment costs	EAD	Adjustment costs
No adjustment		2812		3671		5330	
Adjust-	Retention ar-eas	956.1	221	954.5	280	1066	383
	Dike rein-forcement	1237.3	262	1248.1	340	1385.8	454

	Building security	2809.2	0.3	3663.7	1.2	5314	4.7
	Resettlement	2812	0.1	3671	0.1	5330	0.3

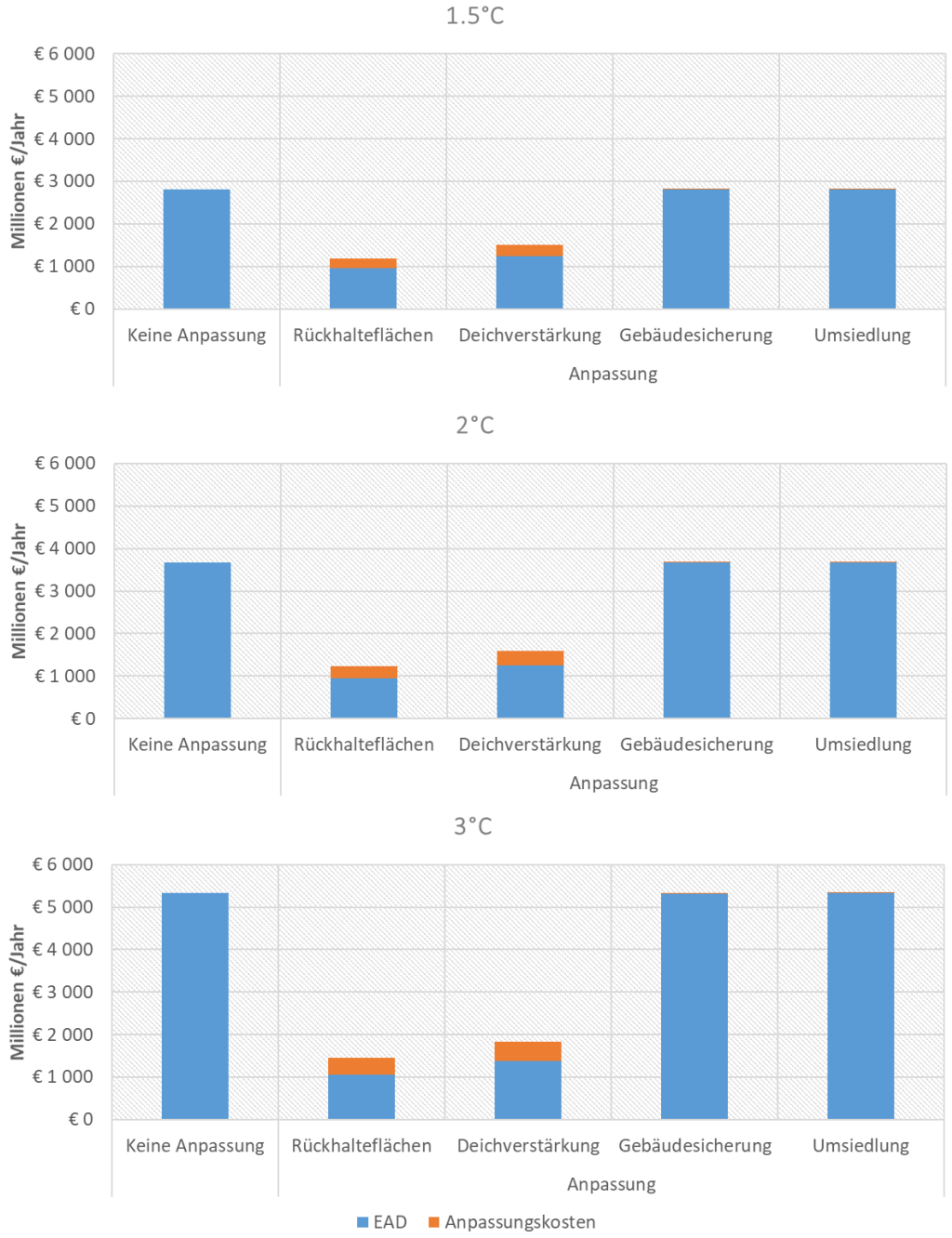

Figure 7: Expected annual damage (EAD) and adaptation costs for four adaptation options: retention areas, dyke reinforcement, building protection and resettlement, in million EUR per year for three global warming levels (1.5°C, 2°C and 3°C); own representation based onDottori et al. (2023)

Infrastructure damage caused by coastal flooding and adaptation costs are calculated using the DIVA model(Hinkel et al. 2014), which has also been used in numerous publications and is available via a public repository. DIVA (acronym for Dynamic Interactive Vulnerability Assessment) provides an

ecosystem of tools and data for modelling coastal impacts and adaptation measures on different spatial and temporal scales.

Figure 8 shows the annual damage and adaptation costs in millions of US dollars for different points in time (2030, 2050, 2080, 2100) and climate scenarios (RCP2.6, RCP4.5, RCP8.5). For each point in time and each climate scenario, there is one scenario without additional adaptation and one with adaptation. However, in the scenario without additional adaptation, maintenance costs associated with the existing infrastructure will still be incurred. The scenario with adaptation assumes explicit investments in the construction of new infrastructure to maintain the level of protection. This means, for example, that dykes must be raised in order to protect against a 100-year flood in the future. The costs shown here are for socio-economic development in line with SSP2 and the average of two climate models (HadGEM2-ES and IPSL-CM5A-LR).

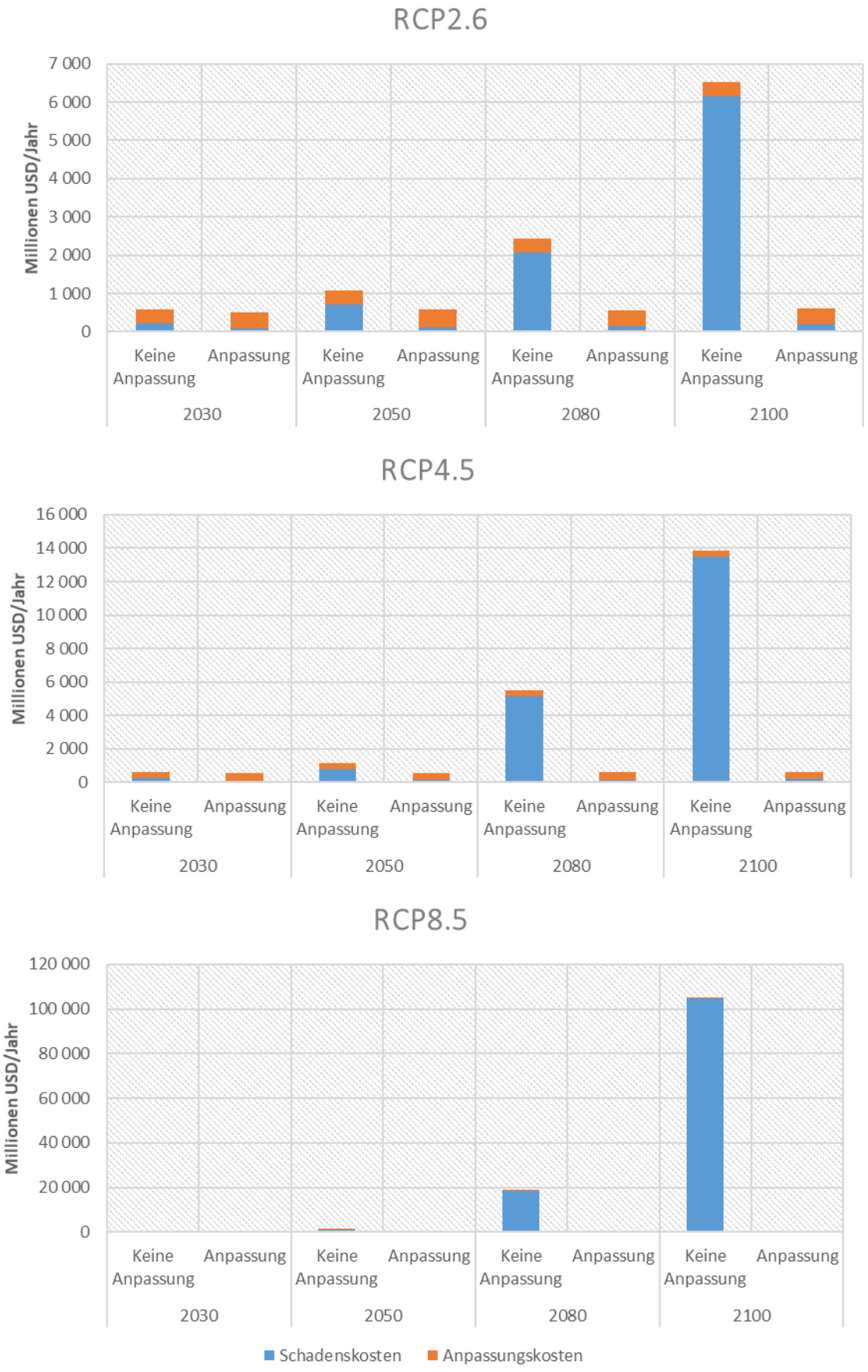

Figure 8: Coastal flooding damage in Germany due to sea level rise and adaptation costs in million USD/year for different points in time (2030, 2050, 2080, 2100) and climate scenarios (RCP2.6, RCP4.5, RCP8.5), own representation based on DIVA(Hinkel et al. 2014), data made available by the authors.

In all scenarios shown, the potential damage caused by coastal flooding (blue bars) increases significantly over time, with the increase accelerating significantly under the different climate scenarios (for better visibility, the scales of the vertical axis are not standardised). The damage costs are particularly pronounced under RCP8.5, rising to over USD 100,000 million per year by 2100 if no adaptation measures are taken. In contrast, if adaptation measures are implemented, the level of damage remains low over the entire period and for all scenarios, with adaptation expenditure (orange bars) increasing only very slightly and remaining significantly lower than the potential damage avoided.

Table 7 :Damage and adaptation costs in million USD/year for coastal flooding in Germany; data based on DIVA (Hinkel et al. (2014), made available by the authors.

		RCP2.6		RCP4.5		RCP8.5	
	Additional adaptation	Damage costs	Adjustment costs	Damage costs	Adjustment costs	Damage costs	Adjustment costs
2030	No	225	361	248	362	220	230
	Yes	86	416	94	490	94	526
2050	No	721	361	799	362	1,002	230
	Yes	116	477	119	468	121	524
2080	No	2,071	361	5,126	361	18,602	230
	Yes	146	420	149	485	178	496
2100	No	6,167	361	13,508	362	104,966	230
	Yes	182	420	179	469	216	496

The results of both studies show that damage costs from inland and coastal flooding will increase over time without adaptation and will be particularly pronounced under severe warming (3°C GWL or RCP8.5) – EUR 5.3 billion for inland flooding and USD 105 billion for coastal flooding per year towards the end of the century. Damage costs with adaptation remain significantly lower for all scenarios and time periods, i.e. adaptation is a cost-effective strategy. At the same time, it is also evident that damage costs with and without adaptation are significantly higher for coastal flooding than for inland flooding. Adaptation costs are low compared to damage costs without adaptation and show a moderate increase over time and between scenarios.

It should also be noted that damage costs and investment requirements in the area of flood protection are considered separately in a separate chapter (Chapter 2.3.2). This chapter draws on additional sources and analyses that go beyond the sectoral and macroeconomic modelling presented in this section.

2.2.2.3.2 Macroeconomic studies

If we consider those economic studies that model not only the consequences of climate change but also explicitly adaptation, the number of estimates for Germany or a larger region that includes Germany decreases dramatically (see Table 8 compared to Table 4). The 66 estimates presented here are taken from the six publications mentioned above (Bachner et al. 2022; Flaute et al. 2024; Knittel et al. 2024; Lutz et al. 2025b; Parrado et al. 2020; Szewczyk et al. 2021). Two publications deal with coastal flooding(Bachner et al. 2022; Parrado et al. 2020), while the other sectors are examined in one publication each. Although there is a macroeconomic estimate of the damage reduction potential of

adaptation for the effects of heat-related losses in labour productivity, it does not take into account the costs of adaptation (Szewczyk et al. 2021).

Table 8: Overview of macroeconomic cost estimates with adaptation: number of data points per warming level (columns 2-5) and number of sources per sector (column 6)

Sector	1.5°C	2	3°C	Total	Number of sources
Damage to infrastructure due to coastal flooding	2	6	10	18	2
Damage to infrastructure caused by inland flooding	4	18	10	32	1
Change in labour productivity			9	9	1
Damage in the transport sector	2	2	2	6	1
Extreme weather events			1	1	1
Total	**8**	**26**	**32**	**66**	**6**

The two publications, which deal with the effects of coastal flooding on infrastructure and the corresponding adaptation measures at the macroeconomic level, are based on data from the DIVA model(Parrado et al. 2020; Bachner et al. 2022). The study byBachner et al. (2022) examines the macroeconomic effects of adaptation strategies in the face of a sharp rise in sea levels by 2050, with a focus on Europe, whereby Germany represents a separate model region. Scenarios are used that reflect different climatic and socio-economic developments (RCPs and SSPs). The focus is on two central adaptation options: technical protective measures (e.g. coastal protection through dykes) and reactive migration from unprotected, flood-prone areas (autonomous adaptation). The modelling takes into account the migration of people from flood-prone coastal regions without adequate protection and compares the macroeconomic costs of different adaptation strategies. Differentiated thresholds are used to trigger migration and coastal protection depending on local economic and demographic conditions. A CGE model is used to simulate the macroeconomic effects.

The results of the study show that in most of the regions examined, a combination of technical protective measures and planned migration leads to lower macroeconomic costs than the use of flood protection measures alone. Nevertheless, flood protection measures prove to be economically viable in almost all regions. For Germany, a moderate climate scenario (RCP4.5) shows that GDP losses for 2030 and 2050 remain almost identical between scenarios with and without adaptation and with and without migration. However, in a more severe warming scenario (RCP8.5), adaptation measures will significantly reduce GDP losses by the middle of the century(Bachner et al. 2022).

Depending on the scenario for ice sheet melt, flood protection alone will reduce GDP losses in Germany in 2050 from 0.43% to 0.18% in a high melt scenario and from 0.24% to 0.2% in a medium melt scenario., if migration is also taken into account, the remaining GDP losses increase slightly and are reduced to only 0.23%(Bachner et al. 2022).

Parrado et al. (2020) examine the fiscal effects of climate change adaptation measures and analyse the macroeconomic impact of damage to infrastructure as a result of coastal flooding. The study also uses a CGE model to simulate the macroeconomic effects and quantifies the damage with and without

adaptation measures in 2050 as a percentage of GDP. Germany is included as part of the Northern EU-15 model region. The analysis is carried out in comparison to a reference scenario without climate change, taking into account socio-economic development according to SSP2 and SSP5. The study covers three climate scenarios defined by the RCPs: RCP2.6 (low warming), RCP4.5 (moderate warming) and RCP8.5 (high warming). With regard to adaptation, it is assumed that the desired level of protection will not remain constant, but will increase in line with rising per capita income, population growth and progressive sea level rise, in accordance with an empirical relationship.

The results show that damage to infrastructure caused by coastal flooding without adaptation measures is significant in all climate scenarios and tends to increase with rising temperatures and assuming socio-economic development in line with SSP5. The implementation of adaptation measures, such as technical coastal protection and migration, leads to a significant reduction in GDP losses. However, the effectiveness of these measures varies depending on the combination of climate scenario and socio-economic development path(Parrado et al. 2020).

Figure 9 shows the projected damage to infrastructure from coastal flooding in 2050, expressed as a percentage of gross domestic product (GDP) in the model region North EU-15, under different climate scenarios (RCP2.6, RCP4.5 and RCP8.5) and socio-economic development paths (SSP2 and SSP5). The bars represent damage with (blue) and without (red) adaptation measures.

The damage without adaptation is significant in all scenarios and increases with the intensity of climate change (from RCP2.6 to RCP8.5). Under SSP5, which assumes a resource-intensive and rapidly growing economy, the damage caused by coastal flooding is significantly higher than under SSP2. This is because SSP5 describes a resource-intensive development with higher economic activity and greater vulnerability to climate risks. The implementation of adaptation measures significantly reduces damage in all scenarios. The reduction in damage is particularly pronounced under SSP5. Damage also increases sharply with rising temperatures. Under RCP2.6, damage is lowest both with and without adaptation, while it is highest under RCP8.5.

The results ofParrado et al. (2020) show that both the intensity of climate change (RCPs) and socio-economic conditions (SSPs) are decisive factors in the amount of damage caused by coastal flooding. Adaptation measures can significantly reduce economic losses, especially in scenarios with high socio-economic development (SSP5) and strong warming (RCP8.5). This underlines the need for a combination of climate protection (to limit warming) and targeted adaptation strategies to minimise the economic impacts of climate change.

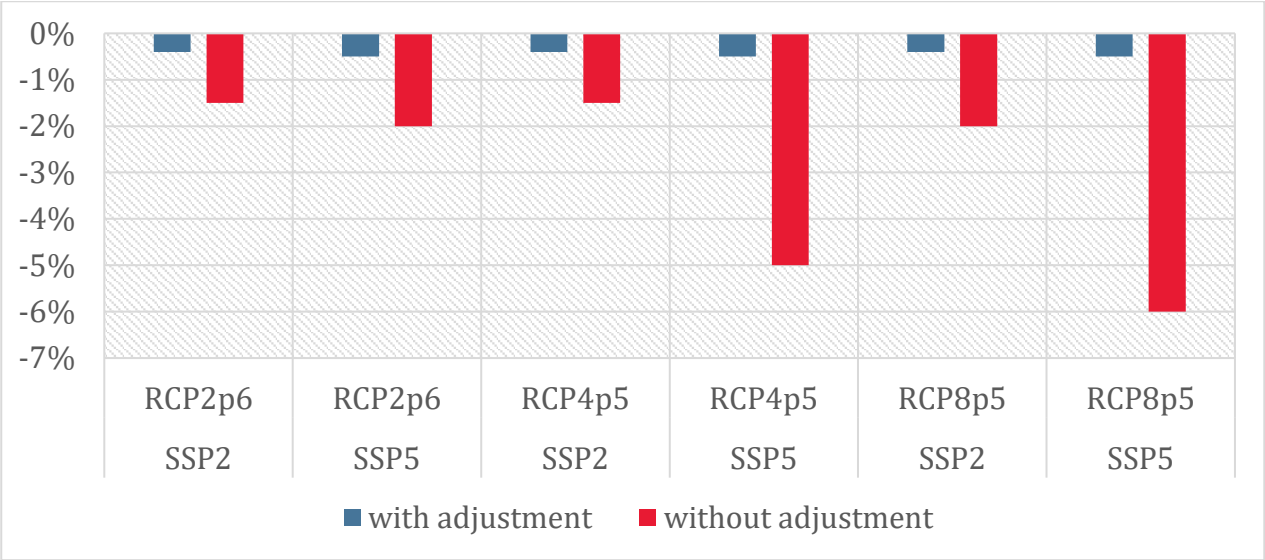

Figure 9 : Damage to infrastructure due to coastal flooding in the model region North EU-15 with and without adaptation in 2050 as a percentage of GDP compared to a scenario without climate change with socio-economic development according to SSP2 and SSP5 for three climate scenarios (RCP2.6, RCP4.5 and RCP8.5); Own representation based on Parrado et al. (2020)

Knittel et al. (2024) examine the macroeconomic effects of flood damage along rivers, taking into account different insurance systems; the study is designed for the EU, and the results are evaluated separately for Germany. While the overall effects of the insurance solutions analysed on GDP show only marginal differences, the results of the study show that the choice of insurance system has a significant impact on the distribution of financial burdens between public and private actors. Accordingly, welfare measures are also a more important indicator in this context. Depending on the climate scenario, model and socio-economic development, this shows a reduction in private welfare losses of 24 to 44% when switching to a public-private partnership and a reduction of 30 to 52% when switching to a solidarity solution, i.e. compulsory insurance with uniform premiums. This means that the welfare losses caused by flooding in Germany would be roughly halved in both compulsory insurance variants compared to the current insurance system (voluntary private insurance), as less ad hoc state disaster aid would be required, thus putting less strain on the public budget. Additionally, households would be faced with lower overall, but regular, insurance costs instead of one-off high restoration costs.

Szewczyk et al. (2021) analyse the effects of heat stress on labour productivity in Europe, including Germany. The study uses climate data from the EURO-CORDEX programme based on the RCP8.5 scenario, a scenario with high greenhouse gas emissions. This scenario is used to analyse the potential effects of heat stress on labour productivity under conditions of severe global warming. The study covers three time periods: the 2020s (near future), the 2050s (medium-term future) and the 2080s (long-term future). The results are compared with a reference period from the 1990s in order to assess changes over time. Three scenarios resulting from uncertainties arising from the use of different climate models and exposure-response functions (impact functions) are also taken into account. The results are thus presented for a "best", "mean" and "worst case" scenario.

Figure 10 shows the projected losses in gross domestic product (GDP) as a percentage caused by heat stress for the three scenarios (best case, mean, worst case) and time periods (2020, 2050, 2080). The losses are shown both for the case with adaptation measures (blue) and without adaptation measures (red). GDP losses increase in all scenarios and time periods, with losses without adaptation measures always higher than with adaptation. In the worst-case scenario in 2020, the losses are around -0.15% without adaptation and -0.14% with adaptation. By 2050, the losses rise to around -0.35% without adaptation and -0.29% with adaptation. In 2080, losses will be highest, reaching around -0.9% without adaptation and -0.65% with adaptation.

While Germany is less affected by heat stress than southern countries such as Spain or Greece, the results nevertheless show regional differences. Occupations involving moderate to high physical exertion, such as in agriculture or construction, could experience productivity losses in Germany. Adaptation measures such as the increased use of air conditioning and portable robotics could also help mitigate the negative effects in Germany. Germany is also highlighted as one of the countries that could benefit from such adaptations due to its technological advances and higher rates of robotisation.

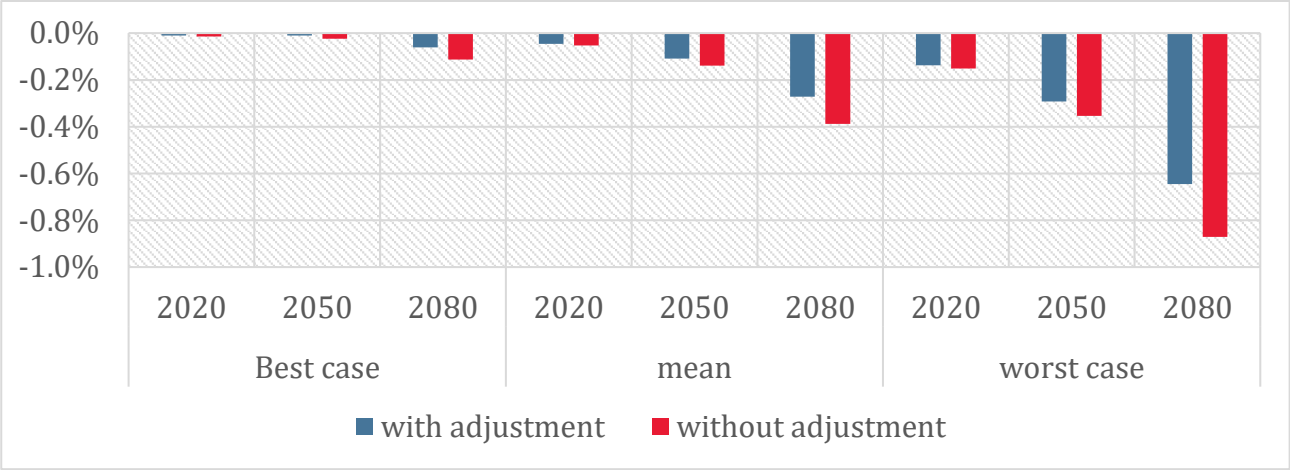

Figure 10 : Percentage losses in gross domestic product (GDP) in Germany due to heat stress for the years 2020, 2050 and 2080 for three scenarios (best case, mean and worst case), shown with (blue) and without (red) adaptation measures, own representation based onSzewczyk et al. (2021)

Flaute et al. (2024) examine the economic impact of selected climate risks (road closures due to flooding, cooling water shortages for coal-fired power plants, heat-related hospitalisations) for Germany under three socio-economic scenarios (trend, stability, dynamics). The effects are calculated using the PANTA RHEI macro model. Economically, the damage found is comparatively low, mostly averaging less than 0.004% of GDP per year. The damage varies depending on the socio-economic scenario: it is highest in the dynamic scenario with stronger growth and higher traffic use, and lowest in the sustainable stability scenario. Adaptation measures such as the expansion of road drainage can reduce damage by around 20% and also generate positive economic momentum through investment. In macroeconomic terms, the average annual damage is therefore less than 0.003% of GDP. Although additional health costs due to heat play a role, they have only a very minor impact on GDP and have therefore not been quantified.

In another study,Lutz et al.(2025b) (Lutz et al. 2025b) analyse the effects of extreme weather events on Germany's gross domestic product (GDP) until the middle of the century. Different mitigation scenarios are examined, both with and without adaptation measures. The results show that GDP will be reduced by up to 0.8% in the scenario without adaptation, while the decline can be reduced to 0.5% if a broad spectrum of adaptation strategies is taken into account.

One challenge in interpreting the results of the last two studies is the lack of consistency with established climate scenarios and economic and demographic developments as presented in comparable scenarios. The analysis is heavily based on assumptions and is not based on consistent, integrated scenarios, which limits the significance and comparability of the results.

2.2.3 Sensitivity analysis

Estimating future financing requirements for climate adaptation measures is fraught with considerable uncertainty. When considering financing requirements, it is therefore important to consider how sensitive the estimates on which the financing requirements are based are to different assumptions and scenarios. Key factors in this context include the different emission scenarios, climate models and

socio-economic projections, all of which have a significant impact on estimates of adaptation costs. The following sections highlight the key influencing factors and explain how they affect cost estimates. First, an assessment is made based on the studies evaluated in Section 2.2.2. Subsequently, Section 2.2.3.2 discusses further influencing factors and considers methodological limitations of quantitative approaches.

2.2.3.1 Estimating the change in financing requirements based on model studies

Quantitatively estimating the change in future financing needs for climate change adaptation is a complex and challenging task, as it is characterised by a multitude of uncertainties and interactions. Nevertheless, different approaches can help to structure this challenge and provide initial guidance. Here we present three approaches that offer different perspectives on the complex task of financing estimation and can be combined or applied individually depending on the availability of data and specific questions: firstly, consideration of changes in adaptation costs themselves; secondly, the damage reduction potential of adaptation; and thirdly, the development of damage costs depending on different analysis periods and scenarios for socio-economic development, climate development and the underlying climate models. All three approaches are applied or presented for the studies evaluated in the Section 2.2.2.

2.2.3.1.1 Focus on adaptation costs

The first approach is based on sectoral modelling studies that take into account specific adaptation goals such as maintaining a constant or cost-optimised level of protection. The adaptation costs are reported here for different scenarios, thus providing a basis for estimating the change in financing requirements. However, this methodological approach is currently only available for a limited selection of climate change impacts, which limits its applicability.

An example of the first approach can be found in the study byDottori et al. (2023). This study presents average annual damage costs caused by river flooding and adaptation costs for four adaptation options, taking into account two key influencing factors: (1) changes in the warming scenario and (2) model uncertainties. The median values of this study have already been presented in the Section 2.2.2.3.1, but without addressing the uncertainties that may play a role in deriving the financing requirements.

The modelling in the study is based on a broad ensemble of climate projections and long-term socio-economic development scenarios, taking into account a variety of possible future paths. Uncertainties in the results are quantified by presenting median and interquartile values from numerous model runs, which enables a robust assessment of potential damage costs.

The costs of reinforcing dykes also increase with rising temperatures. At 1.5°C, they range between EUR 157 and 409 million per year, rising to between EUR 289 and 672 million at 3°C, which corresponds to an increase of around 84% in the lower case and around 64% in the upper case. The costs of building protection show a particularly sharp increase with warming. While they are still relatively low at 1.5°C (EUR 0.1 to EUR 2.5 million per year), they rise dramatically to EUR 0.6 to EUR 78.6 million at 3°C. This suggests that damage to buildings could increase exponentially at higher warming levels. The costs of resettlement remain comparatively low in all scenarios, with a slight increase from EUR 0 to 0.3 million at 1.5°C and 2°C to EUR 0 to 0.5 million at 3°C. The low costs of resettlement are partly due to the fact that resettlement is a cost-effective measure in very few regions.

Table 9 shows the annual costs (in million EUR) for various adaptation measures depending on different global warming scenarios (1.5°C, 2°C and 3°C). The cost ranges reflect uncertainties arising from the underlying models and scenarios.

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Table 9 : Annual costs (in million EUR) and benefit-cost ratios (BCR) for various adaptation measures to river flooding depending on global warming scenarios (1.5°C, 2°C and 3°C). Ranges represent the quartile values (lower and upper quartile: Q1 and Q3, as well as median) from the models and scenarios, based onDottori et al. (2023). Data can be taken directly from the Supplementary Information document for the study.[4]

		1.5°C			2			3		
	Adaptation option	**Q1**	**Med**	**Q3**	**Q1**	**med**	**Q3**	**Q1**	**med**	**Q3**
Costs (in million EUR)	Retention areas	136	221	330	182	280	425	255	383	568
	Dike reinforcement	157	262	409	210	340	508	289	454	672
	Building security	0.1	0.3	2.5	0.2	1.2	9.8	0.6	4.7	78.6
	Resettlement	0	0.1	0.3	0	0.1	0.3	0	0.3	0.5
Benefit-cost Ratio (BCR)	Retention areas	3.10	3.5	4.10	3.2	3.8	4.90	3.10	3.8	5.20
	Dike reinforcement	2.1	2.6	3.2	2.3	3	3.9	2.50	3.2	4.30
	Building security	2.0	3.4	5.0	1.70	2.2	3.7	1.70	2	2.80
	Resettlement	3.30	4.5	6	3.30	4.4	6.0	3.0	4.3	6.0

The ranges are considerable for all measures, which points to uncertainties in the underlying climate models, socio-economic scenarios and assumptions about the effectiveness of the measures. The ranges of adaptation costs also tend to increase with higher warming scenarios. This shows that the uncertainties in the models become even greater in more extreme climate scenarios, which makes it more difficult to plan and prioritise adaptation measures. Nevertheless, the direction of the effects is robust: in all quartiles, the benefit-cost ratios of the adaptation measures are well above 1, so it can be concluded that the measures examined against inland flooding in Germany are cost-effective in any case.

2.2.3.1.2 Analysis of damage reduction potential

Another approach is to analyse the ratio of climate-related costs without adaptation measures to residual costs with adaptation measures (and taking into account adaptation costs) for those areas

[4] https://static-content.springer.com/esm/art%3A10.1038%2Fs41558-022-01540-0/MediaObjects/41558_2022_1540_MOESM1_ESM.pdf

where this estimate is already available. This ratio can serve as an indicator of the effectiveness of the modelled adaptation strategies and can be transferred to areas where such estimates are lacking. The approach is very rough, but in many areas, climate-related costs are already well known, while information on direct adaptation costs is often lacking. The sector-specific differences in these ratios that are already apparent can help to set priorities for investment and plan future financing needs in a targeted manner. The starting point for this is the economic climate-related costs on the one hand and an adaptation target on the other, which allows the financing requirements to be determined using the effectiveness indicators presented here.

Table 10 shows the ratio of climate-related costs without adaptation measures to the costs of implementing adaptation measures in various sectors. This ratio serves as an indicator for estimating the potential effectiveness of adaptation measures and the future financing requirements for their implementation. A higher ratio indicates that adaptation measures are particularly effective, as they significantly reduce damage compared to the scenario without adaptation. The results show that the effectiveness of adaptation measures depends heavily on the sector in question. Adaptation measures can significantly reduce damage, particularly in the case of coastal flooding and extreme weather events, while the effects are less pronounced in other areas such as inland flooding.

Table 10 : Ratio of climate-related costs without adaptation measures to costs with adaptation measures in various sectors in relation to GDP losses.

Sector	Climate-related costs without adaptation compared to costs with adaptation measures	Note on adaptation	Sources
Damage to infrastructure caused by coastal flooding	3	Structural measures and resettlement	Parrado et al. (2020) ;Bachner et al. (2022)
Extreme weather events	1.6	Wide range of adaptation measures	Lutz et al. (2025b)
Change in labour productivity	1.4	Indoor cooling, use of exorobotics, no adaptation costs	Szewczyk et al. (2021)
Damage in the transport sector	1.3	Assumption: adaptation reduces damage by 20%	Flaute et al. (2024)
Damage to infrastructure caused by inland flooding	1.0	Different insurance solutions	Knittel et al. (2024)

The ratio of 3 shows that damage caused by coastal flooding without adaptation is three times higher than when adaptation measures are implemented. On the one hand, this indicates the high effectiveness of measures such as structural protection and resettlement, but on the other hand, it also points to a high financing requirement in terms of high priority in order to implement these measures and minimise future damage.

For extreme weather events, the damage without adaptation is about 1.6 times higher than with adaptation measures. This shows that a wide range of adaptation measures, such as early warning systems or more resilient construction methods, can significantly reduce damage, albeit not as much as in the case of coastal flooding.

The ratio of 1.4 indicates that the negative impact on labour productivity is 40% higher without adaptation measures such as indoor cooling or the use of exorobotics. However, as no direct adaptation costs were taken into account here, the macroeconomic costs could be underestimated.

A ratio of 1.3 shows that adaptation measures in the transport sector can reduce economic damage by around a quarter. This is based on the assumption of a direct damage reduction of 20%, which forms the basis of the calculation. This shows that the reduction potential can be enhanced through economic integration.

The ratio of 1.0 implies that the adaptation measures examined (insurance) do not significantly reduce damage when used as protection against inland flooding. This is because the modelled measure represents an adjustment to insurance solutions, which primarily affects the distribution of costs rather than the overall economic effects. However, other measures against inland flooding, such as structural measures and retention areas, have a significantly more favourable cost-benefit ratio (see Table 9)

2.2.3.1.3 Consideration of damage cost development

The third approach focuses on estimating damage costs, which provide a picture of potentially avoidable damage. Although specific adaptation investments cannot be directly derived from this, these costs can serve as a framework for meaningful adaptation measures. Higher projected damage costs indicate a potentially increased need for adaptation, which underlines the urgency of corresponding investments.

This approach is based on the systematic analysis and aggregation of ranges of results from various studies. The aim is to calculate an average value that serves as a reference point for the magnitude of the influencing factors. Climatic scenarios are taken into account by calculating factors that quantify the difference between a strong and a weak climate or warming scenario. This enables an assessment of the sensitivity of damage to different climate paths. The analysis also includes the influence of socio-economic developments by comparing strong (stressful or vulnerable) socio-economic scenarios with weak (less stressful) scenarios. This takes into account factors such as population growth, urbanisation and economic development. In addition, a distinction is made between the near future and the distant future in order to capture the temporal development of damage and adaptation costs. The calculations are carried out on a sectoral basis in order to identify differences between the various sectors. This enables a differentiated analysis of sectoral sensitivities and adaptation needs. The calculated factors indicate how much the damage or costs differ between the scenarios. A higher value indicates greater sensitivity of the sector to the specific changes. A value of 1 means that the damage in the scenario under consideration, for example in the case of severe warming, is the same as in the comparison scenario, for example in the case of mild warming. A value of 2 would mean a doubling of the damage, and so on.

Table 11 shows the calculated factors for different sectors and scenarios. The last column indicates how many studies were considered for each sector, which also determines the ranking of the sectors. Some sectors, such as economic damage caused by water scarcity and drought, show a change in the direction of the effect depending on the warming scenario, which is why no damage reduction potential can be calculated: Other sectors, such as forestry and fisheries, show only positive effects according to the available studies, and therefore no damage reduction potential can be calculated either. For extreme weather events and tourism, only one scenario was considered in each case, which is why no sensitivity analysis can be performed.

Factors could be calculated for the remaining sectors, and the results show that both the climatic and socio-economic scenarios and the time dimension have a significant impact on damage. In addition, sectoral differences become apparent, indicating the specific sensitivities of the individual sectors.

Damage to infrastructure caused by coastal flooding has the highest factor of 8.6 in the temporal dimension, which means that damage in the distant future will increase almost ninefold compared to the near future. This is consistent with the understanding that sea level rise is a slow process that will have a particularly strong impact towards the end of the century. For adaptation, this may mean that the financing requirement in the long term is 8.6 times higher than in the short term. However, adaptation to sea level rise is often highly structural in nature and has long lead times and implementation phases. This indicator therefore reinforces the urgency of investing in adaptation in good time. Greater warming and socio-economic development could also increase damage in this sector by a factor of slightly more than 5.

The change in labour productivity shows a comparatively moderate sensitivity to climate scenarios with a factor of 2.9. This means that productivity losses are almost three times higher in the case of strong warming than in the case of weak warming. Socio-economic development has a similar impact with a factor of 2.8. In the temporal dimension, the factor is 4.1, indicating that the impacts in the distant future could be more than four times as high compared to the near future.

Cross-sectoral damage shows comparatively small differences with a factor of 1.6 in the dimension of socio-economic development. In the temporal dimension, the factor is 2.1, which means that damage in the distant future could be about twice as high as the near future. Sensitivity to climate scenarios is higher, with a factor of 3.9, meaning that more severe warming scenarios can significantly increase cross-sectoral damage.

Damage to infrastructure caused by inland flooding shows a comparatively small range with a factor of 1.2 in the climate scenario dimension. This means that although damage is higher in the case of strong warming than in the case of weak warming, the differences are less pronounced. The absolute damage can still be high, however, as inland flooding events have a significant impact even under moderate scenarios. Socio-economic development also has a low range with a factor of 1.1, suggesting that adverse socio-economic scenarios only slightly increase the damage. In the temporal dimension, the factor is 1.7, indicating that damage in the distant future could be moderately higher than in the near future. This shows that although adaptation to inland flooding events is less dependent on the scenarios, it is still important, as absolute damage can be significant even with small ranges.

Damage in the transport sector shows moderate sensitivity to climate scenarios with a factor of 2.6. This means that damage could be more than twice as high in the event of severe warming than in the event of mild warming. Socio-economic development has a similar but slightly lower impact with a factor of 2. In the temporal dimension, the factor is 4.7, meaning that damage in the distant future could be almost five times higher than in the near future. This underlines the need to develop long-term adaptation strategies for the transport sector.

Damage caused by changes in energy supply has the highest sensitivity to climate scenarios, with a factor of 6.4. This means that damage could be more than six times higher in the event of severe warming than in the event of mild warming. Socio-economic development also has a significant influence, with a factor of 4.6, suggesting that adverse socio-economic scenarios could significantly increase damage in this area. In the temporal dimension, the factor is 1.9, indicating that damage in the distant future could be moderately higher than in the near future. This shows that energy supply is particularly vulnerable to climate change and that early adaptation measures are necessary.

The change in energy demand shows moderate sensitivity to climate scenarios with a factor of 3.0. This means that energy demand is affected about three times as much by strong warming as by weak

warming. Socio-economic development has a similar influence with a factor of 3.5, suggesting that adverse socio-economic scenarios can also significantly alter energy demand. In the temporal dimension, the factor is 3.5, indicating that the impacts in the distant future could be more than three times higher than in the near future.

Finally,Szewczyk et al. (2021) show that damage caused by changes in heat-related mortality is 2.5 times higher in a higher warming scenario than in a low warming scenario. No scenarios were modelled for the dimensions of socio-economic development and time period, so no further statements can be made about these influencing factors. Nevertheless, the factor illustrates that adaptation to heat waves and improvement of health protection are of central importance in a scenario of strong warming.

Table 11 : Overview of the sectoral impacts of climate change based on climate scenarios, socio-economic developments and time dimensions.
The figures shown are averages of the data points from the various studies. Breakdown into contributions from climate scenarios (high relative to low warming), socio-economic development (high compared to low vulnerability or exposure) and time period (end or middle of the century).

Sector	Climate scenarios	Socio-economic development	Time period	Number Sources
Damage to infrastructure due to coastal flooding	5.3	5.3	8.6	6
Change in labour productivity	2.9	2.8	4.1	6
Cross-sector damage	3.9	1.6	2.1	5
Damage to infrastructure caused by inland flooding	1.2	1.1	1.7	4
Damage in the transport sector	2.6	2.0	4.7	2
Changes in energy supply	6.4	4.6	1.9	2
Change in energy demand	3.0	3.5	3.5	2
Change in mortality due to heat	2.5	-	-	1
Economic damage caused by water scarcity and drought	Effect changes from positive with low warming to negative with high warming			
Extreme weather events	Only one scenario considered			
Tourism	Only one scenario considered			
Change in agricultural yields	Effect varies between positive and negative			
Change in forestry yields	Positive effects, no damage reduction potential			
Change in fishery yields	Positive effects, no damage reduction potential			

2.2.3.2 Preparation of other relevant factors

This chapter brings together key influencing factors for sensitivity analyses. At the same time, a comparison with the studies consulted shows that many of these factors are only partially or not at all explicitly varied in the models – a clear indication of the need for further research. The following studies were used as examples:Bachner et al. 2022),Lutz et al. 2025b), (Parrado et al. 2020) andKnittel et al. 2024).

2.2.3.2.1 Adaptation level and residual risk

The adaptation level describes the level of protection against climate risks (e.g. floods, heat waves) to be achieved through adaptation measures. It determines the extent to which infrastructure, buildings

or areas should be protected against certain extreme events. A high level of adaptation means that a very high level of protection is sought – for example, through particularly robust construction methods, high dykes or comprehensive building cooling. This leads to correspondingly higher investment and running costs. Conversely, a lower level of protection can be chosen, which incurs lower costs but also leads to higher residual risks and potential damage.

The residual risk is the risk that remains despite all the adaptation measures taken – in other words, the remaining risk of damage from climate impacts. It is practically impossible to eliminate all risks completely, as this would incur disproportionately high costs. Instead, in practice, an acceptable residual risk is defined which is accepted for economic, technical or social reasons, for example. The level of accepted residual risk is a conscious political and social decision and has a significant influence on how far-reaching and cost-intensive the chosen adaptation measures will be.

The choice of adaptation level and residual risk is always a trade-off between costs and benefits. A very high level of protection can lead to extremely high costs in individual cases, while too low a level can lead to unacceptable damage and consequential costs. In the cost-benefit analysis, various scenarios are therefore calculated to illustrate the effects of different levels of protection and residual risks on the total costs and remaining damage. The optimal solution usually lies in a balance between reasonable costs and a socially tolerable residual risk(Watkiss 2022). The previous studies operationalise this trade-off in different ways and illustrate the remaining residual risk:

Bachner et al. (2022), for example, indirectly compare different levels of adaptation by running through four scenarios: no adaptation at all, only protective structures (dykes), only retreat/migration, and a combination – showing that despite measures, some damage always remains and the cost-benefit balance varies from region to region.

Lutz et al. (2025b) implement different levels of protection across scenarios and sensitivities (without/with adaptation, combined, doubling of damage and measures) and show that despite adaptation, residual damage remains; however, a formally defined "accepted residual risk" is not calibrated.

Parrado et al. (2020) implement different levels of protection across scenarios: without additional adaptation (protection level at previous level) versus with additional coastal protection through dykes, whose target protection level grows endogenously with prosperity and population density; this significantly reduces damage, but does not completely prevent it, so a residual risk remains. A politically determined "acceptable" residual damage threshold is not calibrated in this case, but residual damage results from the model assumptions.

2.2.3.2.2 Selection and effectiveness of measures

The costs depend heavily on which specific adaptation measures are chosen and how their effectiveness is assessed. Different technical solutions (e.g. construction methods, protection standards) and their costs should be varied, as should assumptions about the actual efficiency of the measures. The combination of measures into so-called measure packages is also particularly relevant here, as individual measures often have a different effect than a whole bundle. Uncertainty about the actual impact of the measures is a key aspect that should be taken into account in sensitivity analyses.

Another important factor is the degree of preparation: proactive, well-planned measures are generally more cost-effective in the long term than purely reactive approaches, where damage is only repaired after an event has occurred. The degree of ambition and foresight in the adaptation strategy should therefore also be included in the analysis.

The example of the range of adaptation costs for buildings according to Sander et al. (2025) shows how significant the influence of the choice of adaptation measures is on the cost analysis. Depending on the measures chosen, the range of costs for adapting a single-family home to heat is between EUR 14,600 and EUR 62,800. For a multi-family house, the range is even wider, from EUR 28,250 to EUR 143,000 (Sander et al., 2025).

The literature shows that the choice and combination of measures have a strong impact on the results: Bachner et al. (2022) show that combinations of protective structures and retreat/migration are often more cost-effective than pure protection strategies; Lutz et al. (2025b) quantify the effect of a specific national package of measures and vary damage and adaptation intensities; Parrado et al. (2020) focus narrowly on dykes (investment and ongoing maintenance) without varying alternatives; Knittel et al. (2024) demonstrate that institutional insurance arrangements (voluntary/solidarity-based/PPP) have a noticeable impact on macroeconomic losses and burden sharing, but do not replace technical protection standards. Overall, technical variants and the effectiveness of individual measures are rarely systematically and sensitively evaluated.

2.2.3.2.3 Delimitation of additional adaptation costs

The estimated costs of adaptation also depend on whether measures relating to general public services or resilience building are also included in their entirety (Lutz et al. 2025a). A key problem is that many general resilience-building measures – such as modernising infrastructure, raising building standards or improving disaster control – can serve both climate protection and general public services or other political objectives (Raffer 2023). Whether and to what extent the costs of such measures can be attributed to climate adaptation is methodologically complex and can have a significant impact on the total amount of adaptation expenditure. Differential calculations that attempt to identify only the additional costs actually caused by climate change are complex and subject to further uncertainties. In practice, therefore, measures are often included in their full amount in the cost estimate, as a differentiated allocation would be too costly and resource-intensive.

This approach means that the reported adaptation costs can vary greatly depending on the definition and methodology used. It is therefore important to make the respective definition and underlying assumptions transparent in the cost assessment. For sensitivity analyses, it is advisable to consider different variants of cost delimitation in order to reveal the range of possible results and to illustrate the effects of different allocation methods on the total costs.

None of the studies discussed above integrate a systematic sensitivity analysis of different cost allocation variants (e.g. incl./excl. public services or co-benefits). All of them work with narrow, clearly defined cost assumptions; transparency regarding assumptions is provided, but the impact of alternative allocation methods on total costs is not simulated.

2.2.3.2.4 Cost types

A decision must also be made as to which cost types are considered: Does the analysis only include one-off investment costs or also medium to long-term maintenance and repair costs? Especially in the case of long-lasting infrastructure, running costs are often considerable and should not be omitted from a comprehensive analysis (Dépoues et al. 2024).

The timing of implementation and the lifespan of the respective investment have a significant impact on the total costs. Short-lived measures can be renewed several times, while long-term investments require forward planning. Long-term infrastructure measures generally have different cost profiles than short-term solutions.

To illustrate the cost structure in the model studies: Bachner et al. (2022) take into account both construction and ongoing maintenance costs and the temporal effect on the economy; however, they do not examine how alternative maintenance rates or different lifespans of the facilities influence the total costs. Similarly, Parrado et al. (2020) integrate one-off investment costs (dyke construction) and ongoing operating and maintenance costs and model the implementation over time across the scenario; however, sensitivity to different rates for ongoing costs, lifespans or replacement cycles of the infrastructure is not included.

2.2.3.2.5 Non-financial barriers and implementation obstacles

In addition to the financial aspects, there are numerous other barriers that make the implementation of climate adaptation measures difficult and often indirectly increase costs. The most important obstacles include long planning and approval times, complex legal procedures, frequent lawsuits, land use conflicts, and bottlenecks in the construction industry and supply chains. Historical contamination, such as contaminated soil, can also significantly delay or increase the cost of certain measures.

Other obstacles to implementation mentioned in the expert interviews include long planning and approval times, land use conflicts, and bottlenecks in the construction industry and supply chains. Historical burdens such as contaminated soil further complicate certain measures. These factors mean that adaptation measures can only be implemented much later, if at all, and that the actual costs increase compared to the originally planned investments(Lutz et al. 2025a). At the same time, many of these aspects are extremely difficult to quantify and can hardly or not at all be systematically reflected in traditional cost estimates.

None of the four studies includes a systematic sensitivity analysis of non-financial barriers (planning, legal issues, land, capacity, supply chains, contaminated sites). Bachner et al. (2022) only mention such non-financial barriers marginally as a limitation and do not quantify them: they emphasise that public protection measures are financed from tight budgets and raise distribution issues, but do not take into account delays due to legal, planning or capacity bottlenecks in their sensitivity analysis.

2.3 Detailed examination of two fields of action

In addition to this comprehensive analysis of climate adaptation financing needs in Germany, two sectors were selected for detailed examination in this study. For these two areas, existing data sets were used to estimate the potential adaptation costs. The sectors under consideration were selected according to where particularly significant damage costs are to be expected as a result of the effects of climate change and where adaptation investments are therefore particularly urgent. Further selection criteria were: the definability of the adaptation needs under consideration, the availability of usable data sets and the influenceability of political decisions at federal level. For example, although there is a significant need for adaptation in the agricultural sector, many political and financial decisions are not made at national level, but at EU level. Based on these considerations, the building sector and flood protection were selected for detailed analysis.

2.3.1 Detailed analysis of the building sector

The building sector in Germany faces considerable challenges due to the increasing effects of climate change. Extreme weather events such as heavy rainfall, flooding and heat waves are already causing considerable damage to buildings and infrastructure. In addition to the direct costs incurred in the event of damage, there are also long-term burdens if the necessary adaptation measures are not implemented in good time. A reliable estimate of the investment costs is therefore crucial in order to quantify the need for political and social action, to target funding instruments and to support owners and local authorities in prioritising measures.

Against this background, the present analysis aims to systematically record the potential costs of climate adaptation measures in Germany's building stock. It is based on several nationwide data sources that provide information on building stock, risk assessments and cost estimates.

2.3.1.1 Data sources

The data sources summarised in the following table form the basis of this analysis.

Table 12 : Overview of data sources used for analysis of adaptation costs in the building sector

Publisher, author	Name	Data type
Sander et al. 2025	Climate adaptation in the construction industry – Future security and growth opportunities for the construction industry	Cost estimates for climate adaptation depending on building type and climate signal
Statistisches Bundesamt 2023	Buildings (as of 15 May 2022)	Number of building types and ownership structures at municipal, state and federal level
Bundesinstitut für Bau-, Stadt- und Raumforschung 2024	Reference tables on spatial divisions of the BBSR. Status as of 31 December 2023	Categorisation of municipalities into spatial types Category used: Regional statistical spatial type Municipal type 5 (Regio (2023) Name)
Gesamtverband der Deutschen Versicherungswirtschaft e. V. 2025	"ZÜRS Geo" – Zoning system for flood risk and assessment of environmental risks	Risk assessment of Germany's building stock for flooding and heavy rainfall
Statistische Ämter des Bundes und der Länder 2024	Buildings (as of 15 May 2022): Year of construction (decades)	Year of construction Building stock in Germany

Based on these data sources, various assumptions were made regarding the expected adaptation costs in the building sector, and the data was cross-referenced to create differentiated cost scenarios for the building stock.

2.3.1.1.1 Cost data for adaptation measures according to climate signal

The basis for calculating adaptation costs is provided by the cost estimates from the study by Sander et al. (2025). In this study, specific packages of measures were developed for each of the three key climate signals – heavy rainfall, flooding and heat – comprising typical structural and technical adaptation measures for different types of buildings (single-family homes, multi-family homes, non-residential buildings). The adaptation levels are defined functionally by the scope and combination of the packages of measures; the study does not provide a formal quantitative definition of objectives in the

sense of specified protection targets (e.g. return intervals such as HQ100 or limit values for summer indoor temperatures). The design is scenario-based (RCP 2.6/8.5) and building type-specific in terms of the costs and scope of implementation of the packages.

For each climate signal, the packages of measures were compiled in such a way that they address the relevant risks.

For heavy rainfall, for example, this package of measures includes:

- property protection measures for building openings (e.g. pressure-water-tight windows, doors, light wells), backflow protection for drainage systems
- Sealing of basements and wall surfaces
- Adaptation of the terrain surface to drain surface water
- Installation of emergency power systems for pumps

For flood protection, these include:
- Raising the base and foundation height of new buildings
- Use of flood-resistant building materials in endangered storeys
- Mobile flood protection systems (bulkheads, dams)
- Protection and relocation of building services from areas at risk
- Terrain adjustments (embankments, dyke fronts)

The package of measures for adapting to heat includes:
- External shading systems (roller shutters, awnings)
- Greening of roofs and facades
- Installation of solar control glazing
- Improvement of thermal insulation in roof and exterior wall areas
- Installation of efficient cooling systems (e.g. split units, heat pumps with cooling function)

The study differentiates the costs for these packages of measures according to building type and provides a range of minimum to maximum adaptation costs for each combination of building type and climate signal. These ranges reflect different levels of equipment, building characteristics and regional price differences. For multi-family dwellings, synergy effects were also taken into account, so that costs do not increase linearly with the number of residential units, but can decrease with increasing building size per residential unit. These packages of measures and the range of associated costs were used as the data basis for the calculations in the following sections.

2.3.1.1.2 Building stock data

The building stock data from the census was used to analyse the climate adaptation costs in the building sector (Statistisches Bundesamt 2023, Stand: 15.02.2022). The census database contains comprehensive information on the number of residential buildings and their distribution across different building types for all municipalities in Germany.

A three-stage, indicator-based classification scheme was used for the present evaluation: (i) single-family house, (ii) multi-family house and (iii) non-residential building. The type was assigned based on the number of dwellings per building: buildings with exactly one dwelling were classified as single-family houses, buildings with more than one dwelling as multi-family houses. In addition to the classification based on the number of dwellings, the census category "buildings with living space" was used for the cost estimates, which is divided into "residential buildings" and "other buildings with living space". The cost rates for "non-residential buildings" defined in Sander et al. (2025) were assigned to "other buildings with living space", as these mixed-use buildings (with

administrative/commercial components) best reflect the adaptation costs of buildings with different uses.

The census data is available at the small-scale municipal level, enabling consistent nationwide recording and evaluation of the building stock by type. It forms the basis for linking with other data sets, such as the BBSR's settlement structure spatial typology, in order to analyse regional differences in building structure and their climate-related risks.

Based on the census data on the building stock and the distribution of building types, the next step was to classify all municipalities according to their settlement structure. This classification according to the BBSR's spatial types makes it possible to differentiate between building structures and climate-related risks not only according to building type, but also according to degree of urbanisation and settlement density.

2.3.1.1.3 Spatial typology of municipalities and cities

For various climate signals, especially heat stress, it is necessary to differentiate between different degrees of urbanisation in the analysis, as the stress varies greatly depending on this. For this purpose, German municipalities and cities were classified according to the BBSR's settlement structure spatial types. The BBSR's spatial typology is based on the so-called Regional Statistical Spatial Typology (RegioStaR), which is regularly updated and adapted to the current territorial status. The aim of this typology is to group territorial and municipal units with similar settlement structure, demographic and economic characteristics in order to better analyse regional differences in development and infrastructure planning.

The classification is carried out at municipal level and distinguishes between different types of areas, which are characterised in particular by features such as settlement density, size, centrality and urban functions. The following five types of areas were used for the present study:

- Small-town, village area
- Urban areas
- Central city, medium-sized city
- Regional centre and large city
- Metropolis

These spatial types allow for a differentiated view of building structure and climate-related risks depending on the degree of urbanisation. Each municipality was assigned to one of these types based on the "Regional Statistical Spatial Typology Municipality Type 5 (RegioStaR 2023)" provided by the BBSR and documented in the reference tables used. By taking these spatial types into account, the adaptation costs could be analysed and interpreted not only at the federal level, but also differentiated according to settlement structure.

2.3.1.1.4 Determination of risk levels – flooding and heavy rainfall

Not all buildings in Germany are equally exposed to the risk of flooding or heavy rainfall. For the purposes of this analysis, risk classifications were therefore differentiated on the basis of a categorisation by the GDV, which in turn is derived from the ZÜRS Geo system. The present analysis takes the percentage shares of affected buildings and applies them. This is a deliberately simplified, baseline-oriented approach that does not take into account future changes or protective measures that have already been implemented, thus providing a cost estimate in the sense of an upper range. Specifically, it was assumed that buildings in the medium risk category would incur the low estimated adaptation costs along the range specified by Sander et al. (2025), while buildings in the high risk category would incur costs at the upper end of the range.

It is assumed that all buildings in these two risk categories have not yet implemented any or only insufficient adaptation measures and therefore the full cost approach applies. To calculate the total costs, the proportions of affected buildings in each municipality – separated into medium and high risk – were multiplied by the respective cost approach from Sander et al. (2025). Example: A municipality with 6.1% of buildings in the medium risk category and 1.5% in the high risk category receives two partial cost amounts (medium risk × low cost estimate, high risk × higher cost estimate), which are then added together. This results in the total costs per municipality, which are then aggregated for evaluation at the state or federal level.

As mentioned above, the risk classifications for heavy rain and flooding are based on the GDV's "ZÜRS Geo" zoning system. This system assigns a hazard class for flooding, backwater and heavy rain to every address in Germany. Three risk classes (low, medium, high) are assigned for heavy rain and four risk classes for flooding. These are based on regional flood statistics, topographical features and empirical values from the insurance industry, among other things. The classification allows for a nationwide, address-specific risk assessment and is used, among other things, to calculate premiums for natural hazard insurance.

Table 13: Percentage of buildings in different risk categories, based on Gesamtverband der Deutschen Versicherungswirtschaft e. V. (2025)

Climate signal	Risk level	Percentage of building stock (%)
Heavy rain	Risk level "low"	22
	Risk level "medium"	65.8
	Risk level "high"	11.8
Flood	Risk level "low"	92.4
	Risk level "medium"	6.1
	Risk level "high"	1.5

2.3.1.1.5 Determination of risk levels – heat

Since, unlike heavy rain and flooding, there are no comprehensive risk classifications from the GDV for the climate signal heat, the year of construction of the buildings was used as a pragmatic proxy. This approach enables a consistent nationwide assessment of heat exposure, even if it does not reflect regional differences in heat stress.

The risk assessment is based on the assumption that the year of construction of a residential building can be a pragmatic proxy for summer heat protection and thus for heat exposure. Several studies have empirically demonstrated a correlation between the age of a building and increased vulnerability to heat exposure(Vandentorren et al. 2006). However, the year of construction thresholds used in the research vary considerably, and there is currently no uniformly recognised classification of heat exposure in existing buildings based on age.

The division into three risk categories (high, medium, low) used here follows the local classification of the City of Cologne (2011), which was also adopted by the Federal Office for Civil Protection and Disaster Assistance (Bach et al. 2013 2013). In Cologne, it was observed that:

- Buildings constructed before 1975 were often retrofitted with insulation and therefore have at least moderate summer heat protection.
- Buildings constructed between 1975 and 2004 were often not renovated and therefore have a poorer insulation standard.

– Buildings constructed after 2005 meet significantly higher legal requirements for thermal insulation (e.g. EnEV 2004) and therefore tend to be better protected against heat.

This specific classification is not based on a nationally established system, but was adopted as the most appropriate and methodologically comprehensible solution in the absence of more detailed data at national level. It enables a rough but comprehensible classification of heat exposure in existing buildings. The percentage distribution of buildings in Germany by age class was taken from the census database (as of 15 May 2022).

This results in the following categorisation:

Table 14: Percentage distribution of the building stock in Germany by year of construction, based on Statistische Ämter des Bundes und der Länder 2024

Risk level	Years of construction	Percentage share of building stock	Reason
High	1975–2004	34	Many buildings without subsequent renovation, poor insulation standard
Medium	Before 1975	55	Mostly old buildings, some retrofitted with insulation, some not renovated
Low	From 2005	16	New buildings with stricter thermal insulation requirements

As with heavy rainfall, it is assumed that for heat, no measures will be implemented for low risk, measures at the lower end of the cost range will be considered for medium risk, and measures at the upper end of the cost range will be considered for high risk.

2.3.1.1.6 Definition of a cost range for each climate signal and risk level

As described in the previous sections, different risk categories were determined for each of the three climate signals considered. In the further analysis, it was assumed that adaptation measures would be implemented for buildings in the medium risk category, which tend to be at the lower end of the cost range developed by Sander et al. (2025). For buildings in the high risk category, it is assumed that measures at the upper end of the cost range will be implemented. However, in order to reflect a range of costs in each case, not only the minimum and maximum values of the total cost range were used, but a range of costs was defined for each risk level. This range covers the 1st to 20th percentile of the total cost range for the medium risk level and the 80th to 100th percentile for the high risk level. For each risk level, a minimum value, a maximum value and a mean value were calculated along this range.

This approach allows three scenarios for the development of adaptation costs to be derived: a minimum (scenario 1), a medium (scenario 2) and a maximum scenario (scenario 3). This allows the range of possible costs to be systematically mapped and uncertainties in the risk analysis to be taken into account more transparently. This corresponds to the attempt to map as realistic a range of adaptation costs as possible. If only a single cost value were used for the calculation, this would suggest a degree of accuracy that the current data does not provide.

The following tables show how the cost estimates, risk levels and affected buildings for the individual building types and climate signals were linked in the analysis:

Table 15: Overview of the ranges of adaptation costs per building type – heavy rainfall

Heavy rainfall								
Building type	**Cost range for adaptation (min.-max.) [EUR]**	**Costs for "medium" risk level**			**Costs for "high" risk level**			
		Proportion of buildings (%)		66	Proportion of buildings (%)		12	
Detached house	3,600 –45,000	Lower end of cost range			Upper end of cost range			
		Minimum cost	Average cost	Cost max	Costs min	Costs medium	Maximum cost	
		3600	7740	11,880	36,720	40,860	45,000	
Multi-family house	7,000 - 110,000	Lower end of the cost range			Upper end of cost range			
		Minimum cost	Average cost	Maximum cost	Minimum cost	Costs medium	Maximum cost	
		7,000	18,300	29,600	87,400	98,700	110,000	
Non-residential buildings	11,300 – 276,00	Lower end of cost range			Upper end of cost range			
		Cost min	Average cost	Cost max	Minimum cost	Costs medium	Maximum cost	
		11,300	37,500	64,000	223,000	249,500	276,000	

Table 16: Overview of the range of adaptation costs per building type – flooding

Flood								
Building type	**Cost range for adaptation (min.-max.) [EUR]**	**Costs for "medium" risk level**			**Costs for "high" risk level**			
		Proportion of buildings (%)		6.1	Proportion of buildings (%)		1.5	
Detached house	3,600 – 53,000	Lower end of cost range			Upper end of cost range			
		Minimum cost	Average cost	Maximum cost	Minimum cost	Costs medium	Maximum cost	
		3,600	8,540	13,480	43,120	48,060	53,000	
Multi-family house	7,000-130,000	Lower end of the cost range			Upper end of cost range			
		Minimum cost	Average cost	Maximum cost	Minimum cost	Costs medium	Maximum cost	
		7,000	19,300	31,600	105,400	117,700	130,000	
Non-residential buildings	11,000 – 275,000	Lower end of cost range			Upper end of cost range			
		Cost min	Average cost	Maximum cost	Minimum cost	Costs medium	Maximum cost	
		11,000	37,400	63,800	222,200	248,600	275,000	

Table 17: Overview of the ranges of adjustment costs per building type – heat

Heat							
Building type	**Adaptation costs (min.-max.) [EUR]**	**Costs for "medium" risk level**			**Costs for "high" risk level**		
		Proportion of buildings (%)	55		Proportion of buildings (%)	34	
Detached house	2,900 – 59,300	Lower end of cost range			Upper end of cost range		
		Minimum cost	Average cost	Maximum cost	Minimum cost	Costs medium	Maximum cost
		2,900	8,540	14,180	48,020	53,660	59,300
Multi-family house	10,300 - 115,000	Lower end of cost range			Upper end of cost range		
		Minimum cost	Average cost	Maximum cost	Minimum cost	Costs medium	Maximum cost
		10,300	20,770	31,240	94,060	104,530	115,000
Non-residential buildings	7,400 – 320,000	Lower end of cost range			Upper end of cost range		
		Cost min	Average cost	Maximum cost	Minimum cost	Costs medium	Maximum cost
		7,400	38,660	69,920	257,480	288,740	320,000

2.3.1.1.7 Heat: differentiation according to urban infrastructure

Since heat stress is influenced not only by the building stock but also by the urban structure and the degree of sealing, the adaptation costs were additionally differentiated according to settlement structure types. This is based on the BBSR classification according to the Regional Statistical Spatial Typology (RegioStaR 2023), which assigns all municipalities in Germany to one of five spatial types: metropolis, regional centre/large city, central city/medium-sized city, urban area and small town/village area.

For the present analysis, each municipality was first assigned a spatial type. A multiplier was then applied to the calculated adaptation costs to take into account the type-dependent differences in heat stress and structural conditions. The multipliers are based on scientific literature and practice-

oriented studies on urban heat island effects, building density and social vulnerabilities (see, among others, Umweltbundesamt 2023a). The value for metropolises (1.0) is used as a reference. Lower multipliers were applied for less densely built-up and more green space-rich areas, for example 0.8 for urban areas or 0.5 for small towns/villages.

This approach makes it possible to supplement the nationwide uniform risk assessment by year of construction with a more realistic spatial structural factor. This takes into account the fact that densely built-up metropolitan areas generally require greater structural and technical expenditure for effective heat protection, while in smaller towns and rural areas, less extensive measures are often sufficient. They do not represent a precise representation of individual building requirements, but are intended to enable a rough, systematic weighting where differentiated data is not available. The factors should always be reviewed and, if necessary, adjusted in the context of specific planning through local surveys and context analyses.

Table 18: Overview of different area types and differentiation of heat stress

Area type	Multiplier	Explanation
Metropolis	1.0 (reference value)	Highest heat stress due to pronounced urban heat island effect (UHI), high levels of soil sealing, high building density, little cooling during tropical nights.
Regional centre / large city	0.8	UHI effect present, but less pronounced than in metropolises; slightly lower building density, better ventilation, lower social vulnerability.
Central city / medium-sized city	0.7	Limited heat islands, often better fresh air supply, more greenery, lower building density; nevertheless, local heating possible in dense old town structures.
Urban area	0.8	Moderate UHI, medium building density, socio-structural risks partially relevant. Adaptation measures often necessary, but to a lesser extent than in metropolitan areas.
Small towns/villages	0.5	Low heat exposure due to low building density, few sealed surfaces, good night-time cooling, more vegetation, lower social vulnerability.

2.3.1.1.8 Differentiation according to regional heat development

In addition, a regional differentiation was made for the climate signal heat, as different federal states are and will be affected differently by heat stress today and in the future, and therefore differentiated assumptions must be made regarding the respective adaptation needs.

The HD35 heat indicator was used to take regional heat development into account, which indicates the annual number of hot days with a maximum temperature above 35°C (median value per federal state and scenario). The data comes from the World Bank's Climate Change Knowledge Portal and is based on CMIP6 projections (multi-model ensemble). Three climate scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5) and two time periods are taken into account: 2020–2039 and 2040–2059. In order to include these values in the cost calculation, the value range (span) of all federal states for the respective scenario was determined (minimum value to maximum value) and divided into three equal intervals.

The development of heat stress up to 2059 was considered for the three different scenarios. Based on the data described above, a classification into three heat stress categories was also made. It was then assumed that 60% of buildings would be adapted in federal states with high heat stress, 40% of buildings in federal states with medium heat stress and 20% of buildings in federal states with low heat stress. This gradation is based on discussions with internal experts. In addition to the assumption that regional differences in heat stress lead to a lower adaptation rate, factors that plays a role here are that:

a) Some of the adaptation measures outlined are not solely due to climate change (e.g. improved thermal insulation), but fall under the general energy-efficient renovation of buildings, meaning that not all costs can be classified as adaptation costs.
b) Many measures have a cooling effect not only on the individual building but also on the surrounding area, thereby reducing the UHI effect overall.

Thus, the assumption that all buildings need to be adapted even in the event of high heat stress is not valid.

Table 19: Degree of adaptation of the building stock in % by federal state and climate scenario

Federal state	SSP1-2.6 (2040–2059)	SSP2-4.5 (2040–2059)	SSP5-8.5 (2040–2059)
Baden-Württemberg	40	40	60
Bavaria	20	40	60
Berlin	40	40	60
Brandenburg	40	40	60
Bremen	20	20	20
Hamburg	20	20	20
Hesse	20	40	60
Mecklenburg-Western Pomerania	20	20	20
Lower Saxony	20	20	40
North Rhine-Westphalia	20	20	40
Rhineland-Palatinate	40	40	60
Saarland	40	40	60
Saxony	40	40	60
Saxony-Anhalt	40	40	60
Schleswig-Holstein	20	20	20
Thuringia	20	20	40

2.3.1.2 Results

This chapter summarises the key findings of the detailed analysis for the building sector: cost ranges for structural adaptation measures against heavy rain and flooding, as well as for heat protection, broken down by area type and cost scenario and, in the case of heat, differentiated according to climate scenarios. A more detailed classification of investment and damage costs in the context of flood protection is provided in the following chapter on the detailed analysis of flood protection.

2.3.1.2.1 Heavy rainfall

In the low-cost scenario, heavy rainfall accounts for around EUR 65 billion for buildings at medium risk (66% of the stock) and EUR 137 billion for buildings at high risk (12% of the stock), resulting in total costs of EUR 203 billion.

In the medium cost scenario, the costs for medium risk rise significantly to EUR 158 billion, while high risk costs EUR 154 billion – here, the two risk classes are almost equal. The stronger increase in aggregate costs in the medium scenario results from the fact that for the "medium" risk level, there is a shift from the lower end of the cost range to the respective mean value of the 1st-20th percentile band; the relative difference between these two points is greater than the relative difference between the low end and the mean value of the 80th-100th percentile band, which represents the upper end of the cost range. This leads to a disproportionate increase in costs in the medium risk scenario and thus to a convergence of the total costs of both risk classes. The total costs amount to EUR 312 billion.

In the high cost scenario, the total costs amount to EUR 312 billion for medium risk and EUR 171 billion for high risk, totalling EUR 422 billion. Here, too, medium risk dominates the total costs, mainly due to the high proportion of affected buildings (66%), although higher adaptation rates are applied per building in the high risk category.

Table 20: Total costs for adaptation measures to heavy rainfall in the building sector according to cost scenarios

Scenario	Cost Risk Medium (EUR)	Costs High risk (EUR)	Total costs of heavy rainfall (EUR)
Scenario 1 – Low cost rates	EUR 65 billion	EUR 137 billion	EUR 203 billion
Scenario 2 – Medium cost rates	EUR 158 billion	EUR 154 billion	EUR 312 billion
Scenario 3 – High cost rates	EUR 251 billion	EUR 171 billion	EUR 422 billion

The cost estimates for heavy rainfall adaptations in the building sector show significant differences depending on the type of area and risk category (see Tables 21-23). In all scenarios, metropolitan areas have the highest average adaptation costs, followed by regional centres and large cities. Smaller spatial types such as central cities/medium-sized cities, urban areas and small towns or villages have significantly lower average costs. This pattern is mainly due to the higher building density and the larger total number of buildings in metropolitan areas.

Across all spatial types, it is consistently apparent that the average costs of the "medium" risk category approach the average costs of the "high" category as the cost scenarios increase, and in some cases exceed them in the high cost scenario. As inTable 20, this is due to the larger relative increase in the estimated cost rates in the medium risk level within the defined cost bands; with unchanged building shares, this means that the volume effect of the medium risk category has an increasingly stronger impact on the aggregate costs.

Table 21: Average total costs per room type for the adaptation of the building sector to heavy rainfall – low cost scenario – low cost scenario

Area type	Average total costs of buildings with medium heavy rainfall risk **(EUR)**	Average total cost of buildings with high heavy rainfall risk **(EUR)**	Average aggregate **total costs (EUR)**
Metropolis	EUR 407 million	867 million	1,273 million
Regional centre / large city	109 million	EUR 232 million	341 million
Central city / medium-sized city	EUR 26 million	EUR 54 million	EUR 79 million
Urban area	EUR 8 million	16 million	EUR 25 million
Small towns/villages	EUR 2 million	EUR 5 million	EUR 7 million

Table 22: Average total costs per area type for adapting the building sector to heavy rainfall – medium cost scenario

Area type	Average total costs of buildings with medium heavy rainfall risk **(EUR)**	Average total cost of buildings with high heavy rainfall risk **(EUR)**	Average aggregate total costs **(EUR)**
Metropolis	1,006 million EUR	EUR 975 million	1,981 million
Regional centre / large city	EUR 268 million	EUR 260 million	EUR 528 million
Central city / medium-sized city	EUR 62 million	EUR 60 million	122 million EUR
Urban area	EUR 19 million	19 million	EUR 38 million
Small towns/villages	EUR 6 million	EUR 5 million	10 million

Table 23: Average total costs per area type for adapting the building sector to heavy rainfall – high cost scenario

Area type	Average total costs of buildings with medium heavy rainfall risk **(EUR)**	Average total cost of buildings with high heavy rainfall risk **(EUR)**	Average aggregate total costs **(EUR)**
Metropolis	1,605 million EUR	1,082 million	2,688 million
Regional centre / large city	EUR 428 million	EUR 289 million	EUR 717 million
Central city / medium-sized city	EUR 98 million	EUR 67 million	165 million EUR
Urban area	EUR 31 million	EUR 21 million	EUR 52 million
Small towns/villages	EUR 9 million	EUR 6 million	15 million

Overall, the total costs depend largely on two factors: the building density in the respective area type, which determines the absolute costs, and the combination of risk category and associated cost rates, which influences the relative share of the categories in the total sum. A small number of buildings with very high individual rates can result in similarly high or even higher total costs than many buildings with low cost rates; at the same time, an increase in cost rates in the medium risk category – with unchanged building shares – means that their aggregate costs quickly approach those of the high risk category or exceed them in the high cost scenario.

2.3.1.2.2 Flood

The cost estimates for flood protection measures in the building sector show that the total costs in all three scenarios are significantly lower than for heat or heavy rain adaptations. In the low cost scenario, the total costs are around EUR 27 billion, in the medium scenario EUR 39 billion and in the high cost scenario EUR 51 billion.

Despite the comparatively low impact – 6.1% of buildings in the medium risk category and only 1.5% in the high risk category – higher costs are incurred in the "high risk" category in all scenarios. This is because significantly higher cost rates are applied to high-risk buildings, which more than compensate for the smaller proportion of buildings. This shows that the cost rates in the "high" category are the decisive driver of the total sums, even though these buildings only make up a small part of the stock.

Table 24: Total costs of flood adaptation in the building sector according to cost scenarios

Scenario	Total costs Buildings with medium flood risk **(EUR)**	Total costs for buildings with high flood risk (EUR)	**Aggregate total costs** of flooding (EUR)
Scenario 1 – Low cost rates	EUR 6 billion	EUR 21 billion	EUR 27 billion
Scenario 2 – Medium cost rates	EUR 15 billion	EUR 23 billion	EUR 39 billion
Scenario 3 – High cost rates	EUR 25 billion	EUR 26 billion	EUR 51 billion

The results for adaptation costs in the building sector by type of area show a clear pattern: in all cost scenarios, the highest average costs are incurred by metropolitan areas, followed by regional centres/large cities. Smaller settlements such as "small towns/villages", on the other hand, account for only a small fraction of the total costs.

- Low cost scenario: Metropolitan areas (EUR 171 million) clearly dominate the cost estimate, while rural areas account for less than EUR 1 million and are therefore negligible.
- Medium cost scenario: Average costs rise sharply, especially for metropolitan areas (EUR 247 million) and large cities (EUR 66 million).
- High cost scenario: Metropolises reach average costs of over EUR 323 million, while regional centres/large cities also exceed EUR 86 million.

Table 25: Average total costs per area type for the adaptation of the building sector to flooding – low cost scenario

Room type	Average total costs of buildings with medium flood risk **(EUR)**	Average total cost of buildings with high flood risk **(EUR)**	Average aggregate **total costs (EUR)**
Metropolis	38 million EUR	132 million	171 million
Regional centre / large city	EUR 10 million	EUR 36 million	46 million
Central city / medium-sized city	EUR 2 million	EUR 8 million	11 million EUR
Urban area	EUR 0.8 million	EUR 3 million	EUR 3 million
Small towns/villages	EUR 0.2 million	0.7 million EUR	EUR 0.9 million

Table 26: Average total costs per area type for adapting the building sector to flooding – medium cost scenario

Area type	Average total costs of buildings with medium flood risk **(EUR)**	Average total cost of buildings with high flood risk **(EUR)**	Average aggregate **total costs (EUR)**
Metropolis	EUR 99 million	148 million	EUR 247 million
Regional centre / large city	EUR 26 million	EUR 40 million	EUR 66 million
Central city / medium-sized city	EUR 6 million	EUR 9 million	EUR 15 million
Urban area	EUR 2 million	EUR 3 million	EUR 5 million
Small towns/villages	EUR 0.5 million	EUR 0.8 million	EUR 1.3 million

Table 27: Average total costs per area type for adapting the building sector to flooding – high cost scenario

Area type	Average total costs of buildings with medium flood risk **(EUR)**	Average total cost of buildings with high flood risk **(EUR)**	Average aggregate **total costs (EUR)**
Metropolis	160 million EUR	164 million	323 million
Regional centre / large city	EUR 42 million	EUR 44 million	EUR 86 million
Central city / medium-sized city	EUR 10 million	EUR 10 million	EUR 20 million
Urban area	EUR 3 million	EUR 3 million	EUR 6 million
Small towns/villages	EUR 0.8 million	EUR 0.8 million	1.6 million

The evaluation clearly shows that the cost difference is primarily due to the higher cost intensity of the measures in the high-risk category – not the number of buildings affected. Although only 1.5% of the building stock is in the high-risk category (compared to 6.1% in the medium-risk category), these buildings incur significantly higher adaptation costs in all types of areas. The exception is the high-cost scenario, in which the aggregate average costs of buildings in the medium and high risk categories are similar, because although the individual costs per building are lower in the medium risk category (see Table 16), a larger number of buildings are affected.

2.3.1.2.3 Heat

The following table shows the total costs for heat protection measures in the building sector for Germany, broken down into three different cost scenarios (low, medium, high) and the climate scenarios considered (SSP126, SSP245, SSP585) for the period 2040–2059. The results show that the costs of heat protection measures increase significantly with increasing warming and more ambitious climate scenarios. In the low cost scenario, the total costs range from around EUR 97 billion (SSP126) to EUR 181 billion (SSP585). For medium cost rates, values of approximately EUR 123 billion (SSP126) to EUR 230 billion (SSP585) are calculated for Germany as a whole. In the high cost rate scenario, the total costs rise to just under EUR 278 billion in the SSP585 scenario. The results clearly show how strongly the financial requirements for the building sector depend on future heat trends.

Table 28: Building adaptation costs to heat under different climate change and cost scenarios

Scenario	SSP126	SSP245	SSP585
Scenario 1 – Low cost rates	EUR 97 billion	EUR 114 billion	EUR 181 billion
Scenario 2 – Medium cost rates	EUR 123 billion	EUR 144 billion	EUR 229 billion
Scenario 3 – High cost rates	EUR 149 billion	EUR 174 billion	EUR 278 billion

The evaluation of adaptation costs for heat protection measures by area type shows clear differences between the various settlement structures. In all scenarios, the highest costs are incurred by metropolitan areas, followed by large cities and central medium-sized towns. In small towns and villages, the costs are comparatively low. As the warming pathway increases (from SSP126 to SSP585), costs rise significantly in all types of areas. The requirements for heat protection measures increase particularly sharply in metropolitan areas, where costs in the high-cost scenario add up to EUR 2.3 billion in the SSP585 scenario.

These results underscore the particular importance of urban areas for climate adaptation and show that targeted investments are particularly appropriate in densely populated areas. Certain measures – such as greening facades and roofs, unsealing surfaces or providing shade – can have neighbourhood-wide effects (e.g. cooling, reduction of the UHI effect) in addition to protecting buildings, thus generating additional added value beyond the individual building. These potential synergy effects are not taken into account in the present estimates and could dampen the reported investment requirements in the future.

Table 29: Average total heat costs by room type and climate scenario – low cost scenario

Room type	SSP126	SSP245	SSP585
Metropolis	EUR 866 million	EUR 977 million	EUR 1,506 million
Regional centre/large city	EUR 174 million	EUR 192 million	EUR 323 million EUR
Central city / medium-sized city	EUR 37 million	EUR 41 million	EUR 69 million
Urban area	EUR 14 million	EUR 17 million	EUR 27 million
Small towns/villages	EUR 2 million	EUR 3 million	EUR 4 million

Table 30: Average total heating costs by room type and climate scenario – medium cost scenario

Room type	SSP126	SSP245	SSP585
Metropolis	EUR 1,091 million	EUR 1,231 million	EUR 1,897 million
Regional centre / large city	EUR 219 million	EUR 242 million	EUR 408 million
Central city / medium-sized city	EUR 47 million	EUR 53 million	EUR 88 million
Urban area	EUR 18 million	EUR 22 million	EUR 35 million
Small towns/villages	EUR 31 million	EUR 38 million	EUR 59 million

Table 31: Average total costs of heat by area type and climate scenario – high cost scenario

Area type	SSP126	SSP245	SSP585
Metropolis	EUR 1,316 million	EUR 1,485 million	EUR 2,288 million
Regional centre / large city	EUR 265 million	EUR 292 million	EUR 493 million
Central city / Medium-sized city	EUR 576 million	EUR 642 million	EUR 106 million
Urban area	EUR 22 million	EUR 27 million	EUR 42 million
Small towns/villages	EUR 38 million	EUR 46 million	EUR 72 million

2.3.1.3 Cost distribution

The question of who will ultimately bear the considerable costs of climate adaptation for existing buildings is closely linked to the ownership structure of buildings in Germany. The overwhelming majority of buildings are privately owned: according to current census data, around 94% of existing buildings are owned by private owners, homeowners' associations and homeowners. A further 3% is owned by private housing companies or other companies.

The public sector – i.e. local authorities and the federal and state governments – together own only around 1.9% of the building stock (local authorities: 1.77%, federal or state government: 0.13%). This means that the majority of the costs for climate adaptation measures – regardless of the climate signal (heat, heavy rain, flooding) – must be borne by private owners. Although the public sector has a special responsibility to set an example and adapt public buildings, the main financial burden clearly lies with private households and companies.

This distribution of the cost burden has considerable social and political relevance. It makes it clear that support programmes, incentive systems and information campaigns must be specifically targeted at private owners in order to enable the necessary adaptation of the building stock to climate change across the board. At the same time, solutions are needed to support lower-income owner groups in particular in financing the sometimes very high investments.

2.3.1.4 Classification of results

When assessing the total costs of adapting the building stock to various climate signals, it must be taken into account that many measures have overlapping effects. In the area of heavy rain and flooding in particular, there are numerous structural adaptations – such as backflow valves, waterproofing or securing basement access points – that can protect against both heavy rain and flooding. If the costs of adaptation to each individual climate risk are simply added up, there is a risk of double counting, as individual measures are included multiple times. In addition, it is important to note the synergies between heat protection measures and the energy-efficient renovation of existing buildings (see Section 2.3.1.1.8). Measures such as external shading, insulation, highly reflective roofs or green facades and roofs improve summer heat protection and at the same time increase energy efficiency. In practice, such investments are often implemented as part of renovations that are already planned. The costs shown therefore do not always represent purely additional adaptation investments, but also include measures that can be bundled with energy-efficient modernisation and thus generate multiple benefits. Furthermore, this analysis was unable to take into account any assumptions regarding

adaptation measures that have already been implemented, which tends to result in a high cost estimate.

In practice, many adaptation measures are implemented as packages that address various risks simultaneously. The cost calculations in the underlying studies (such as Sander et al. 2025) already take this into account by defining packages of measures for different levels of risk. Nevertheless, an aggregated cost analysis may reveal overlaps that would distort the overall result.

For a realistic estimate of the actual investment requirements, it is therefore essential to take into account the synergy effects and overlaps between the measures. The total costs reported for adaptation to various climate signals should therefore not be interpreted as purely additive values, but rather represent the specific requirements for the respective risk – with some measures and investments being common to several risks.

2.3.2 Detailed analysis of flood protection

Flooding is one of the climate-related natural hazards with the greatest potential for damage in Germany. The latest models and studies show that both the frequency and intensity of river and coastal flooding events will change significantly as a result of climate change. In addition to direct damage to buildings and infrastructure, and indirect economic losses – such as production losses or interrupted supply chains – can also have significant economic consequences.

This section summarises the available findings on damage costs and adaptation costs. First, the results of the latest modelling and studies on the expected damage costs for various climate scenarios are presented.

Building on this, we then consider the adaptation costs in various sectors – from building protection and large-scale river and coastal protection measures to property-specific interventions on transport routes. Finally, selected individual measures are explained in more detail to show how large-scale protection systems and property-specific adaptations can complement each other. This provides a comprehensive picture of the options for action in flood protection – from the perspective of society as a whole to concrete technical implementation.

2.3.2.1 Damage costs

The economic impact of flood events can be assessed both on the basis of empirical damage data from past events and by modelling future risks. Empirical data – for example, from the Elbe and Danube floods in 2002, the June floods in 2013 or the extreme events in the Ahr Valley in 2021 – show that individual events in Germany can cause damage amounting to tens of billions of euros. Projections from current studies illustrate that, under worsening climatic conditions, both the probability of occurrence and the expected amount of damage are increasing. The results vary depending on the climate scenarios, modelling approaches and underlying socio-economic assumptions used.

The following section presents the key findings of selected models and empirical evaluations of various impacts of climate change in the field of flood protection. The aim is to paint as realistic a picture as possible of the current and future potential for damage, thereby creating a sound basis for the subsequent consideration of adaptation costs and protective measures.

2.3.2.1.1 River flooding

As already mentioned, empirical data from the last 20 years show that extreme river flooding has already caused billions of euros in damage. Examples of this are:

- The Elbe flood of 2002, which caused around EUR 11.6 billion in direct damage in Germany
- The floods on the Elbe and Danube in 2014, causing around EUR 8 billion in direct damage (BK 2025)
- Storm Bernd in 2021, with around EUR 40 billion in direct and indirect damage (Trenczek et al, 2022).

Together, these three events alone caused economic losses of around EUR 60 billion.

Despite technical improvements in flood protection, the damage caused by subsequent events remained high. The low insurance coverage rate highlights the high burden on households, businesses and the public sector. These experiences confirm the modelled projections of increasing future risks and underline the need for effective adaptation strategies.

Various studies have produced projection data on how future damage levels from river flooding in Germany will develop.Table 32 summarises the expected annual damages (EAD) from three different studies. Despite methodological differences – for example, in the choice of climate scenarios (RCP-based vs. temperature-based), regional resolution and the hydrodynamic models used – all approaches show a clear trend: without adaptation, damage in Germany will increase significantly over the course of the century. The extent of the increases varies, which is due to different input data, assumptions and damage functions. While Haas et al. (2024) focus on EU-wide comparisons and map RCP pathways, Ciscar et al. (2018) and Brasseur et al. (2017) focus on temperature increases in fixed increments (+1.5 °C, +2 °C, +3 °C), thereby providing a more direct picture of climate sensitivity.

Table 32 : Overview of expected annual damage caused by river flooding in Germany

Scenario	Period / Year	EAD Germany (billion EUR/year)
PESETA III study (Ciscar et al. 2018)		
Reference scenario	1976–2005	0
+ 2 °C	2021–2050	1.6
+ 2 °C	2071–2100	2
Haas et al. 2024		
RCP4.5	2050	1.87
RCP4.5	2100	>1.00
RCP8.5	2050	1.87
RCP8.5	2100	>4.00
Brasseur et al. 2017		

Reference scenario	1976–2005	0.7
+1.5 °C	2021–2050	1.5
+2 °C	2021–2050	1.5
+3 °C	2021–2050	1.8

2.3.2.1.2 Heavy rainfall

An analysis by the German Insurance Association (GDV) in collaboration with the German Weather Service (DWD) shows that heavy rainfall events are already causing considerable damage today. Between 2002 and 2017, the total economic damage to residential buildings – including uninsured damage – amounted to around EUR 6.7 billion, spread across almost 1.3 million registered claims.

These events are typically short, heavy rainfall lasting between one and nine hours and can affect almost any region in Germany. The regional distribution shows clear differences: relative to the building stock, Saxony (133 affected buildings per 1,000), Berlin (131/1,000) and Bavaria (88/1,000) were the most severely affected. In terms of absolute damage costs, Bavaria (EUR 1.485 billion), North Rhine-Westphalia (EUR 1.306 billion) and Saxony (EUR 890 million) were at the top of the list (Gesamtverband der Deutschen Versicherungswirtschaft e. V. 2022).

In contrast to river flooding, there are currently only a few quantitative projections available for heavy rainfall events. Modelling is methodologically challenging because pluvial flooding is caused by short, often locally limited heavy rainfall events, the frequency and intensity of which vary greatly from place to place. Comprehensive EAD estimates at national level are therefore rare and subject to a high degree of uncertainty. However, current climate projections indicate a significant increase in the frequency and intensity of heavy rainfall, especially in the summer months and under the RCP8.5 scenario. Studies using high-resolution regional climate models show a significant increase in the probability of events with more than 20 mm/h occurring in many regions of Germany by the middle of the century. Model-based projections assume that, assuming the socio-economic structure remains unchanged, the average annual damage costs will increase by a factor of 1.5 to 2 by 2050 compared to today (Spekkers et al. 2017). Urban agglomerations are particularly at risk, as in many places the existing drainage infrastructure is not designed to cope with the loads expected in the future.

However, the high spatial and temporal variability of heavy rainfall events, the low density of measuring stations with high temporal resolution, and the insufficient separation between pluvial and fluvial events in damage statistics make it difficult to assess the risk in this area and thus to estimate future damage. Socio-economic developments such as increasing soil sealing or the increase in value of infrastructure are also only partially taken into account in many scenarios.

2.3.2.1.3 Coastal flooding

Table 33 shows a selection of significant coastal flooding events in Germany and their estimated direct damage costs. It illustrates that the amounts of damage vary greatly – from single-digit millions for regionally limited storm surges (e.g. Baltic Sea coast in 1995) to several hundred million euros for large-scale and extreme events (e.g. Hamburg in 1962 or the Baltic Sea storm surge in 2023). Particularly severe storm surges on the North Sea and Baltic Sea regularly cause damage on a scale that requires considerable investment in reconstruction and protection.

Table 33: Overview of past coastal floods and damage costs for Germany

Year	Location/event	Estimated damage (EUR)	Source
1962	Storm surge (Hamburg, North Sea coast)	~ EUR 410 million (DM 820 million)	Forschungsstelle für Zeitgeschichte 2025
1976	Hurricane *Capella* (storm surge, North Sea coast)	~ EUR 445 million (DM 870 million)	dpa-infocom GmbH 2017
1995	Storm surge (Baltic Sea coast of Mecklenburg-Western Pomerania)	~7.7 million euros (at least 15 million German marks)	dpa-infocom GmbH 2017
2006	Storm surge (Baltic Sea coast)	*"several million EUR"*	dpa-infocom GmbH 2017
2023	Baltic Sea storm surge (Oct. 2023)	~200 million euros	Lübecker Nachrichten 2023

With regard to the projected developments in this category of events, available model studies consistently indicate that, without additional adaptation measures, the economic consequences of coastal flooding in Germany would increase significantly by the end of the century. Bosello et al. (2012) model a loss of around 0.94% of the country's land area by 2085 in a scenario with high sea level rise and without adaptation. In the associated macroeconomic model, the economic effects are shown as GDP deviation in 2085 compared to the baseline; for Germany, this amounts to around 0.0057% of GDP in 2085 in the high sea level rise scenario without adaptation.

The use of coastal protection measures could reduce land loss to 0.046%. The annual costs of such protection measures are estimated at 0.009% of GDP, which corresponds to a significant increase in investment in the coastal protection sector (+4.08% compared to the 2085 baseline).

Vousdoukas et al. (2017) provide direct estimates of expected annual damages (EAD) in Germany until 2100 without additional adaptation. Under an RCP 4.5 scenario, the authors assume damages of EUR 6 billion per year, and under an RCP8.5 scenario, as much as EUR 38.8 billion per year. The number of people affected is also rising sharply, from around 2,000 in the reference scenario to 23,000 in the RCP4.5 scenario and 113,000 in the RCP8.5 scenario.

The authors emphasise that ambitious protective measures – e.g. dyke heightening, storm surge barriers or retention areas – could prevent most of the projected damage in highly developed countries such as Germany. However, the necessary investment would be considerable and would have to be maintained on a permanent basis.

2.3.2.2 Adaptation costs

Climate adaptation measures incur very different costs depending on the sector, type of measure and spatial context. This chapter presents exemplary cost estimates for key areas of flood protection based on current studies, modelling and practical experience. The analysis is divided into sectors and types of hazards. In the building sector, measures to protect against flooding and heavy rainfall are considered, supplemented by cost examples for unsealing in urban areas. For transport infrastructure, adaptation options for coastal and river flooding are examined. In addition, other relevant measures that

contribute to increasing climate resilience are listed. The aim is to provide an overview of the range of possible investment requirements.

2.3.2.2.1 Building sector

The cost estimates for flood-related adaptation measures in this sector are based on the calculations made in the detailed analysis of the building sector (Chapter 2.3.1). Accordingly, the total costs for structural flood protection measures in the building sector range between EUR 27 billion (low cost rates) and EUR 51 billion (high cost rates) (see Section 2.3.1.2.2). In the medium cost scenario, EUR 15 billion is attributable to buildings with medium risk and EUR 23 billion to buildings with high risk. The total cost of structural measures to protect against heavy rainfall ranges between EUR 203 billion (low) and EUR 422 billion (high). In the medium cost scenario, EUR 158 billion is attributable to medium-risk buildings and EUR 154 billion to high-risk buildings.

As already explained, the amounts for flood and heavy rainfall protection cannot be added together, as individual measures reduce both types of risk at the same time and are therefore included in both calculations (see Section 2.3.1.4).

2.3.2.2.2 Costs for unsealing measures

The unsealing of surfaces is considered a key measure in climate adaptation, particularly for reducing pluvial flood risks. Heavy rainfall events cause high damage costs, especially in heavily sealed urban areas, as precipitation water cannot infiltrate or run off the surface quickly enough. Restoring water-permeable surfaces increases local retention capacity, reducing peak runoff and mitigating flooding. In addition to directly reducing the potential for damage, unsealing also contributes to improving the urban climate, promoting biodiversity and replenishing groundwater.

The following assumptions were made to calculate the costs for this area:

With regard to the area suitable for unsealing, the survey by the Federal Environment Agency was used (Pannicke-Prochnow et al. 2021) There, a renaturation or unsealing potential in the order of approximately 1% is given as a rough guideline for the area "buildings and associated open spaces". In order to derive a nationwide order of magnitude, we use this 1% approach as a conservative, simplified assumption for the settlement and transport area (approx. 5.2 million hectares or 14.5% of the federal area). This results in a calculated potential of around 520 km^2 or 520 million m^2.
Note: The 1% value is taken methodologically from the UBA as an approximate value and originally refers to "buildings and associated open spaces"; the transfer to the entire settlement and transport area serves here to estimate the order of magnitude and overestimates or underestimates the actual realisable potential depending on the local area structure. With regard to the costs of unsealing measures per m^2, three categories of measures were distinguished:

- Partial unsealing (e.g. replacement with permeable paving): 60–180 EUR/m^2
- Full unsealing (complete dismantling, greening): EUR 50–120/m^2
- Full unsealing + blue-green infrastructure (e.g. troughs, tree locations): EUR 150–250/m^2

The cost ranges are based on figures from the Berlin Rainwater Agency (Regenwasseragentur Berlin n.d.) and the City of Neuwied (Stadt Neuwied 2024).

In order to calculate various implementation scenarios, the total costs were calculated for different assumptions regarding the scope of implementation of the unsealing potential: in a low implementation scenario, it was assumed that 25% of the unsealing potential would be realised; in a medium scenario, 50% of the potential would be realised; and in a high implementation scenario, 75% would be realised. To illustrate the range of costs that would result, calculations were made using both

the low end of the cost range per m^2 and the high end of the cost range. This resulted in the following calculation formula:

$$Total\ cost = Potential\ area \times Realisation\ percentage \times Cost\ per\ m2$$

Table 34 shows the various cost estimates resulting from this approach.

Table 34: Results of unsealing costs

Type of measure	Costs_min_EUR/m^2	Costs_max_EUR/m^2	Implementation rate	Total_costs_min_billion EUR	Total cost_max_billion EUR
Partial unsealing	60	180	25	**7.8**	**23.4**
			50	**15.6**	**46.8**
			75	**23.4**	**70.2**
Complete unsealing	50	120	25	**6.5**	**15.6**
			50	**13**	**31.2**
			75	**19.5**	**46.8**
Complete unsealing + blue-green infrastructure	150	250	25	**19.5**	**32**
			50	**39**	**65**
			75	**58.5**	**97.5**

The sample cost calculation clearly shows that even with a conservative implementation of only 25% of the potential for unsealing, considerable investment would be required. Depending on the type of measure, the total costs in this scenario range from around EUR 6.5 billion (full unsealing in the lower cost segment) to EUR 32.5 billion (full unsealing with blue-green infrastructure in the upper cost segment). With 50% implementation, the investment sums rise to EUR 13–46.8 billion for conventional measures and to EUR 39–65 billion for complex blue-green projects. If 75% of the potential is exploited, the amounts triple accordingly and reach just under EUR 100 billion in the most expensive case.

The types of measures differ not only in terms of their costs, but also in terms of their functional added value: while complete unsealing is comparatively inexpensive, the integration of blue-green infrastructure – such as tree trenches, infiltration basins or combined retention areas – makes the greatest contribution to climate adaptation. These measures significantly increase storage and infiltration capacity, reduce peak runoff during heavy rainfall and also improve the microclimate and biodiversity.

It should also be noted that unsealing measures may conflict with economic land use interests (e.g. competition between retention areas and building or commercial areas). Depending on the data used, there is a difference between technical potential (areas that can in principle be unsealed under land use and building planning law) and economically and socially feasible potential. Furthermore, the costs shown here do not reflect potential savings, such as reduced wastewater charges, reduced follow-up costs for flood prevention or avoided damage during heavy rainfall events. These aspects must be taken into account in the interpretation of investment requirements and quantified separately in further economic assessments.

2.3.2.2.3 Transport infrastructure

Germany's transport infrastructure – consisting of roads, railways, inland waterways, seaports and airports – is significantly at risk from flooding. In addition to large-scale river flooding, flooding due to sea level rise and storm surges in coastal regions also poses relevant risks. Reducing these risks requires targeted investment in adaptation measures such as raising dams, securing bridges and critical junctions, raising or relocating routes, and protecting port and terminal facilities.

The present estimate of adaptation costs in the area of transport infrastructure with regard to flooding is based largely on a study by the European Commission, which estimates the investment required to adapt the TEN-T network to the consequences of climate change (Schade et al. 2024). The TEN-T network (German: TEN-V network) is a trans-European transport network consisting of three levels: the core network, the extended core network and the comprehensive network (Bundesministerium für Verkehr 2024). The transport corridors that are part of this network are multimodal and are intended to strengthen cross-border connections within the EU and its neighbouring countries (Bundesministerium für Verkehr 2024). The study by Schade et al. (2024) shows specific adaptation costs and investment requirements for the core and comprehensive networks. As these figures only reflect the proportion of German transport infrastructure that is part of the TEN-T network, the percentage share of the TEN-T network in the respective infrastructure component (e.g. 22% for roads, 33% for railways) was determined (see Table 35) and the cost estimates were then extrapolated to the entire national inventory. The adaptation costs, which were taken from Schade et al. (2024), are based on an RCP6.0 climate change scenario and cover the period up to the middle of the century.

Table 35: Overview of the share of the TEN-T network in Germany's total transport infrastructure

Infrastructure type	Germany as a whole	TEN-T total network (DE) Total	Share of the TEN-T network in the total stock (DE) in %
Roads[5] (km)	50,956	11,396	22
Rail passenger and freight transport (km)	39,200	12,765	33
Inland waterways (km)	approx. 7,500	4,258	57
Ports (number)	181	108	60
Airports (number)	approx. 35	24	69

The estimates for Germany presented inTable 36 show the costs of adapting transport infrastructure to river flooding. The estimated costs for the entire German transport network amount to approx. EUR

[5] Includes federal roads and motorways.

1.53 billion. The largest share of these costs is accounted for by adaptation activities for rail infrastructure (approx. 63%), followed by roads and inland waterways.

Table 36: Estimated adaptation costs for river flooding for German transport infrastructure by mid-century under the RCP6.0 scenario

Infrastructure component	Adaptation costs TEN-T network in Germany	Extrapolated costs (Germany total)
Airports	EUR 11 million	EUR 50 million
Rail	EUR 317 million	EUR 960 million
Road	EUR 197 million	EUR 328 million
Inland waterways	EUR 123 million	EUR 187 million
Total		**EUR 1,525 million**

The costs of adapting to coastal flooding over the same period and under the same climate change scenario amount to around EUR 9 billion, with the adaptation of seaports accounting for the largest share of the costs, followed by rail and road infrastructure in exposed coastal locations.

Table 37: Estimated adaptation costs to coastal flooding for German transport infrastructure by mid-century under the RCP6.0 scenario

Infrastructure component	Adaptation costs TEN-T network in Germany	Extrapolated costs (Germany total)
Rail	EUR 0.96 billion	EUR 2.92 billion
Road	EUR 0.62 billion	EUR 2.82 billion
Seaports	EUR 1.98 billion	EUR 3.29 billion
Total		**EUR 8.96 billion**

2.3.2.3 Explanations of individual adaptation measures

The previous chapter presented aggregate adaptation costs for key areas of action – buildings, unsealing and transport infrastructure. These totals are based on projections and models that combine various individual measures. The following chapter takes a closer look at these individual measures. For relevant areas, the most important types of measures, how they work and, where available, typical cost ranges are presented. The information is mainly taken from German studies and official sources, supplemented by EU studies with direct relevance to the German context.
This detailed analysis is intended to clarify the specific adaptation measures behind the total costs reported in the previous chapter and enables a more differentiated assessment of their effectiveness and feasibility.

2.3.2.3.1 Building protection measures

Property-specific measures are used to protect individual buildings from extreme weather (especially heavy rain and flooding). Typical examples include the installation of backflow valves, water-tight building elements or, in extreme cases, even the relocation of entire buildings from danger zones.Table 38 provides an illustrative overview of this. The individual measure costs listed here are not directly comparable with the package or scenario costs reported in the building chapter (Section 2.3.1.1.4), as

Sander et al. (2025) report individual measures per building type, while the measures packages are aggregated according to adaptation level (low/medium/high).

Table 38: One-off investment costs of selected structural adaptation measures to protect single-family homes from heavy rain and flooding (Sander et al. 2025)

Measure	Costs (low)	Costs (high)
Raising thresholds (on doors and light wells)	1,200	1,800
Backflow valves	2,240	2,908
Special cellar windows	4,375	4,375
Relocation of building services	10,944	19,152
Tiling lower floor	4,800	8,000

Backflow valves and flaps are among the most cost-effective building protection measures. Simple backflow protection devices can be installed for just a few thousand euros. Water-tight (flood-proof) windows and doors incur average one-off investment costs in the higher four-digit range per opening. They are particularly worthwhile for low-lying parts of buildings; during the July 2021 floods in Germany, for example, it became apparent that houses with such protective windows had significantly less water damage in their basements (protection up to the window sill).

Relocating buildings from at-risk zones is rarely practised in Germany, as the costs per property are enormously high and often approach the current value of the building. However, the example of Röderau-Süd (Saxony) shows that in extreme cases, entire districts are abandoned: In 2003, the complete relocation of a new development area at risk of flooding cost around EUR 36 million, equivalent to approximately EUR 195,000 per house – financed by flood relief funds (Winter 2003). Although such measures completely eliminate the risk, they are only cost-effective in exceptional cases.

2.3.2.3.2 Transport infrastructure

To adapt transport routes to climate change, protective measures are being implemented at various levels, which can be divided into large-scale, systemic protective measures and infrastructure-specific, object-oriented adaptations.

2.3.2.3.2.1 Large-scale protective measures

Large-scale protective measures (e.g. dyke systems, retention areas) are not exclusively attributable to transport infrastructure. They represent cross-sectoral flood protection measures and are explained here with regard to their relevance for transport routes. They have a network-wide or nationwide effect and protect not only individual infrastructure elements, but entire sections or regions from flooding. They are often very cost-intensive, but also highly effective.

- Dykes, dams and protective walls (e.g. along river or coastal sections)
- Retention basins and designated floodplains
- Port and waterway protection (e.g. breakwaters, bank protection structures)

This level is usually the responsibility of water management and coastal protection authorities and also serves to protect settlements, agriculture and transport infrastructure. Below is a list of possible adaptation measures that are relevant to transport infrastructure but also have protective effects on other areas. The table is taken from the study by Schade et al. (2024).

Table 39: Overview of measures for adapting transport infrastructure, based on Schade et al. (2024)

Mode of transport	Event type	Adaptation measures	Effectiveness
Road	Coastal flooding	Dykes, protective walls and embankments	Effective in preventing flooding, but expensive and maintenance-intensive
Road traffic	River flooding	Drainage systems	Significantly reduces water accumulation; effectiveness depends on the quality of the drainage systems
Rail	Coastal flooding	Dykes, protective walls and embankments	Protects railway infrastructure from water damage, but requires significant investment
Rail transport	River flooding	Drainage systems, designated flood areas	Protects railway infrastructure from flooding; effectiveness depends on the quality of implementation
Airports	Coastal flooding	Protective dams, dykes or bank protection	Can significantly reduce flood risk, but requires ongoing maintenance and investment
Airports	River flooding	Increasing drainage capacity and improving drainage systems	Reduces the risk of flooding at airports; effectiveness depends on system design and maintenance
Seaports and inland ports / waterways	Coastal flooding	Construction of breakwaters	Protects ports and waterways from the effects of sea level rise; however, incurs significant costs
Sea and inland ports / waterways	River flooding	Retention basins and designated floodplains	Helps manage excess water and reduces impact on infrastructure
Inland waterways	River flooding	Retention basins and designated floodplains	Helps manage excess water and reduce the impact on infrastructure

For individual coastal protection measures, cost estimates per unit (per metre or kilometre) can be listed. Breakwaters and similar coastal structures typically cost tens of thousands of euros per metre.

The figure of EUR 10,000–20,000/m is based on Dutch calculations for massive breakwaters and jetties(Europäische Umweltagentur 2022). They protect ports or exposed coastal sections by breaking the force of the waves, which reduces the maintenance costs for dykes and shorelines.

Traditional sea dyke construction is also expensive: one kilometre of North Sea dyke, raised by one metre and reinforced, was recently estimated to cost around EUR 3–4 million(Deutschlandfunk Kultur 2020). Dikes not only need to be raised, but also widened at their base and covered with robust revetment (stone/turf), which drives up costs (Deutschlandfunk Kultur 2020).

Nevertheless, dyke heightening is considered a necessary investment, as without it the potential damage caused by dyke breaches would be immense. For example, Schleswig-Holstein is now planning for a 50 cm rise in sea level by 2100 instead of the previous 25 cm, which will require corresponding dyke heightening (Deutschlandfunk Kultur 2020).

The most complex individual structures are storm surge barriers. Such barriers protect large regions from flood damage. They are highly effective – storm surge barriers completely hold back rising water levels – but they must be designed for extreme scenarios and kept functional over the long term (decades). The following examples illustrate the wide range of realistic construction and kilometre costs for storm surge barriers, for which, however, no location-specific cost-benefit assessments are available:

- The Thames Barrier in London was opened in 1984 after eight years of construction and at a cost of GBP 535 million (equivalent to approximately GBP 2.4 billion in 2024) (Environment Agency 2024). With a span of 520 m and 10 gates weighing up to 3,000 tonnes each, it is one of the largest movable flood barriers in the world (Environment Agency 2025). At current exchange rates, the technically highly complex Thames Barrier costs over GBP 4.62 billion per kilometre (equivalent to approximately EUR 5.34 billion).
- The Dutch Oosterschelde storm surge barrier was inaugurated in 1986 after 19 years of construction and, with a length of 9 km, 3 km of which can be closed, cost approximately EUR 2.5 billion at today's prices(Watersnood Museum n.d.). The price per kilometre of the facility is therefore approximately EUR 278 million.
- The German Eider barrage (built in 1973) cost around DM 170 million to build (Buchwald 2025 2025; according to Deutsche Bundesbank 2025, this corresponds to around EUR 303 million) and, at 4.9 km in length, is the largest coastal structure in Germany. The construction costs amounted to approx. EUR 62 million/km.

The wide price range illustrates that, in the case of storm surge barriers, the specific technical design is more important than the sheer length of the structure. The complexity required in each case depends on the local geophysical conditions and can vary considerably.

Table 40: Unit prices for individual coastal protection measures

Measure (coastal protection)	Unit price (approx.)	Source	Protective effect
Offshore breakwater	10,000–20,000 EUR per metre length	Europäische Umweltagentur (2022)	Significantly reduces wave height and energy on the coast, reduces dune and dyke erosion during storm surges
Coastal dyke elevation	3–4 million EUR per kilometre	Deutschlandfunk Kultur (2020) + own interviews	Improves protection against storm surges by providing a safety reserve (50 cm sea level rise can be compensated for in this way); significantly reduces

			the risk of flooding in the hinterland
Storm surge barrier	Wide range depending on location and technical complexity: Approx. 62 million – approx. 5.34 billion EUR per km	Europäische Umweltagentur (2016),Environment Agency (2025),Watersnood Museum (o. J.)	Protection against storm surge flooding for an entire estuary/area; expensive, large-scale projects with long implementation times and long lifespans (50+ years)

2.3.2.3.2.2 Transport infrastructure-specific measures

These measures are implemented directly on transport routes and are specifically designed to ensure the functionality of individual objects or sections of route. They can operate independently of large-scale protection systems or complement them. Examples of such measures include raising roads and railway lines, adapting bridges, and installing road and rail drainage systems.

Roads and railway lines can be protected against flooding by targeted raising or the construction of accompanying protective structures such as dykes or dams. Such measures are mainly implemented in low-lying or flood-prone sections and can vary greatly depending on the topography, the necessary protection height and the existing infrastructure.

Bridges are special cases. Existing bridges can be protected against overtopping though underpinning and scour protection (protection against washouts) or by raising the abutments. It is difficult to quantify specific unit prices here, as each bridge is unique. However, one thing is clear: building long viaducts or bridges that are flood-proof is many times more expensive than a road embankment. For example, elevated roads on pillars (bridge-like structures) cost many times more than an earth embankment of the same length (Europäische Umweltagentur 2025).

Table 41: Overview of adaptation measures against flooding with cost data from Schade et al. (2024)

Adaptation measure	Type of hazard	Mode/area of application	Cost	Cost unit	Country/region
Dykes and dams	Flood	Inland waters	300-4500	€/m	USA
Flood barriers	High water	Inland waters	1,840,000,000	€/case	USA
River flood wall	High water	Inland waters	340–1230	€/m	USA

Seawalls	High water	Coast	460-12,300	€/m	USA
Preventive investment in road bridges	Flood	Roads	800,000,000	€/year	France
25% reduction in landslide risk	Flood	Railways	95,000,000	€/case	United Kingdom
Motorway improvements: embankment/raising	Flood	Roads	5	% above base investment (without improvement)	Overall
Improvement of secondary urban roads	Flood	Roads	5	% above base investment (without improvement)	Overall

In practice, a combination of measures is often chosen: smaller culverts and bridges are raised or fitted with mobile protective elements, while on a larger scale, bypasses on higher ground or dams are preferred. Overall, these measures aim to maintain the functionality of transport routes in the event of flooding – for example, to enable evacuations and reduce economic damage caused by infrastructure failures.

The analysis shows that effective flood and heavy rain protection cannot be reduced to a single measure. Rather, a combination of large-scale, systemic protection systems – such as dykes, retention basins or barrages – and targeted, object-specific adaptations, for example to buildings or transport routes, is required. While the former offers a high degree of security for entire regions, the latter ensures the functionality of critical infrastructure even in the event of partial failure of the higher-level protection systems. The range of investment requirements is considerable: from relatively inexpensive property protection measures to complex large-scale structures with very high construction and maintenance costs. Strategic prioritisation according to risk, protective effect and cost-benefit ratio is therefore essential. The measures presented make it clear that early and gradual adaptation can not only significantly reduce future damage, but also strengthen the resilience of entire sectors in the long term.

2.4 Overview of research needs

This chapter brings together research needs from two complementary perspectives: (1) model-based, predominantly top-down approaches that map macroeconomic interdependencies and feedback loops (section 2.4.1), and (2) bottom-up approaches based on measures, packages and sector- or object-specific data (sections 2.4.2 –2.4.4). Both perspectives are necessary for a robust assessment of adaptation needs and costs and should be methodologically interlinked. The bottom-up part addresses in particular the consistent definition of adaptation scenarios and protection levels, the assessment of the baseline, the derivation of implementation costs from policy target frameworks (DAS/APA IV) and the systematic consideration of operating and maintenance costs. Linking both approaches makes it

possible to validate the costs and effects of measures from practice with macroeconomic results and to prioritise them on an evidence-based basis.

2.4.1 Research needs for model-based approaches

The need for research arises from the limited number of studies available for Germany and the limited consideration of impact areas and channels. In general, most studies consider flooding of rivers and coasts, yield losses in agriculture and forestry, energy demand and supply, and the effects of heat on labour productivity.

Fewer studies are available on the economic consequences of extreme weather events, changes in tourism, and economic losses due to water scarcity and drought. In addition, there are key areas that have hardly been addressed in research to date because they can only be modelled partially or not at all and are also difficult to quantify – for example, biodiversity loss. There is a clear need for research in this area, as a better understanding of the economic consequences of previously less researched impact channels is essential for targeted and effective adaptation in order to be able to assess Germany's adaptation needs more comprehensively and to prioritise adaptation measures on a sounder basis.

However, in order to reduce uncertainties and increase the robustness of the results, further research is also needed in areas that have already been studied in greater depth. Here, it is advisable to increase the involvement of German teams in international research projects (e.g. via Horizon Europe, JPI Climate, ERA Net) and, in the case of national projects, to establish strong links with other international projects and to use international comparative data such as ISI-MIP. In national projects, care should also be taken to involve as many macroeconomic teams as possible with different modelling approaches. Further research is also needed to analyse high-end scenarios, supplemented by storyline approaches that examine past extreme events such as the 2021 Ahr floods under future climatic conditions.

There is also a need for further research into regionalisation, which is particularly important for a large and diverse country: very few studies examine the economic consequences of climate change at the level of states and municipalities. However, a deeper understanding of these effects is essential for targeted adaptation.

There are considerable gaps in research, particularly in the area of adaptation measures, especially with regard to a holistic economic assessment. The development and integration of differentiated adaptation scenarios into future models is therefore essential in order to create a sound basis for political decision-making.

2.4.2 Development of an adaptation scenario and baseline data

Another key research need is to clearly define the underlying adaptation scenario for the analysis. This concerns both the selection of the climate change scenario to which adaptation is to take place and the determination of the desired level of protection or the accepted residual risk. It would be conceivable to consider different scenarios – such as different degrees of global warming or different targets for the level of adaptation – but these must be clearly and comprehensibly defined in each case.

Part of developing an adaptation scenario involves analysing what specific measures would be necessary to achieve the desired level of adaptation. This analysis is inevitably subject to uncertainties and assumptions, particularly with regard to the actual effectiveness of individual measures. Accordingly, the underlying assumptions about the impact of each measure would have to be made transparent.

It is also crucial that the study not only considers the effects and costs of individual adaptation measures, but also takes a holistic view of the measures as a whole. Adaptation measures often only become effective when they interact with each other; their effects can reinforce or weaken each other. In order to define a desirable adaptation scenario, it is therefore necessary to comprehensively consider the respective packages of measures in order to determine which bundle of measures is necessary to actually achieve a certain level of adaptation.

There is also a significant need for research due to the insufficient data available on the current state of climate adaptation in Germany. For reliable analyses and targeted strategies, it is necessary to first conduct a comprehensive assessment of the baseline. However, there is currently a lack of differentiated and systematic data on the extent to which adaptation and modernisation measures have already been implemented in various sectors.

In practice, it is often simplistically assumed that all objects under consideration – such as dykes, buildings or infrastructure – are at the same starting level and that no adaptation measures have been taken to date. However, this assumption does not correspond to reality and leads to distortion and inaccuracy in the analyses. In fact, the state of adaptation is very heterogeneous: while some dykes have already been raised and comprehensively modernised, others still have a significantly lower level of protection. There are also major differences in the building stock – some buildings already have measures such as heat protection or flood protection in place, while others do not. However, there is currently no comprehensive and detailed data on the condition and equipment of buildings.

2.4.3 Adaptation targets and implementation costs of APA IV

As mentioned in the sensitivity analysis, one of the factors required for a valid estimate of adaptation costs is a clearly defined adaptation scenario. An important basis of information for such a scenario is a clear definition of the adaptation goal: what exactly does "successful" adaptation look like? The new German Adaptation Strategy (DAS) provides measurable adaptation goals for the first time, which offer a basis for a detailed estimate of the associated investment requirements.

One way to approximate the expected adaptation costs for Germany at the federal level would be to analyse the current adaptation plan (APA IV). This plan represents the current status of the federal government's adaptation measures. An analysis of the costs associated with the implementation of this plan could therefore capture the currently planned costs. Unlike APA III, APA IV itself does not yet contain any cost estimates for individual measures.

The aim should be to systematically record the costs of fully implementing all measures provided for in APA IV and, in addition, to back up the adaptation targets defined in APA IV and DAS with reliable, comprehensible cost estimates. Against the background of the data and methodological shortcomings described in Section 2.4.2, it is important to explain transparently on what basis targets are set and what cost assumptions underlie them. In doing so, it is important to consider not only expenditure at federal level, but also the costs incurred by other actors, such as states, municipalities, companies or private households. Many measures, such as legislative changes, do not cause any direct additional costs for the federal government, but do lead to financial expenditure for other parties involved. In order to obtain a realistic picture of the total costs, the costs along the entire impact chain of each individual measure would therefore have to be considered.

However, it has not yet been conclusively clarified to what extent the implementation of APA IV is actually sufficient to achieve the level of adaptation deemed necessary to meet the objectives of the German Adaptation Strategy (DAS) and its targets. There is a need for accompanying monitoring and evaluation instruments that enable performance review and, if necessary, corrective action. The relevant data and analyses are not yet available and should be developed specifically as part of future research.

2.4.4 Analysis of maintenance costs

Another important area of research is the differentiated consideration of investment costs versus the ongoing care and maintenance costs of adaptation measures. In interviews, it was repeatedly pointed out that in practice and in research, the focus is usually only on one-off investment costs – both in the planning and in the design of support programmes. The long-term costs of maintenance, care and operation, on the other hand, are often neglected, even though they can be considerable over the lifetime of a measure.

Infrastructures such as dykes, green spaces, technical facilities and building protection measures in particular incur ongoing expenses to ensure the long-term functionality and effectiveness of the adaptation. If these costs are not taken into account sufficiently, there is a risk that measures will lose their effectiveness over time or that additional, unplanned expenses will be necessary. A comprehensive analysis that systematically includes both investment and ongoing maintenance and servicing costs is therefore necessary for a realistic assessment of the actual financial requirements and the sustainable design of adaptation strategies.

3 Fiscal risks of climate change

Table 42: Overview of results

RESULTS AT A GLANCE

- Climate risks affect public budgets in different ways depending on the federal level: local authorities are particularly affected, as they have limited resources but direct responsibility for vulnerable infrastructure and disaster management; the federal states coordinate regional adaptation processes and support local authorities, while the federal government finances supra-regional infrastructure projects and provides disaster relief.
- Fiscal risks can be divided into revenue-side and expenditure-side risks:
    - Expenditure side: here, the main factors are damage costs caused by extreme weather phenomena and adaptation investments.
    - Revenue side: this is particularly affected by reduced tax revenues, which are attributable, for example, to reduced turnover at companies affected by extreme events, rising inflation and falling consumption in the domestic market and in export markets.
- In the federal system, fiscal equalisation mechanisms provide basic protection for financially weaker states and municipalities, but these mechanisms are reaching their limits in view of investment backlogs and rising financing requirements.
- The lack of financial resources for adaptation measures increases the vulnerability of both residents and households in the affected areas.
- The federal government, states and municipalities already finance climate adaptation with various instruments; however, these are not sufficient to cover the financing requirements quantified in chapter 2.
- Support programmes are an essential tool for current adaptation financing, but they are criticised for their sheer number, the administrative burden they entail and the lack of long-term financing security.
- In order to meet the challenges of adaptation financing and the rising costs of dealing with climate damage for public budgets in Germany, a range of innovative instruments (e.g. catastrophe bonds, parametric insurance, climate-resilient debt clauses, municipal K-CLOs) are outlined and considered that expand the financing and risk management of public budgets and mobilise additional private capital for climate adaptation.

Progressive climate change is placing a considerable financial burden on public administration in Germany. Fiscal risks include growing expenditure on adaptation measures and restoration work after damage has occurred, as well as potential revenue shortfalls as a result of climate-related disruptions to the economy. Against this backdrop, there is an urgent need to make public budgets resilient in both the short and long term and to establish appropriate instruments to effectively counter these risks.

3.1 Overview of fiscal climate risks caused by climate change

The financial and fiscal risks posed by climate change affect all levels of the federal system, although the specific impacts may vary. Local authorities are particularly hard hit, as they are directly responsible for numerous vulnerable infrastructures, often have limited financial resources and frequently have to take direct action in disaster management. The federal states are faced with the task of managing regional adaptation processes, organising support for affected cities and municipalities, and ensuring the functioning of regional infrastructure. At the federal level, on the other hand, the

focus is on financing infrastructure projects of supraregional importance, providing funds for disaster relief, and coordinating adaptation strategies at the national level.

Beyond federal responsibilities, financial risks can also be differentiated according to whether they affect the expenditure or revenue side of public budgets.

3.1.1 Expenditure side

The following chapter describes how the economic impacts and financing requirements outlined in the previous chapter affect the expenditure side of public budgets in Germany. The federal levels are considered separately, and a distinction is made between damage costs and adaptation costs.

3.1.1.1 Local authorities

3.1.1.1.1 Costs due to damage

In the event of damage, costs at the local level arise in particular from damage to local infrastructure, the failure of which and reconstruction of which incurs costs. This includes, for example, schools, local buildings such as swimming pools, libraries, etc., but also roads and other transport infrastructure, e.g. bridges. This damage can be considerable: according to the BMI and BMF, the 2021 floods caused damage to municipal infrastructure in North Rhine-Westphalia amounting to EUR 4.5 billion. In Rhineland-Palatinate 103 bridges in the Ahr Valley alone were severely damaged or completely destroyed, with damage to public infrastructure in the state totalling EUR 7 billion(Bundesministerium des Innern und für Heimat and Bundesministerium der Finanzen 2022).

3.1.1.1.2 Costs of adaptation

Local authorities incur further costs through the implementation of climate adaptation measures that fall within their area of responsibility. As outlined in chapter 2.3.1.3, local authorities own the majority of public buildings in Germany. The costs of adaptation measures for these buildings, which are necessary because of the exemplary role played by the public sector, are therefore the responsibility of the municipalities. Adaptation measures relevant to municipalities include the development and implementation of heat action plans, greening of roofs and facades, and rainwater management through unsealing and the construction of retention basins to prevent flooding during heavy rainfall (see Chapter 2.3).

In the KfW Municipal Panel 2023, local authorities stated that adaptation investments accounted for approximately 4% of total municipal investments, corresponding to approximately EUR 1 billion in 2021. The same amount was estimated in the medium-term financial planning for the coming years, although the majority of local authorities expected adaptation costs to rise in the future (Brand et al. 2023 and 2023; see Chapter 2.2.1.1). Heilmann et al. (2024) estimate the investment required by municipalities for climate adaptation by 2030 at a total of EUR 28.5 billion and point out that the actual requirements are likely to be considerably higher (see Chapter 2.2.1.1).

The expert interviews also revealed that local authorities may incur additional, sometimes considerable, adaptation costs in the context of municipal enterprises, particularly in the area of water supply and water management (e.g. municipal utilities). The 2021 flood disaster highlighted the vulnerability of the sector and the need for adaptation measures: in Rhineland-Palatinate alone, the sewage treatment plants in Altenahr, Mayschoss and Sinzig were destroyed, and it is estimated that it will take at least 1.5 years to repair them completely (Koks et al. 2022). The Association of Municipal Companies estimates that adaptation measures will account for around 10-15% of the total investment

of EUR 800 billion estimated for the necessary renewal of networks and their adaptation to the consequences of climate change over the next 20 years – this corresponds to an investment requirement of EUR 80-120 billion by 2045 (VKU 2025).

3.1.1.2 Country level

3.1.1.2.1 Costs due to damage

The federal states also incur damage costs as a result of extreme weather events, insofar as these affect state-owned infrastructure. Depending on the federal state, this includes state-owned roads, universities and colleges, state authorities and administrative buildings, state-owned health facilities and state-owned cultural institutions such as museums and theatres.

As a result of the 2021 flood disaster, damage to state-owned infrastructure in North Rhine-Westphalia alone amounted to over EUR 250 million (Bundesministerium des Innern und für Heimat and Bundesministerium der Finanzen 2022). The federal government and the affected states agreed on emergency aid of EUR 800 million, half of which was borne by the federal government (see below) and half by the affected states (Bundesministerium der Finanzen 2021). The sum was not based on a damage assessment, but covered the costs of measures that benefited particularly affected citizens, businesses, farmers and local authorities (Oberpriller et al. 2025).

3.1.1.2.2 Costs of adaptation

Under the KAnG, the federal states are obliged to carry out climate risk analyses and draw up climate adaptation strategies, and they must bear the associated administrative costs. In the draft KAnG bill, the federal government estimated the one-off costs for the federal states at between approximately EUR 66 million and EUR 1.9 billion, depending on how the federal states implement the law. In addition, there are annual costs of between EUR 830,000 and EUR 1.67 million (Bundesregierung 2023b). The draft KAnG estimated the costs of developing municipal climate adaptation concepts at between EUR 956 million and EUR 1.912 billion (see Chapter 2.2.1.1.3.4); In accordance with the principle of connectivity under state constitutional law (see Chapter 3.2.3.1), these costs must be financed by the states, as they are responsible for implementing the KAnG below the federal level(Fischer-Hotzel and Meyer 2024).

In addition, the federal states must also pay for adaptation measures in certain areas, such as flood protection. This requires high investments that place a burden on state budgets (see Chapter 2.3.2). Heilmann et al. (2024) assign adaptation costs of EUR 9.5 billion to the federal states by 2030, although the fact that their survey does not take into account numerous cost areas and long-term measures suggests that the real requirements are likely to be considerably higher (see Chapter 2.2.1.1).

3.1.1.3 Federal level

3.1.1.3.1 Costs due to damage

Climate-related damage also incurs costs at federal level. The federal government steps in to provide financial assistance in the event of extreme events. In the case of the 2021 flood disaster, the Federal Cabinet approved emergency aid of EUR 400 million from the federal budget. In addition, it was decided to waive the reimbursement of expenses "incurred by the Federal Agency for Technical Relief (THW), the Federal Police, the Customs Administration, the German Armed Forces, the Federal Waterways and Shipping Administration and the use of temporary bridges as part of on-site support" (Bundesministerium der Finanzen 2021).

In the course of approving the emergency aid, the Federal Cabinet also decided to set up a special fund, "Reconstruction Aid 2021", to provide medium to long-term support for reconstruction. This fund has a total volume of up to EUR 30 billion. The federal government is contributing half of the funding for the reconstruction programmes of the federal states, providing EUR 14 billion for this purpose; the federal states are contributing EUR 14 billion. A further EUR 2 billion is earmarked for repairing damage to federal infrastructure (Bundesregierung 2021). Of this, the Deutsche Bahn alone estimates the damage to its facilities at up to EUR 1.3 billion (Bundesministerium des Innern und für Heimat and Bundesministerium der Finanzen 2022). Among other things, 180 level crossings, almost 40 signal boxes, over 1,000 overhead line and signal masts and 600 km of track were destroyed (Koks et al. 2022). The remaining sum was needed, among other things, to repair more than 130 km of motorway, which was necessary as a result of flood damage (Koks et al. 2022).

The increased occurrence of extreme weather events as a result of climate change and the financing of damage repair and necessary emergency aid therefore pose a considerable fiscal risk at the federal level. The establishment of special funds, which places certain costs outside the federal budget, also ties up financial resources and reduces the financial leeway for future investments.

A reduction in economic growth and higher unemployment figures caused by climate change would also result in higher social security expenditure for the federal government. Depending on the climate change scenario used as a basis, a climate change-related decline in employment of 0.1-0.3% is forecast for Germany in 2030; for 2050, the expected decline is 0.3-0.7% (Flaute et al. 2022).

In addition, financial support from the federal government may be necessary if, for example, more frequent heat events increase the burden on the health and care sector and health and nursing care insurance funds find themselves in financial distress given their already strained financial situation(cf. ZDFheute 2025). This, too, can tie up substantial financial resources and place an enormous strain on the federal budget.

3.1.1.3.2 Costs due to adjustment

The federal government also bears a number of adaptation costs within the federal system. These include, for example, support programmes (see Chapter 3.2.2.1), research projects, financial support for adaptation activities at state and local level, and adaptation measures for federal infrastructure. The federal government also pays for the provision of data and information – for example, the federal government's climate risk analysis, as stipulated in the KAnG, can be explicitly used as a basis for the climate risk analyses of the states (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz 2023b). An analysis of the 2022 federal budget showed that federal expenditure on climate adaptation for this year ranged between EUR 2.1 and 3.4 billion (Hölscher et al. 2025b). As outlined in Chapter 2, a significant increase in this expenditure will be necessary in the coming years.

The federal government also incurs administrative costs in connection with the KAnG: as explained in more detail in Chapter 2.2.1.1.3.4, the federal government estimates its annual administrative costs for complying with the legal requirements at approximately EUR 2.75 million; in addition, there are one-off costs of around EUR 16.5 million (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz 2023b).

3.1.1.4 EU level

The European Union's budget is also affected by expenditure resulting from climate change. One important instrument is the EU Solidarity Fund (*Solidarity and Emergency Aid Reserve*, SEAR). This plays an important role in providing short-term financial assistance following extreme weather events.

For example, following the floods in 2021, the EU Solidarity Fund paid out over EUR 612 million to Germany (Europäische Kommission 2022).

The fund's annual allocation has been significantly increased in the last two EU budget cycles. Since 2024, the total annual allocations to the fund by the EU have risen by 46%; however, during the same period, the annual economic damage caused by natural disasters has more than doubled (García-Herrero and Mejino-López 2024), implying that the fund will be underfunded in the medium term and highlighting that the consequences of climate change will exacerbate the fiscal burden on the EU budget in this single item in the future.

3.1.2 Revenue side

In addition to the direct costs that extreme weather events have on fiscal budgets, climate change can also have a negative impact on the revenue side of budgets through indirect effects. These "indirect monetary costs" (Hirschfeld et al. 2021) are reflected, for example, in the form of reduced tax revenues in budgets. The following section describes various mechanisms that can lead to a fiscal burden on public budgets in Germany. As these risks cannot be described with the same degree of precision across the federal levels, they are instead differentiated according to the type of impact process.

3.1.2.1 Effects of climate change-induced migration

The migration described in the Chapter 2.2.2.3.2 due to climate impacts also has a negative impact on the budgets of affected countries and municipalities, both through the loss of local tax revenues and through reduced allocations of funds from fiscal equalisation, which are usually based on population size (see Chapters 3.2 and 0).

On the other hand, the settlement of people affected to other countries and municipalities that are less exposed to climate risks improves the position of these territorial units in the fiscal equalisation system and leads to a redistribution of equalisation funds, which directly counteracts the climate-related financing needs of territorial units with high risks.

3.1.2.2 Changes in production

Various climate risks can have a negative impact on economic production. For example, heat and higher humidity not only lead to a higher risk of illness (e.g. in the form of heat stroke, dehydration or fainting), but also to more frequent errors and accidents among workers, which are attributable to productivity losses and reduced concentration (Knittel et al. 2020). Heat stress not only affects workers' general well-being, but also their ability to work and their productivity, thus having a direct impact on the company's production and the economy as a whole (Kjellstrom et al. 2009). In their study for the UBA, Zacharias and Koppe (2015) concluded that as early as 2012, the health impact of the weather on working people in Germany had caused economic damage amounting to EUR 10 billion; with climate change progressing, this figure is expected to increase significantly both now and in the future.

Even beyond the effects of heat, productivity can be impaired. Natural damage and the associated changes to the living environment and landscape, including the loss of biodiversity, can also have a negative impact on people's well-being and health, thereby reducing the workforce (Hirschfeld et al. 2021).

Damage to relevant infrastructure, for example due to flooding or storm damage, represents another significant risk factor for the economy. This can affect company buildings and machinery, etc., as well as relevant supply routes and employees' commutes. The disruption of supply chains can mean that

this damage has an impact far beyond the location of the incident, for example if components or resources necessary for production are missing and production has to be shut down.

According to a study, the hot and dry summers of 2018 and 2019 caused direct damage of approximately EUR 5 billion in industry and commerce as a result of heat-related productivity losses, as well as indirect damage in other downstream industries along the value chains amounting to EUR 4.2 billion (Trenczek et al. 2022). BASF alone recorded a loss of EUR 250 million in the second half of 2018 due to the low water level of the Rhine, as the supply of raw materials by inland waterway transport to the Ludwigshafen site came to a standstill and plant utilisation had to be reduced (BASF 2019). Flaute et al. (2022) state that, depending on the climate change scenario (weak, medium, strong), a climate change-related GDP loss of EUR 5-25 billion is to be expected in Germany for 2030 and a GDP loss of EUR 20-79 billion for 2050.

A decline in economic output in Germany affects public sector revenues in various ways. The most important component is trade tax, which is one of the main sources of revenue for local authorities and is levied on profits from commercial activities (IHK München n.d.). Losses in corporate profits are therefore directly reflected in local tax revenues. If production declines as a result, this also has an impact on value added tax, as fewer products are available for sale, and staff cuts or company bankruptcies reduce income from income tax and social security contributions (Bär et al. 2023).

3.1.2.3 Changes in the sales market for companies

In addition to production, climate change can also affect sales of manufactured goods, which is reflected in changes in tax revenues and public budgets. The potential tax losses that may occur as a result of climate change have not yet been scientifically quantified for Germany; however, the basic mechanism of action can be deduced. In general, consumers often respond to economic crises by reducing their consumption (cf. Deutschlandfunk 2025), which has an impact on revenue from value added tax. In addition (2024a) describe how the hot summer of 2022, with its far-reaching consequences for agriculture and the economy, led to an increase in food inflation of approximately 0.6%. By 2035, global warming and extreme heat could increase annual food inflation by up to 3.2% per year and overall inflation by up to 1.18% per year. Although inflation can lead to increased tax revenues from sales tax due to a rise in consumer prices (Calvo and La Cruz 2024), rising prices also lead consumers to buy less or cheaper goods (Bobasu et al. 2024), which reduces business sales and revenue from sales tax. This has a direct impact on the budgets of the federal government, the states and local authorities in the context of fiscal equalisation (see Chapter 3.2).

A decline in sales also reduces the profits of manufacturing companies and intermediaries, thus causing a loss of public revenue along the mechanisms described in chapter 3.1.2.1.

The climate change risks for the German economy are by no means limited to Germany, but also have a significant impact on international sales markets. The effects of climate change outside Europe have a much greater impact on the German economy than those within Europe, as the effects of climate change outside Europe are much more pronounced (Peter et al. 2020). Due to the strong export orientation of the German economy, the economic impact of climate change on foreign trade is at least as significant as that occurring within Germany (Peter et al. 2020). Reduced demand for German products abroad threatens the sales figures of German companies and affects tax revenues in various ways: decreased profits reduce corporate income tax and trade tax revenues, while reduced bonus payments, declining salaries and staff cuts in exporting companies lead to reduced income and wage tax revenues. Declines in transport and production also affect energy tax revenues, for example, due to reduced consumption of electricity, gas, mineral oil, etc. In addition, climate-related changes in global trade have a particularly negative impact on the German economy and ultimately also place a strain on

public finances. This can include, for example, the disruption of international supply chains, which leads to delays in the delivery of products.

3.1.2.4 Sector-specific revenue losses

Sectors such as forestry, agriculture and fisheries, which depend on the existence of intact environmental ressources (forests, water bodies) that are or will be particularly affected by climate change, are particularly vulnerable to climate change.

In agriculture, the majority of economic damage is caused by extreme heat and drought. Between 1995 and 2019, extreme drought caused an average of approximately EUR 80 million in damage per year (Söder et al. 2022), particularly in northern and eastern Germany. Further climate-related damage is caused by extreme heat during the flowering period of certain crops, waterlogging (in winter cereals) or late frosts. In their comprehensive analysis for the Thünen Institute, Söder et al. (2022) conclude that no significant increase in average total yield losses is to be expected by the middle of the century; on the contrary, yield increases are to be expected in some areas, for example due to rising average annual temperatures and longer growing seasons. However, the range of precipitation forecasts is very wide, and climate risks vary greatly from region to region (cf. Kahlenborn et al. 2021), so it can be assumed that individual local and state budgets will nevertheless suffer increasingly from climate change-related agricultural yield losses.

In their analysis of the damage caused by the heat and drought summers of 2018 and 2019,Trenczek et al. (2022) estimate the total damage to agriculture at EUR 7.8 billion. In forestry, the damage amounted to as much as EUR 15.67 billion. This is spread across several cost factors: there was a significant increase in damaged timber and logging, which resulted in additional costs and lower revenues; in addition, there was also a considerable impact on downstream industries that rely on wood as a raw material.

The significant impact of climate change on entire sectors of the economy poses challenges for public budgets on both the revenue and expenditure sides: on the one hand, there is a threat of loss of tax revenue, not only due to losses incurred by companies following damaging events, but also, in the longer term, due to the possibility of climate-induced structural change, which could lead, for example, to the relocation of certain areas of cultivation due to changing local climatic conditions, with corresponding negative economic consequences for the previous cultivation areas. On the other hand, it may also be necessary to set up structural support programmes or government investment in new economic sectors in order to support the affected regions.

3.1.2.5 Opportunities: positive effects through investment in climate adaptation

Climate adaptation is a mammoth task for society as a whole, requiring not only large investments but also considerable resources. In this context, however, the planning and implementation of climate adaptation measures also offer economic opportunities. These basically include the reduction of the climate change-related revenue losses described in the previous Chapters, but go even further, particularly through labour market effects.

In a study on climate adaptation in the construction industry, Sander et al. (2025) state that in a mild climate change scenario, approximately 7,700 additional full-time equivalents would be needed in the industry to implement all necessary adaptation measures; in a severe climate change scenario, almost twice as many jobs (15,300) would be needed. Across all sectors and occupational groups, Bernardt et al. (2024) forecast an additional demand for around 70,000 workers by 2030. The creation of new jobs offers career opportunities for employees and, through income from wage and income tax, also fiscal opportunities for public budgets. However, given the already acute shortage of skilled workers, particularly in the occupational categories necessary for climate protection and digitalisation (Verband

Deutscher Ingenieure 2024), it can be assumed that filling the newly created positions will also pose a considerable challenge in the future.

The investments required for climate adaptation also contribute to value creation in Germany. In North Rhine-Westphalia alone, overarching climate adaptation measures contributed EUR 1.235 billion to gross value added in 2023, with the sector employing 15,000 people (Lühr et al. 2024). Bernardt et al. (2024) model a cumulative increase in real economic output of around EUR 150 billion for Germany for the period 2022 to 2040 as a result of additional expenditure and investment in climate adaptation. It should also be noted that the investments are not purely additive, but tie up resources that could otherwise have been used elsewhere. However, since adaptation investments often promote future-oriented industries, this can result in further growth effects and innovation opportunities that can have an economic impact, e.g. through the export of adaptation-related technologies. This applies, for example, to companies in the water management and flood protection sectors (see Chapters 2.3.2.2 and 3.1.1.1.2), but also to companies that develop digital twins for adaptation purposes (cf. Becker 2024) or adaptation solutions for agriculture (Klodt and Rutz 2024).

This results in various approaches for public budgets that can strengthen the fiscal situation. If the up to 70,000 skilled workers hired were previously unemployed, additional payroll taxes would be incurred, while social security contributions would be eliminated. The contracted companies contribute to the budget through trade and sales tax. Furthermore, rising economic output could improve the consumer climate, thereby increasing revenue from sales tax as well as the revenue of the companies offering the services and the amount of tax they pay.

3.2 Overview of financial compensation mechanisms

The financial and structural impacts of climate change pose enormous challenges for public budgets in Germany. Between 2000 and 2021, the consequences of climate change caused damage amounting to at least EUR 145 billion in Germany alone (Bundesministerium für Wirtschaft und Klimaschutz 2023). According to forecasts, the costs that could arise by 2050 will be between EUR 280 billion and EUR 900 billion(Bundesministerium für Wirtschaft und Klimaschutz 2023). The federal structure of the Federal Republic of Germany means that responsibility for dealing with this damage and providing financial support is divided in many different ways.

On the one hand, the division of responsibilities between the federal government, the states and the municipalities require a differentiated approach that can take local characteristics into account, but on the other hand this also leads to diverging standards and funding opportunities in the various federal states. In this context, the primary function of the federal government is to create overarching framework conditions and to provide support in the event of major disasters. The states, on the other hand, establish their own funding programmes that are tailored to specific regional needs and can provide incentives for the implementation of climate protection and climate adaptation measures.

The following chapter provides an overview of the most important existing compensation mechanisms and describes the extent to which these are already being used to finance climate protection, climate adaptation and damage in the context of climate change. It considers both financing mechanisms that come into play in the event of damage (disaster relief, reconstruction, financial assistance for damage repair) and those that provide support for adaptation to the effects of climate change. It then critically reflects on and classifies the existing instruments and identifies areas for possible improvement.

EXCURSUS: FEDERAL FISCAL EQUALISATION

The federal system of the Federal Republic of Germany provides for a number of ways in which financial resources can be redistributed between the different levels (vertically) and within a level between structural units of equal status (horizontally). The instruments that currently enable this form of redistribution are described below. The mechanisms described form the basis of public financing in Germany. Any future financing instruments will also be placed in the context of fiscal equalisation mechanisms and are therefore presented here at a higher level. Existing points of reference in the current equalisation structures for damage remediation and climate adaptation are described in the following subchapters.

Value added tax distribution (vertical)[6]

Sales tax distribution is the central element of vertical fiscal equalisation between the federal levels in Germany. The total revenue from value added tax is divided between the federal government, the states and the municipalities according to fixed percentages. In 2024, the federal government received 48.1%, the states 49.1% and the municipalities 2.8% of the value added tax revenue of around EUR 302 billion (Bundesministerium der Finanzen 2025b). This distribution is regulated by the Fiscal Equalisation Act (FAG) in accordance with Article 106(3) of the Basic Law and can be modified by fixed amounts or percentage adjustments in the event of changes in financial requirements (Article 106(4) of the Basic Law). The horizontal distribution of the federal states' share is initially based on population size. Subsequently, surcharges and discounts are applied as part of financial equalisation in order to compensate for differences in financial strength between the federal states. Financially weak federal states receive surcharges, while financially strong federal states must accept discounts (Bundesministerium der Finanzen 2025b).

Financial equalisation (horizontal)

Financial equalisation (FKA) compensates for differences in the financial strength of the federal states through a transparent, horizontal redistribution process. In 2024, around EUR 18.7 billion was redistributed between the federal states. Four states were net contributors: Bavaria (EUR 9.77 billion), Baden-Württemberg (EUR 5.03 billion), Hesse (EUR 3.73 billion) and Hamburg (EUR 106 million). The twelve recipient states received compensation payments, with Berlin (EUR 3.94 billion), Saxony (EUR 3.25 billion) and Thuringia (EUR 2.04 billion) receiving the largest amounts (Bundesministerium der Finanzen 2025b). The system is based on the financial strength index[7] and the compensation index[8] of the federal states. The difference is compensated for 63% (Bundesministerium der Finanzen 2025b). This mechanism deliberately maintains the original financial strength ranking of the federal states in order to maintain incentives for economic performance.

Federal supplementary grants (vertical)

Federal supplementary grants (BEZ) are financed by the federal government from its budget and represent a vertical equalisation instrument with horizontal effect, as they compensate for differences in financial strength between the federal states. They are divided into three categories:

[6] The other community taxes (income tax, corporation tax and capital gains tax) follow fixed distribution keys enshrined in the constitution in accordance with Article 106(3) of the Basic Law. Only in the case of value added tax are the distribution quotas flexibly adjusted by the Fiscal Equalisation Act, which makes it the basis for vertical fiscal equalisation in Germany.

[7] Financial strength index: for each state, a share of the total compensation-relevant revenue is calculated according to that state's share of the total weighted population. The population figures for city states are increased mathematically by means of so-called population weights; according to Section 9 FAG, this valuation is 135% for Berlin, Hamburg and Bremen (Bundesministerium der Finanzen 2025b 2025b).

[8] Compensation index: When calculating the municipality-related compensation indices, city states are taken into account at 135% and sparsely populated states with special population weights; the state shares of the compensation-relevant municipal revenues are determined in accordance with the shares of the weighted population figures, and the state compensation index is the sum of the state and municipality indices (Bundesministerium der Finanzen 2025b).

- General federal supplementary grants: These compensate for remaining differences in financial strength after horizontal financial equalisation. States whose financial strength after equalisation is below 99.75% of the states' average receive an 80% top-up to make up the difference to this value (Bundesministerium der Finanzen 2025b).
- Federal supplementary grants pursuant to Article 107(2) sentence 6 of the Basic Law: These comprise two special types of equalisation:
    - Compensation for municipal tax revenue: States with below-average municipal tax revenue (less than 80% of the federal average) receive a 53.5% top-up to make up the shortfall (Bundesministerium der Finanzen 2025b). This indirectly strengthens the climate adaptation capacity of municipalities, as they have more funds available for local measures. (tes)
    - Research funding compensation: States with below-average net research inflows (less than 95% of the average) receive a 35% top-up (Bundesministerium der Finanzen 2025b). This funding also supports research projects on climate protection and climate adaptation.
- Special needs federal supplementary grants (SoBEZ): These cover special burdens; the funds can be used indirectly for structural transformations towards climate neutrality and adaptation:
    - Costs of political leadership: Smaller states receive subsidies for above-average per capita costs of political leadership (Bundesministerium der Finanzen 2025b).
    - Structural unemployment: The new federal states receive compensation payments for disproportionate burdens due to structural unemployment (Bundesministerium der Finanzen 2025b).

Municipal financial equalisation

The municipal financial equalisation system (KFA) is organised independently by each federal state and represents an essential source of funding for municipal tasks. In all federal states, equalisation takes the form of vertical equalisation with a horizontal effect, i.e. the funds distributed by the federal state to the municipalities (vertically) are calculated in such a way as to achieve a balancing effect between the municipalities (horizontally) (Eggert and Minter 2018).

The system follows a multi-stage procedure: First, the joint revenue is calculated as a percentage of total state revenue, including revenue from joint taxes. Next, the financial strength and financial needs of each municipality are determined, and the difference is (partially) compensated for by key allocations at a certain percentage rate (Eggert and Minter 2018).

The federal states apply different approaches here: Brandenburg and Schleswig-Holstein, for example, use a composite quota system with a symmetry requirement, which covers the total revenue of the state and local levels beyond the joint revenue and also takes into account the burdens of performing tasks at both levels. In this way, not only are differences in municipal revenues balanced out, but changes in the use of municipal and state-provided public services are also taken into account in order to distribute the financial resources of the municipalities as evenly as possible (Thöne and Bullerjahn 2020).

3.2.1 Damage repair and disaster relief

Damage repair and disaster relief in Germany are financed through a multi-level system involving various actors and instruments. In addition to nationwide and European aid mechanisms, the federal states also have their own programmes for disaster relief and damage repair following extreme weather events. Examples include Bavaria with its Bavarian Special Investment Programme for Disaster Control Bavaria 2030, which has provided over EUR 160 million in funding for disaster prevention and management costs in the 2019-2025 budgets (Bayrisches Staatsministerium des Innern, für Sport und Integration n.d.), and Baden-Württemberg, which bundled existing state and funding programmes for flood relief after the 2024 floods in order to simplify the application process and ensure that funds were made available quickly (Ministerium des Inneren, für Digitalisierung und

Kommunen Baden-Württemberg 2024). A complete overview of all state programmes would go beyond the scope of this analysis, which is why the following discussion focuses on the key overarching financing instruments.

3.2.1.1 Damage financing from fiscal equalisation

The structural design of the fiscal equalisation systems in the German federal system (see above) means that damage costs can also have a downstream effect on future equalisation allocations, as they affect the distribution of VAT shares within the framework of fiscal equalisation – these are calculated on the basis of financial data from the previous year. In municipal fiscal equalisation, too, tax losses due to extreme weather events affect the measurement of tax revenue. States and municipalities that experience climate-related tax losses or reductions in their determined financial strength thus receive additional funds to cover the damage costs incurred and to finance necessary repairs.

However, fiscal equalisation is only of limited use as an instrument for financing climate damage: on the one hand, the fact that the damage is only recorded in the following year means that the distribution of additional funds is significantly delayed and cannot be used for acute emergency aid in the event of a disaster. In addition, financial losses are only compensated on a pro rata basis under the financial equalisation scheme, meaning that local authorities still have to bear part of the damage costs themselves. This makes the use of additional financing instruments indispensable.

3.2.1.2 Reconstruction aid fund as a special fund

Throughout its history, Germany has used several special funds as specific financing instruments to deal with crises and disasters. These "side budgets" are set up by the federal government, particularly in times of upheaval and crisis, to finance extraordinary tasks (Deutscher Bundestag 2022).

The first special fund, "Aufbauhilfe" (reconstruction aid), was established in 2002 by Article 5 of the Flood Victims Solidarity Act. EUR 7 billion was made available to repair flood damage, primarily along the Elbe and Danube rivers, and to rebuild the devastated regions (Wissenschaftliche Dienste des Deutschen Bundestages 2025). Another flood event triggered the establishment of the second special reconstruction fund: the EUR 8 billion special fund was set up by the federal government in 2013 to repair damage and rebuild destroyed infrastructure following flooding along the Elbe, Danube and other rivers (Wissenschaftliche Dienste des Deutschen Bundestages 2025).

The instrument can be illustrated in detail using the most recent establishment of a special reconstruction fund following the 2021 flood disaster:

In the summer of 2021, heavy rainfall caused catastrophic flooding in Western Europe (Germany, Belgium, the Netherlands, France, Luxembourg), which caused devastating damage in the German states of Rhineland-Palatinate, North Rhine-Westphalia, Bavaria and Saxony. In Germany, more than 180 people lost their lives and over 800 were injured, some seriously. The total damage is estimated at over EUR 40 billion (Bundesministerium des Innern und für Heimat and Bundesministerium der Finanzen 2022).

To deal with the damage, the 2021 Reconstruction Assistance Fund was set up as a special federal fund with up to EUR 30 billion. The fund finances both emergency aid for private households and businesses and the reconstruction of infrastructure at state, local and federal level (Bundesministerium der Finanzen 2021).

The funds were distributed according to a fixed formula, with Rhineland-Palatinate receiving 54.53% of the funds due to the particular severity of the damage in the Ahr Valley (Bundesregierung 2021). An innovative aspect of the fund is its explicit promotion of climate-resilient reconstruction

measures. According to the Reconstruction Assistance Ordinance, measures are eligible for funding "if, in terms of their nature, location or scope, they are rebuilt in a manner appropriate to the respective flood risk in accordance with generally accepted technical rules for the prevention of future damage" (AufbhV 2021, Section 3, Paragraph 2; Bundesregierung 2021).

In November 2023, the Federal Government reported to the Committee on Housing, Urban Development, Construction and Local Government that, as of 23 October 2023, around EUR 3.057 billion had been disbursed from the special fund. Of this, around EUR 484 million was allocated to measures in the area of federal infrastructure, and approximately EUR 2.573 billion went to state programmes. As the deadlines for submitting applications set as a result of the establishment of the 2021 Recovery Fund proved to be too short, particularly for residents in the affected regions, the 2023 application deadline was extended to 30 June 2026 and the approval deadline to 31 December 2030 (Deutscher Bundestag 2023).

3.2.1.3 EU Solidarity Fund

The EU Solidarity Fund supplements national disaster relief in the event of major natural disasters. Germany can apply for support if the damage exceeds EUR 3.59 billion (inflation-adjusted limit) or 0.6% of gross national income (Ruppert 2021).

The fund covers emergency and reconstruction measures, including the repair of damaged infrastructure, the protection of cultural heritage and clean-up work. Applications must be submitted within twelve weeks of the initial damage occurring, ensuring a timely response (Ruppert 2021). Applications are submitted via the competent national authorities, in Germany via the BMF. In the case of the 2021 flood disaster, the total damage incurred was estimated at approximately EUR 29 billion based on the figures reported by the affected states and federal institutions and reported by the BMF to the European Commission (Bundesministerium des Innern und für Heimat and Bundesministerium der Finanzen 2022), which, after review, approved the payment of over EUR 612 million to Germany at the end of 2022 (Europäische Kommission 2022). In October 2024, the European Commission proposed EUR 112 million in flood aid for Bavaria and Baden-Württemberg following the floods in May and June of that year (Europäische Kommission 2024).

3.2.1.4 Sectoral aid programmes

Sectoral aid programmes complement general disaster relief by providing targeted support to particularly affected sectors of the economy. The 2023 National Framework Directive on the granting of state financial aid to deal with damage in agriculture and forestry is particularly relevant to the study, as it enables both regional and national aid programmes to provide rapid and legally compliant support to affected businesses. Agriculture and forestry are particularly vulnerable to extreme weather events and climate-related damage. The framework guideline covers damage caused by natural disasters such as floods, storms, droughts, hail or frost and provides for gross aid intensities of up to 100% of the total damage, depending on the type of damage. The aid can be granted in the form of subsidies or low-interest loans and reaches those affected via the competent authorities under state law (Bundesministerium für Ernährung und Landwirtschaft 2023).

3.2.2 Climate adaptation financing

3.2.2.1 Federal funding programmes for climate adaptation

Climate adaptation in Germany is currently financed by a series of federal funding programmes. Important programmes are described below as examples; a comprehensive overview is provided by the funding database of the Climate Adaptation Centre[9].

The National Climate Adaptation Programme brings together various funding guidelines under one umbrella. Through the DAS funding guideline, the Federal Ministry for the Environment promotes municipal climate adaptation measures, with a particular focus on nature-based solutions (Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit 2025b).

The federal programme "Adaptation of urban and rural areas to climate change" promotes investment projects for the development of green and open spaces that are highly effective for climate protection and climate adaptation. To date, EUR 576 million has been made available from the KTF for this purpose (Bundesinstitut für Bau-, Stadt- und Raumforschung n.d.).

The promotion of climate adaptation in social institutions addresses particularly vulnerable groups. The programme has three funding priorities: concept development (up to EUR 70,000), implementation of measures (up to EUR 500,000) and overarching support from climate adaptation officers. Both nature-based solutions and technical infrastructure measures are eligible for funding (Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit 2025a).

Climate adaptation measures are also partly funded by climate protection subsidies, provided that the measure in question contributes to both objectives: since 12 February 2024, the Federal Office of Economics and Export Control has been promoting the installation of refrigeration and air conditioning systems for commercial users as part of the National Climate Protection Initiative. Since only systems using non-halogenated refrigerants are eligible for funding, the programme also contributes to increasing energy efficiency and reducing emissions of fluorinated greenhouse gases (Bundesamt für Wirtschaft und Ausfuhrkontrolle n.d.). Integrated climate protection and climate adaptation concepts are also funded by the federal government: The second ANK-DAS call for funding[10] (funding window 15 May to 5 August 2025) supports municipal concepts for sustainable climate adaptation and natural climate protection. Funded climate adaptation managers are to develop concepts that focus on synergies between climate adaptation, natural climate protection and biodiversity enhancement using nature-based solutions (Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit 2025b).

3.2.2.2 EU Structural Funds and climate adaptation

EU Structural Funds, in particular the European Regional Development Fund (ERDF), are also used to strengthen national support programmes, for example within the framework of the Joint Task "Improvement of Regional Economic Structures" (GRW; Bundesministerium für Wirtschaft und Energie 2025). This opportunity to obtain additional funding also applies to suitable climate adaptation projects, meaning that EU funds can contribute to the implementation of adaptation measures in this way.

In North Rhine-Westphalia, around EUR 37 million from ERDF funds are being made available in the "Klimaanpassung.Kommunen.NRW" funding call alone; in the third round of submissions, 24 projects

[9] https://ad.zentrum-klimaanpassung.de/foerdermoeglichkeiten/suchergebnisse?fulltext=&foerdergeber[]=99
[10] ANK: Action Programme for Natural Climate Protection.

with a total volume of EUR 27 million were funded (Ministerium für Wirtschaft, Industrie, Klimaschutz und Energie des Landes Nordrhein-Westfalen n.d.). Bavaria is also providing significant ERDF funding for flood protection measures for climate adaptation (Bayrisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie n.d.), while Brandenburg is mobilising up to EUR 55 million in ERDF funding for heavy rain prevention and the protection of listed gardens and parks (Ministerium für Wissenschaft, Forschung und Kultur des Landes Brandenburg 2024).

ERDF funding focuses on specific areas of climate adaptation. Priority funding areas include measures to protect against overheating, drought and aridity, and the creation of evaporative cooling. Of particular importance are nature-based solutions for restoring natural soil exchange processes and implementing the sponge city principle for the infiltration, evaporation, storage and pollutant-free drainage of rainwater. Flood protection measures for adaptation to climate change are another priority, in particular the planning and implementation of flood protection facilities and their retrofitting to protect residential areas and infrastructure (See Ministerium für Wirtschaft, Industrie, Klimaschutz und Energie des Landes Nordrhein-Westfalen n.d., Bayrisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie n.d., Senatsverwaltung für Mobilität, Verkehr, Klimaschutz und Umwelt n.d.).

3.2.2.3 Special Fund for Infrastructure and Climate Neutrality

The Special Fund for Infrastructure and Climate Neutrality was established in 2025 with a credit authorisation of up to EUR 500 billion. It has two main objectives: additional investment in infrastructure and investment to achieve climate neutrality by 2045. EUR 100 billion is available to the federal states for infrastructure investments, with a further EUR 100 billion going to the Climate and Transformation Fund (KTF). The remaining EUR 300 billion is earmarked for federal investments. A key element is the additionality test: investments must be demonstrably additional to existing expenditure (Bundesregierung 2025).

While considerable financial resources are thus being made available for climate protection, the use of these funds for climate adaptation is possible to varying degrees depending on the share of the special fund. According to the draft SVIKG, the investment funds allocated to the federal government can be used for climate adaptation, particularly in the sectors specified in Section 4 (1) SVIKG: civil protection and civil defence, transport infrastructure, energy infrastructure, and research and development (Deutscher Bundestag 2025a). The use of state funds is to be regulated by the State and Municipal Infrastructure Financing Act (LuKIFG). The explanatory memorandum to the draft law expressly clarifies that preventive measures such as heat, flood and coastal protection are eligible for funding within the framework of civil protection (Bundesrat 2025). The KTF funds, on the other hand, are earmarked for climate protection measures (Wissenschaftliche Dienste des Deutschen Bundestages 2023) and can therefore only be used for adaptation objectives within the framework of integrated climate protection and climate adaptation measures (see Chapter 3.2.2.1).

3.2.2.4 Climate adaptation in federal fiscal equalisation

Municipal fiscal equalisation is fundamentally important for climate adaptation, as it ensures that municipalities have the financial capacity to act. Municipalities with sufficient financial resources are more likely to invest in preventive climate adaptation measures, while financially weak municipalities often have to forego voluntary self-government tasks, which include climate protection and climate adaptation measures (Schanze et al. 2017).

As can be seen from the description of the federal fiscal equalisation mechanisms in chapter 3.2, the current system is only designed and able to cover the financing requirements resulting from necessary adaptation measures to a very limited extent, as the equalisation indicators do not include any climate

risk criteria or similar. Although the financing needs of local authorities are taken into account in the distribution of municipal fiscal equalisation, these are currently calculated primarily on the basis of ex-post, empirically clearly defined indicators such as population size or number of pupils per municipality (Eggert and Minter 2018; Döring et al. 2024) and do not include adaptation financing or climate protection investments. The integration of climate criteria into financial equalisation is discussed in Chapter 3.3 as a novel, expanded financing instrument.

3.2.2.5 Urban development funding

Urban development funding is one of the most important instruments for sustainable urban development with a direct link to climate change. The federal government, together with the states, provides financial assistance for investments in the renewal and development of cities and municipalities. The 2025 federal budget allocates EUR 790 million to urban development programmes (BMWSB n.d.). Funding is provided according to the one-third model: the federal government bears one-third of the costs, while the states and municipalities together bear two-thirds. The administrative agreement between the federal government and the states makes green and blue infrastructure measures mandatory, with at least one climate measure to be implemented during the funding period.

Since 2020, measures for climate protection and adaptation to climate change have been a prerequisite for funding in all three programmes:

- Vibrant centres (EUR 300 million): preservation and development of city and town centres
- Social Cohesion (EUR 200 million): Stabilisation of disadvantaged neighbourhoods
- Growth and sustainable renewal (EUR 290 million): Coping with demographic change

Climate protection, climate adaptation and "green in the city" have since been systematically anchored as cross-cutting tasks in the funding logic. The great opportunity lies in not implementing climate-measures in isolation, but rather anchoring them within the framework of holistic and integrative urban renewal.

However, this new orientation brings with it planning and implementation hurdles. Local authorities have to deal with legal, organisational and technical issues while making do with limited financial and human resources. The diversity of area types – from mixed-use urban areas and large housing estates to inner-city areas and brownfield sites – calls for tailor-made solutions that do justice to the specific characteristics of the respective neighbourhoods. Small and medium-sized municipalities with fewer than 100,000 inhabitants in particular lack the necessary expertise to independently meet the complex requirements of climate integration. In addition, funding guidelines vary from country to country, leading to different approaches and implementation speeds.

The special characteristics of urban development funding – such as specific area demarcations, mandatory integrated urban development concepts (INSEK) and complex financing structures – require tailor-made solutions that go beyond general climate strategies. Although urban planning offices are familiar with the creation and updating of INSEK, the integration of climate protection and climate adaptation requires additional technical expertise and capacity. At the same time, this shows that many local authorities lack sufficient human resources to make optimal use of funding instruments.

3.2.2.6 Mixed financing and other instruments

3.2.2.6.1 Joint tasks under Article 91a of the German Basic Law

Joint tasks describe tasks of the federal states in whose implementation the federal government participates by contributing to the financing (mixed financing) and framework planning. According to

Article 91a of the German Basic Law, this is possible if the tasks are significant for the whole and their implementation is necessary to improve living conditions (Eggert 2018).

In addition to the joint tasks considered below, the creation of a further joint task for climate adaptation has been under discussion for several years; this project is considered in the info box in Chapter 3.3.

3.2.2.6.1.1 Joint Task for the Improvement of Regional Economic Structures (GRW)

The GRW is the central financing instrument of German regional policy. It pursues three main objectives: securing employment and income, compensating for locational disadvantages and accelerating transformation processes towards a climate-neutral and sustainable economy (Bundesministerium für Wirtschaft und Energie 2025).

The GRW has developed into an important financing instrument for climate protection since the 2022 GRW reform explicitly anchored the transformation to climate neutrality as one of its main objectives (Bundesministerium für Wirtschaft und Energie 2025). Funding is provided for commercial investments, business-related infrastructure and non-investment activities such as cluster formation in structurally weak regions (Bundesministerium für Wirtschaft und Energie 2025).

While climate protection is thus included in the GRW, there is no clear reference to the financing of climate adaptation measures. However, financing integrated climate protection and climate adaptation measures is conceivable in principle, and the potential positive employment effects of climate adaptation (see Chapter 3.1.2.5) also open up points of contact.

3.2.2.6.1.2 Joint Task for Agricultural Structures and Coastal Protection (GAK)

The GAK is the central nationwide funding instrument for improving agricultural structures and coastal and flood protection, and sets nationwide framework plans that are implemented by the federal states. It is jointly financed (usually 60% by the federal government and 40% by the federal states) and combines federal policy objectives with state and location-specific implementation (Bundesministerium für Ernährung und Landwirtschaft 2025). As a financial compensation instrument, it mitigates regional disparities and anchors priority investments in rural areas. The GAK is particularly important for climate protection and adaptation because it covers climate-relevant sectors and co-finances the implementation of Germany's climate protection and adaptation goals through measures such as dyke construction, nature-based coastal protection measures, water management infrastructure and emission-reducing agricultural practices.

3.2.2.6.2 Art. 104b GG Investment Aid

Article 104b of the Basic Law allows the federal government to provide financial assistance to the states for particularly significant investments by the states or municipalities. It is a required prerequisite is that the investments either:

1. prevent a disturbance of the overall economic balance,
2. balance out differences in economic strength within the federal territory, or
3. promote economic growth. (Art. 104b (1) GG)

Urban development funding under Article 104b of the Basic Law thus enables the federal government to participate in urban development measures (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen 2024). Climate adaptation measures have been a prerequisite for funding since 2020, making this instrument an important climate financing tool (see Chapter 3.2.2.5).

Article 104b (1) No. 3 of the German Basic Law (GG) also opens up far-reaching possibilities for granting financial assistance for economic growth. In their legal opinion prepared for the BMUV on "Legal issues relating to the joint financing of climate adaptation and nature conservation measures by the federal and state governments,"Kaufhold and Heitzer (2024) conclude that climate adaptation measures can be assigned to this funding purpose in many areas, as they contribute to securing long-term economic performance.

3.2.2.6.3 Stability Council and fiscal monitoring

The Stability Council was established as a joint body of the federal and state governments as part of the Second Federalism Reform. It monitors budgets to prevent budgetary emergencies and ensure compliance with European fiscal rules (Stabilitätsrat n.d.a, n.d.b).

This is based on annual stability reports with defined indicators for assessing the budgetary situation. In the event of impending budgetary emergencies, the Stability Council initiates a comprehensive evaluation process and, if necessary, agrees on restructuring programmes (Stabilitätsrat n.d.b).

The Stability Council is relevant for climate financing because it monitors compliance with EU fiscal rules at the national level and thus influences the framework for climate-related investments (Deutsche Bundesbank 2019). The debt brake and fiscal surveillance can have both a limiting and a structuring effect on climate-related expenditure; on the one hand, they restrict financial leeway, but on the other hand, they also contribute to the transparency of financing channels and to the evaluation and impact-based prioritisation of measures (see Chapter 4). Special funds such as the Reconstruction Assistance Fund or the Special Fund for Infrastructure and Climate Neutrality also make it possible to finance climate-related investments outside the regular budgetary rules.

3.2.3 Critical reflection on existing mechanisms

3.2.3.1 Shortcomings of existing financing mechanisms

The existing financing mechanisms in the federal system of the Federal Republic of Germany have a number of weaknesses and shortcomings with regard to the financial risks of climate change, which are outlined below. This is based on the previous literature review as well as a series of expert interviews conducted as part of the research project.

The biggest and most fundamental problem is the huge gap between the financing requirements described in Chapter 2 and the funds actually available. Even without the necessary future expenditure on climate adaptation and the expected costs of climate damage, local authorities recorded a record deficit of EUR 24.8 billion in 2024 (Statistisches Bundesamt 2025), and the KfW Municipal Panel 2025 recorded a perceived investment backlog of EUR 215.7 billion (KfW Research 2025b). In addition, municipal utilities, extra-budgetary funds and municipal companies are putting additional investment pressure on local authorities.

Article 104a (1) of the German Basic Law stipulates that the federal government and the federal states must bear the costs incurred in the performance of their tasks themselves – the so-called principle of connectivity. In this sense, the federal government is also prohibited from financing the tasks of the federal states (financing ban)(Verheyen and Franke 2025). In the context of financing municipal tasks, the principle of connectivity under state constitutional law, which is regulated in the individual state constitutions, also applies: if the state assigns tasks to a municipality (mandatory municipal tasks), it must ensure adequate financial compensation (Wohltmann 2018).

In practice, the principle of connectivity reaches its limits: local authorities often complain that the tasks assigned to them are not backed up by the necessary budgetary resources (bpb 2023) and thus

place an additional burden on local authority budgets. For example, changes in social legislation (SGB II, SGB VIII) led to considerable additional burdens on local authorities without always being fully compensated (Grohs and Reiter 2014). The share of social expenditure in total municipal expenditure is rising steadily (Statistisches Bundesamt 2025). In 2023, municipalities accounted for 14.2% of tax revenue, while they had to bear 28.4% of total public expenditure (excluding social security)(Döring and Wohltmann 2025) – this structural underfunding, which relies on additional grants from the federal states and the federal government, further exacerbates the problem of the financing gap in the face of climate change. The principle of connectivity is particularly relevant for climate adaptation, as the KAnG assigns new tasks to local authorities, at least indirectly.

In the context of climate protection and adaptation, the current municipal financing situation is complex: the mandatory financial compensation for municipal mandatory tasks does not provide any fiscal incentive for the federal states to regulate climate protection and adaptation uniformly and predictably within the framework of mandatory tasks. The federal government, in turn, is not allowed to cover the costs of municipal mandatory tasks, as these are a matter for the federal states (financing ban). As a result, local authorities can currently only undertake climate protection and adaptation tasks on a voluntary basis and at their own expense, and may have to access subsidies for this, which brings its own challenges (see below)(Verheyen and Franke 2025).

Since climate adaptation measures must primarily be implemented at the local level, the fiscal situation of local government budgets poses a considerable risk to the achievement of climate targets and the implementation of adaptation measures. A lack of investment in adaptation measures increases the vulnerability of both local government budgets (see Chapter 3.1) and residents to the consequences of climate change. Where budgetary resources are lacking, there is also a risk of cuts to climate-related budget items, such as the provision of public transport (Kessler 2025) – a failure of fiscal compensation mechanisms can therefore also have concrete negative effects on the climate. The strained financial situation of local authorities also leads to competition between future-oriented investments in climate adaptation, social welfare, security of supply, etc., which requires local authorities to prioritise, even though all investments would be necessary in themselves.

Some critics of the fiscal equalisation mechanisms used in Germany point out that the high degree to which financial differences are equalised means that recipient states and local authorities have little incentive to increase their tax revenues and thus increase the total available fiscal assets. In addition, the lack of transparency and high complexity of the distribution mechanisms are criticised, as they make democratic oversight difficult (Bielicki 2012).

The current financing landscape for climate adaptation in Germany relies heavily on funding programmes. These offer various advantages: for example, they are relatively easy to implement and enforce in terms of policy and budgetary law, and they enable the targeted management of the measures or investments being financed. At the same time, however, they are also a source of criticism, especially at the municipal level. For example, there are complaints that the large number of different funding programmes makes it difficult to get an overview of them as a whole (see also KPMG n.d.). In addition, funding applications usually have to be prepared at great expense and reviewed according to strict criteria. This ties up human resources at both the applicant and funding agency levels and can lead to delays in project implementation. In view of the already considerable shortage of personnel in local authorities, which is expected to become even more acute in the future (Klimaschutz Kommune 2025), applying for funding can become an insurmountable hurdle, especially for small local authorities or those particularly affected by staff shortages – with the result that funds to tackle the climate crisis are not accessed and appropriate measures are not implemented. In addition, financial support from funding programmes is limited and usually only covers the one-off investment costs of a measure, but not the ongoing maintenance and upkeep costs, which often represent significant cost

factors. These must be borne by the local authorities after the measure has been implemented and place a strain on the local authority budget.

The dependence of the availability of funding on the political will of the funding bodies and the budgetary situation also leads to uncertainty and reduced predictability on the part of recipients, as budget cuts by funding bodies or, for example, at the state level have a direct impact on the funds available to local authorities for climate adaptation. However, given that some adaptation measures involve infrastructure projects of considerable scope, planning security and secure medium-term financing are essential for their implementation. Flood protection is a good example of this: long-term flood protection projects depend on reliable financing frameworks. The permanent provision of adequate commitment appropriations is crucial, as the projects often run for several years. However, the annual budget cycles of the federal states and the federal government make this difficult: insufficient commitment appropriations in the National Flood Protection Programme (NHWSP) recently forced the financially weaker eastern German states in particular to divide up large measures and award them in several smaller tenders. This led to higher personnel and cost expenditure as well as delays in implementation.

The specific design of some instruments may also contribute to them not being fully effective in terms of climate adaptation. Although the 2021 Reconstruction Assistance Fund covers adaptation measures in the area of flooding (e.g. raising buildings), modernisation measures are only eligible for funding if there is an existing legal obligation to do so. When designing the fund, the state government of Rhineland-Palatinate expressed the wish to also make the establishment of future energy standards, which are already provided for by law, eligible for funding; however, the federal government did not comply with this request, citing the applicable legal norms and standards (Deutscher Bundestag 2023). This meant that an opportunity was missed to link reconstruction to a forward-looking climate policy approach instead of simply restoring the status quo. The EU Solidarity Fund has also come under criticism because it does not allow for reconstruction in line with the UN's "build back better" principles[11] (García-Herrero and Mejino-López 2024) .

3.2.3.2 Starting points for possible improvements

In view of the existing criticisms and weaknesses of the current financing mechanisms, there is considerable potential for improving or expanding the financing of climate adaptation measures.

The high financing requirements and the insufficient financial resources available in public budgets to finance climate damage and climate adaptation highlight the need to tap into additional sources of financing that go beyond the redistribution of existing budgetary resources and make use of funds from the private sector or the financial sector, for example.

The German funding landscape should be simplified and digitised in order to speed up processing and, in particular, to reduce the workload on local authorities. During the interviews, the desire for flexible funding instruments that can be accessed in the long term was frequently expressed. In addition to funding programmes, other forms of financing should also be given greater consideration. The financing instruments should also be designed in such a way that they offer clear financing commitments over longer terms, thus enabling planning for implementation. Adaptation and resilience criteria should also be taken into account when designing the instruments in order to ensure that the funds are used in a future-proof manner.

[11] "Built back better" describes the approach of using the phases of recovery, rehabilitation and reconstruction after a disaster to strengthen the resilience of nations or communities by incorporating disaster prevention measures into the restoration of infrastructure, the economy and nature (United Nations Office for Disaster Risk Reduction 2017).

In view of the strained personnel and fiscal situation of many German municipalities, it also seems worthwhile to design instruments that operate at the regional level and can efficiently bundle needs and capacities. These could take the form of regional special-purpose entities that bundle the needs of several municipalities and exploit economies of scale.

3.3 Additional financing mechanisms

Climate change poses a variety of fiscal risks for public budgets in Germany, and the existing compensation mechanisms identified in Chapter 3.2 are increasingly insufficient to address these risks. This chapter presents a list of innovative approaches to closing the existing financing gap, which address the previously identified weaknesses of the current financing system and operate at various levels of the federal system, reallocate existing budgetary resources or mobilise additional funds from the private sector or institutional contexts, and finance preventive adaptation measures or provide ex-ante support for coping with climate impacts (seeTable 43). The name of each mechanism includes a link to the respective profile in the appendix.

Table 43: Overview of new financing mechanisms

Designation	Brief description	Category
Levying (local) taxes for climate protection and adaptation	Earmarked municipal levies (e.g. on sealed surfaces) to finance local adaptation measures such as unsealing, greening or rainwater management.	Systemic redistribution and fiscal control
Catastrophe bonds (cat bonds)	Public bonds. If a defined disaster event occurs, the capital invested by investors is used in whole or in part for rapid financing; otherwise, it is repaid at the end of the term.	Risk transfer and damage protection
Climate-resilient debt clauses (CRDCs)	Contractual deferral options in loans: Following climate events (e.g. drought, flooding), repayment and interest payments can be temporarily suspended to provide short-term relief for the budget.	Liquidity relief and debt management in the event of climate shocks
Expansion of local climate funds	Expansion of existing municipal climate funds to include adaptation projects; financing from budgetary resources and contributions from business, foundations and civil society.	Systemic redistribution and fiscal control
Resilience assessment of infrastructure investments	Mandatory assessment of climate risks in public construction and infrastructure projects to ensure long-term functionality and economic efficiency.	Regulatory quality assurance and mainstreaming

Designation	Brief description	Category
Integration of climate protection and climate adaptation into horizontal fiscal equalisation	Climate risks, benefits and adaptation needs are systematically included in the distribution of funds between states and municipalities in order to take appropriate account of impact and performance.	Systemic redistribution and fiscal control
Municipal Climate Collateralised Loan Obligations (K-CLOs)	Bundling of many small municipal climate loans into a tradable package for investors. This mobilises additional capital for local projects.	Prevention and investment financing via capital markets
Parametric insurance	Insurance with clearly defined triggers (e.g. a certain amount of precipitation). When a specified threshold is reached, payment is made quickly without lengthy damage assessment.	Risk transfer and damage protection
Reformed federal supplementary grants with climate forecast factor	Federal funds are additionally distributed according to climate indicators (risks, adaptation needs, damage history) in order to provide more predictable support to particularly affected countries.	Systemic redistribution and fiscal control
Resilience bonds with a focus on prevention	Bonds that finance preventive measures in addition to covering damage. Monetised damage prevention contributes to the financing of protective infrastructure.	Prevention and investment financing via capital markets
The state as the insurer of last resort	The state acts as a reinsurer, covering extreme risks when private (re)insurance is insufficient. This ensures that insurance cover remains available and affordable.	Insurance against damage

The list of proposals was compiled on the basis of the team's relevant prior knowledge, previous literature research and a series of expert interviews. For clarity, all instruments are presented in the form of standardised profiles. For each instrument, the basic mechanism of action is described first, before specific advantages and challenges are identified and examples of application are given. Particular attention is paid to anchoring the instruments in the federal context, so that it is clearly stated at which level which responsibilities lie for the implementation of the instrument.

The complete profiles of all instruments discussed can be found in the appendix to this report.

EXCURSUS: CLIMATE ADAPTATION AS A JOINT TASK

The idea of a joint task for climate adaptation has been under discussion for several years and has become increasingly important in political discourse in Germany. The focus is on establishing climate adaptation as a new joint task under Article 91a of the German Basic Law in order to enable the coordinated and joint financing of climate adaptation measures by the federal government, the states and local authorities (see Chapter 3.2.2.6.1).

In 2021, the UBA proposed the creation of a new joint task for climate adaptation in order to implement the objective set out by the then Federal Environment Minister Svenja Schulze (SPD) of creating a reliable legal and financial framework for climate adaptation (Umweltbundesamt 2021). In 2024, an expert opinion commissioned by the BMUV on "Legal issues of joint financing of climate adaptation and nature conservation measures by the federal and state governments" was published by Prof. Ann-Kathrin Kaufhold and Dr. Sonja Heitzer. The expert opinion outlines concrete possibilities for how Article 91a of the German Constitution could be expanded to include climate adaptation (Kaufhold and Heitzer 2024).

The call for a joint task for climate adaptation is supported by a broad alliance of various stakeholders. In July 2024, the Association of German Cities and Municipalities called for climate adaptation to be enshrined in the Basic Law in order to cover the financing requirements arising from the KAnG; the then Federal Environment Minister Steffi Lemke (Alliance 90/The Greens) also spoke out in favour of a corresponding amendment to the law, and the CDU/CSU parliamentary group in the Bundestag also expressed its openness to the creation of the joint task at the time (tagesschau.de 2024).

On 29 November 2024, at the 103rd Conference of Environment Ministers in Bad Neuenahr-Ahrweiler, the state environment ministers stated that it was necessary to establish a new joint task for climate adaptation and climate protection measures. To this end, a new working group on "joint financing" was set up to develop key points for a possible new joint task (Ministerium für Klimaschutz, Umwelt, Energie und Mobilität des Landes Rheinland-Pfalz 2024). The issue has also resonated with civil society: an online petition calling for climate protection and climate adaptation to be enshrined in the Basic Law as part of municipal public services had already collected over 100,000 signatures by August 2025 (BürgerBegehren Klimaschutz 2025).

In view of the advanced state of the discourse on a new joint task for financing climate adaptation, this instrument was not examined in depth in this study; instead, the focus was on more far-reaching, novel approaches that open up additional paths for financing climate damage and climate adaptation alongside a possible future joint task.

3.3.1 Cross-sectional considerations

In the course of developing and analysing the proposals presented, a number of thematic focal points were identified that unite the instruments developed or along which individual instruments can be grouped. These overlaps in content are considered and classified below.

3.3.1.1 Need for precise parameter data

In many cases, the implementation of the financing instruments presented requires the availability of precise, up-to-date, high-resolution data on various climate indicators (e.g. precipitation, water levels, temperature, wind speed). These are necessary, for example, to control the payout of parametric insurance or catastrophe bonds. In view of the current research needs already identified in Chapter **Error! Reference source not found.**, there is an even more urgent need for the future and the i mplementation of additional financing models to collect, catalogue and make available this and other climate data according to uniform criteria.

3.3.1.2 Creation of uniform taxonomies

The profiles consistently show that the lack of standardised assessment frameworks and taxonomies for resilience projects is a key barrier. This leads to increased modelling costs for individual projects, makes comparison and assessment by investors more difficult, and potentially disadvantages smaller municipalities due to high fixed costs. In particular, municipalities could be relieved by the creation of uniform framework criteria for the implementation of systematic assessment procedures, which, given the high financial and personnel demands on many municipalities, could be an important step towards enabling the implementation of adaptation measures.

While CO_2 reduction is available as a uniform measure of effectiveness for climate protection, there is no comparable universal indicator for climate adaptation. This makes the development of uniform assessment criteria for climate adaptation significantly more complex. International references such as the African Development Bank's Adaptation Benefits Mechanism or the European Commission's Climate Resilience Check can be used as starting points for standardised assessment procedures. In this context, the federal government is needed as a coordinator (see below). Possibilities for the standardised assessment of adaptation measures, the current state of research and further research needs are discussed in Chapter 4.

3.3.1.3 Central role of local authorities

Even in the context of the new financing instruments, local authorities retain their prominent role as the primary implementers of climate adaptation. Ultimately, all of the instruments presented aim to provide or make available additional funds to local authorities for coping with climate risks, to close existing financing gaps, and to create certainty in the planning and implementation of adaptation measures, which has been lacking to date.

3.3.1.4 The federal government as coordinator and integrator

The federal government has a number of key coordination tasks in the implementation of the financing instruments presented. For example, it can promote the standardisation of mechanisms that trigger the disbursement of certain funds (e.g. catastrophe bonds), assessment taxonomies and data bases (see above), and provide the necessary technical and human infrastructure for collecting and processing the necessary data. The implementation of CRDCs in federal financial relations, the issuance of resilience bonds or the structuring of K-CLOs also require specific legal frameworks. The United Kingdom could serve as a model for the development of context-specific national standards, where a working group convened by the government developed a standardised template for climate-resilient debt clauses (CRDCs)(Cravero et al. 2025 2025 ; see profile 7.4).

The federal government can also accelerate the market ramp-up of innovative instruments through targeted pilot projects. K-CLOs would require a central data infrastructure, support programmes and risk mitigation. Standardisation frameworks and best practices could be established for resilience bonds.

Last but not least, the federal government is responsible for overall coordination between the states and municipalities; it would also be responsible for anchoring the new financing instruments in the context of the European financing framework.

3.3.1.5 Federal government as guarantor

The financing of climate adaptation measures is increasingly reaching its limits, especially for transformative projects with high risk and uncertain returns. Such projects often cannot be realised by banks or private investors alone. This is why the state has a central role to play as a guarantor: it

assumes risks so that municipalities or companies can obtain loans on affordable terms – not in the form of direct subsidies, but by hedging risk positions that private investors would not bear.

Comparable models already exist: export credit guarantees ("Hermes cover") and investment guarantees from the federal government protect companies in risky foreign markets, e.g. in politically unstable regions,(Bundesministerium für Wirtschaft und Energie n.d.; Bundesministerium für Wirtschaft und Energie and Euler Hermes n.d.). In the domestic market, the state supports guarantee banks through counter-guarantees, which secure loans for small and medium-sized enterprises, start-ups or founders (Verband Deutscher Bürgschaftsbanken e.V. n.d.).

In the context of the financing instruments presented, government guarantees make sense in some cases – e.g. for municipal K-CLOs or CRDCs – as uncertainties regarding follow-up costs, potential savings or revenues go beyond established financing mechanisms. Guarantees, loan commitments or default guarantees could improve the risk-return profile in such cases to such an extent that private investors would be willing to get involved. This would not only close financing gaps, but also scale investments and mobilise private funds. In view of growing climate risks and scarce budgetary resources, government guarantees could become a key pillar of climate adaptation financing – similar to what has been the case in export promotion for decades.

3.3.1.6 Mobilising private/institutional capital

In order to put climate adaptation and the financing of reconstruction after climate damage on a secure footing for the future, it is essential to raise additional funds from the financial and private sectors. Measures such as the issuance of catastrophe bonds, resilience bonds or local climate funds aim to transfer fiscal risks to investors and/or acquire funds with which adaptation measures can be implemented. The key approach here is to harness existing market mechanisms for climate adaptation goals and thereby increase the fiscal resilience of public budgets.

3.3.2 Research needs

While Chapter 3.1 provides an overview of fiscal risks posed by climate change, there has been a lack of systematic research on the fiscal risks of climate change for public budgets in Germany.

One approach could be derived from the "stress tests" commonly used in the financial sector, which examine the financial impact of certain shocks or developments. In 2022, the ECB conducted its first climate risk stress test for the Eurosystem's balance sheet to examine the sensitivity of its monetary portfolios to physical and transition risks. The exercise showed that physical risks are generally more significant than transition risks and that the main burdens are on corporate and covered bonds as well as secured lending transactions (Germann et al. 2023). In 2023, the Bundesbank presented a study on climate transition risks (Frankovic et al. 2023) that outlined a methodological approach for German banks, insurers and funds. It developed regular and short, shock-like transition scenarios, incorporated company-specific emissions data and quantified the impact on the balance sheets of financial intermediaries. The aim was to assess the vulnerability of the financial system to regulatory or market-induced CO_2 price jumps.

Both approaches focus on the risk profile of financial institutions and not directly on public budgets. Nevertheless, the findings can be transferred: the use of multi-year physical and transition scenarios and the translation of macro-financial shocks to specific portfolios provide a methodological framework. Comparable stress tests could be developed for public budgets, in which climate scenarios are applied to revenues (e.g. tax losses due to crop failures) and expenditures (e.g. reconstruction costs after extreme events). The challenge would be to define suitable indicators and data sources for budget items and to calibrate scenario parameters according to fiscal issues.

Further research is needed due to the current lack of systematic ex-post evaluations to assess the efficiency and effectiveness of existing support programmes and adaptation instruments. This could involve examining which indicators – such as cost-benefit ratio, degree of target achievement or distribution effects – are best suited for a comparative analysis, how data-based case studies on, for example, municipal climate adaptation funds could be conducted to quantify actual emission reductions and adaptation achievements, and how feedback loops should be designed so that findings can be incorporated in a targeted manner into the optimisation of programme and process design.

A recurring criticism of the current structure of climate financing in Germany is the lack of a uniform data basis, which would be necessary for the evaluation and implementation of measures or for the approval of funding applications, for example. The standardisation of processes and measures could also significantly facilitate and accelerate implementation. Against this background, there is a corresponding need for research, which should ideally be coordinated by a central body, e.g. at federal level, in order to establish uniform standards nationwide.

4 Prioritisation of adaptation measures

Table 44: Results at a glance

RESULTS AT A GLANCE:

- Three main methods are used for the ex-ante assessment of climate adaptation measures: cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA). In addition to supporting well-founded prioritisation, structured assessment methods also represent significant added value for the financing instruments described in Chapter 3.
- Practical examples show that the selection and weighting of evaluation criteria is often participatory and context-specific, which increases the acceptance and relevance of the results. Practical implementation requires a solid information base, methodological know-how and, where necessary, supporting tools; initial guidelines and software solutions are available but not yet established across the board.
- The main challenge is that the impact of climate adaptation measures can only be determined to a limited extent in a standardised manner, and that important assessment data, such as the costs of inaction, are lacking.
- Uncertainties in the assessment process make it difficult to estimate impacts accurately. Depending on the assessment context, these uncertainties have varying relevance for the prioritisation of measures. At the municipal level, it is apparent that the focus is particularly on no-regret and low-regret measures, meaning that uncertainties in climate scenarios play a subordinate role in municipal practice.
- The complexity of the assessment procedures is an obstacle to their implementation at all levels of governance. Knowledge of possible assessment procedures is hardly widespread in practice.
- Assessment procedures are highly context-dependent. In the further development of the procedures, the possibility of a more modular structure should continue to be considered. In order to estimate the impact of measures more precisely, the integration of impact structures should be further investigated and innovative approaches to taking into account multi-causal effects should be examined.
- There is a need for research into the extent to which criteria developed for the first time to record transformative measures can be transferred to other assessment contexts and procedures, and whether the integration of additional measures creates added value.
- For the broader application of assessment procedures, the focus on low-threshold implementation in practice is crucial. The provision of practical, easily understandable tools and guidelines, ideally as digital applications, is crucial to facilitate entry and the selection of suitable assessment procedures.
- There is a need to be able to evaluate not only individual measures but also policy mixes in terms of their combined impact.
- Promoting exchange formats for users and highlighting and disseminating examples of good practice can support broader application.

A wide range of measures are available at federal, state and local level to reduce the risks posed by increasingly extreme weather events. In view of limited resources and the growing risk of

maladaptation[12], it is necessary to prioritise measures in order to use the available funds as effectively as possible (Environmental Protection Agencies Network 2025, p. 3; Guerrero-Hidalga et al. 2020; Intergovernmental Panel on Climate Change 2023, p. 8). Ex-ante assessments are important procedures that enable a systematic evaluation of the impact and thus create a sound basis for prioritisation(Environmental Protection Agencies Network 2025, p. 5). Based on these assessments, not only can particularly effective and efficient measures be identified, but risks such as maladaptation can also be detected early and avoided (Environmental Protection Agencies Network 2025, p. 5; Intergovernmental Panel on Climate Change 2022, p. 2602). The systematic approach also makes uncertainties transparent and reduces them through comprehensive assessment when selecting measures (Guerrero-Hidalga et al. 2020).

Research findings and initial examples of the practical application of assessment methods are already available. However, there is no consensus on what constitutes effective adaptation and which criteria are best suited for recording it (Dalitz et al. 2023; Guerrero-Hidalga et al. 2020; Owen 2020). Ex-ante assessments in climate adaptation are also particularly challenging compared to other policy areas, as there are no fixed units of measurement for adaptation success and the impact of measures depends heavily on local contexts, synergies and uncertainties about future climate conditions (Owen 2020). The complexity is further increased by the diversity of actors, decision-making levels and cross-sectoral interactions of measures in the cross-cutting issue of adaptation (Owen 2020).

Ex-ante assessments can contribute significant added value to the effective design of climate adaptation, but there are major challenges in their methodological and practical implementation. The following chapter provides an overview of existing research and assessment practices and develops recommendations for the further development of assessment procedures. To this end, the three central ex-ante assessment methods – cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA) – are explained at the outset and illustrated with practical application examples. Due to the great importance of MCA, this method is dealt with in particular detail. Building on this research overview, the challenges and requirements for the further development of assessment methods are then identified. Both methodological aspects and practical implementation are considered. In the third step, recommendations for the further development of these methods are presented, based on the aforementioned obstacles. The findings of this chapter are based on a comprehensive literature review and interviews with experts from the field.

4.1 Ex-ante assessment methods for estimating the effectiveness of climate adaptation measures

When prioritising adaptation measures, systematic assessments are a helpful approach for arriving at a well-founded and transparent selection of measures. Various methods are used to assess climate adaptation measures, three of which – cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA) – are particularly common. These assessment methods differ in terms of their methods, criteria and areas of application. It is important to note that in practice, the terms used to describe the various methods are not used in a strictly defined manner and combinations of methods are also implemented. In addition to scientific publications, the descriptions of the assessment methods are based in particular on guidelines issued by the federal and state governments and on pilot projects in practice. The literature focuses on the European context, whereas the practical examples are exclusively from Germany. It should also be noted that both the practical examples and the results on the establishment of ex-ante evaluation in Germany are based on an

[12] Maladaptation describes the potentially negative effects of adaptation, which lead to the reproduction, shift or increase of vulnerability (Intergovernmental Panel on Climate Change 2022, p. 2600; Juhola et al. 2022).

exploratory study. In the following, the three evaluation methods are presented in detail, implications for practical implementation are described and the methods are critically reflected upon.

Table 45 : Overview of ex-ante assessment methods

Methodological approach	Brief description	Data basis	Advantages	Disadvantages
Cost-benefit analysis (CBA)	Monetary evaluation of the costs and benefits of a measure in order to determine its social added value.	Monetarily assessable data on costs and benefits; estimates for non-marketable services, if applicable.	Direct comparison of economic benefits; comparison between different areas possible.	Non-monetisable effects (e.g. social aspects, sustainability) are often not recorded; uncertainties in monetisation.
Cost-effectiveness analysis (CEA)	Quantitative assessment of the costs in relation to the effectiveness of a measure (not exclusively monetary).	Non-monetary, quantifiable data on measurable effects (e.g. reduction in heatwave days, flood damage) and monetarily quantifiable implementation costs.	Also suitable for measures whose benefits cannot be quantified in monetary terms.	Comparison usually only possible within one area; factors that are difficult or impossible to quantify (e.g. social aspects & sustainability) often not taken into account; only suitable to a limited extent for non-technical measures.
Multi-criteria analysis (MCA)	Evaluation of measures based on a wide range of (quantitative and qualitative) criteria, often participatory and context-specific.	Different types of data: monetary, quantitative, qualitative data; expert assessments and stakeholder input.	Comprehensive consideration of diverse criteria; suitable for complex decision-making situations; involvement of various stakeholders.	Subjectivity due to expert assessments; high effort; inconsistencies in the evaluation possible.

Source: adelphi's own representation; based on the StMUV (2021, p. 98)

4.1.1 Cost-benefit analysis (CBA)

4.1.1.1 Description of the evaluation procedure

A CBA is an assessment method that compares the positive and negative effects of measures in monetary units in order to justify the selection of climate adaptation measures from an economic

perspective (Lehr et al. 2020, p. 21). In extended CBAs, non-marketable environmental services can also be represented using economic assessment methods (Grothmann et al. 2021). CBA is particularly suitable for clearly definable measures where costs and benefits can be determined in monetary terms, such as operational flood protection, greening and shading measures, or increasing surface reflectivity (BMVBS 2013, p. 17). A particular added value of this method lies in the direct comparability of different measures, even from different sectors, with a focus on economically efficient prioritisation.

4.1.1.1.1 Criteria & indicators

As the name suggests, a CBA only considers two criteria: costs and benefits. Costs are usually defined as investment and ongoing maintenance costs for the implementation of climate adaptation measures (Dehnhardt et al. 2020; Grothmann et al. 2021). The benefits of the measures are also expressed in monetary terms. By comparing the costs and benefits of different measures, their opportunity costs can also be identified. The positive economic benefits of non-marketable services, such as improved air quality, can be represented using various economic assessment approaches. These include damage costs, the replacement cost approach and a survey of the population's willingness to pay (Dehnhardt et al. 2020, p. 2)[13].

4.1.1.1.2 Method

The CBA approach follows a systematic, multi-step process (BMVBS 2013, p. 29; Dehnhardt et al. 2020, p. 4; Europäische Union 2025b; Stadt Jena 2012, p. 116). First, all costs and benefits of the various alternative courses of action are recorded for the defined evaluation period, taking into account both direct and indirect effects. In the second step, the costs and benefits are discounted[14] in order to relate values incurred at different points in time to a common reference date. In the third step, the net benefit is determined from the sum of the discounted costs and the benefit-cost ratio is calculated(BMVBS 2013, p. 29; Dehnhardt et al. 2020, p. 2). The option with the greatest net benefit or the highest benefit-cost ratio is considered the most efficient. Finally, a sensitivity analysis is carried out to check the robustness of the results when parameters change. When defining the specific definition of costs and benefits, the participatory consultation with local stakeholders is emphasised (BMVBS 2013; Grothmann et al. 2021, p. 8).

4.1.1.1.3 Practical implementation

Projects and guidelines on CBA show that no software is necessary for implementation, but specialised assessment software such as PRIMATE supports the implementation of the procedure (BMVBS 2013, p. 29; Dehnhardt et al. 2020, p. 4). Another tool for implementing a CBA is the Excel-based Risk Analysis Tool (RAT) from the Technical University of Munich. Its aim is to support quantitative risk analyses for natural hazards and to develop alternative risk reduction strategies based on a CBA

[13] The damage cost approach captures the costs incurred by society as a result of environmental and health damage. The replacement cost approach, on the other hand, takes into account the expenses necessary to compensate for the losses caused by an intervention. Surveys on the population's willingness to pay can be used to determine the amount people are willing to pay for the preservation or restoration of environmental services (Dehnhardt et al. 2020, p. 2 2020).

[14] Discounting refers to a method of converting future costs and benefits into their present value. This takes into account the fact that sums of money that will only be incurred in the future are worth less than sums available today due to factors such as inflation or lost interest. A discount rate is used to discount future payments so that they can be compared and evaluated together. Discounting converts all future costs and benefits to their present value and presents them as net present value (NPV) (Dehnhardt et al. 2020, p. 2 2020). The UBA usually recommends applying a discount rate of 1% for this purpose (Bünger and Matthey 2018, p. 32; Dehnhardt et al. 2020, p. 4 2020). Further information on discounting future costs and benefits can be found in the UBA publication "Methodological Convention 3.0 for Determining Environmental Costs" (Bünger and Matthey 2018).

(Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 96; Technische Universität München n.d.).

4.1.1.1.4 Critical reflection

CBA serves as a decision-making tool by enabling a simple comparison of measures, even from different areas. By quantifying the benefits of climate adaptation measures in monetary terms, the method can help to raise social and political awareness of the value of nature and the monetary benefits of climate adaptation (Naturkapital Deutschland – TEEB DE 2012). A major weakness of the method is that criteria for which a monetisable representation is not methodologically possible cannot be taken into account (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 98). Furthermore, important effects of measures, for example in the area of sustainability, can only be represented to a limited extent. For example, it is difficult to determine a value for the preservation of ecosystems or species, especially independently of direct human benefits. Likewise, the potential future benefits are often difficult or impossible to quantify completely. In addition to sustainability aspects, synergies between measures can often only be partially represented, if at all. Another methodological challenge is the uncertainty surrounding the accuracy of the monetarily estimated benefits (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 98). Dealing with the range of possible climate scenarios also contributes to uncertainties in the assessment and limits the reliability of the projected costs and benefits. The choice of discount rate also has a strong influence on the assessment: a high discount rate greatly devalues benefits that lie far in the future, making measures with long-term returns – such as many climate adaptation investments – appear less economical. A low discount rate, on the other hand, emphasises the value of later benefits more strongly, favouring projects with long-term effectiveness. The chosen time horizon, i.e. how long costs and benefits are considered, also influences the assessment results. A time horizon that is too short may not adequately reflect long-term benefits and residual risks, while a time horizon that is too long increases forecast uncertainty. Overall, these factors are crucial for the informative value and comparability of CBA in climate adaptation.

4.1.1.2 Practical example: Extended cost-benefit analysis in the BREsilient project

An outstanding example of the implementation of a CBA procedure is the extended CBA in the BREsilient project (Grothmann et al. 2021; Dehnhardt et al. 2020). This project determined the costs and benefits of selected green climate adaptation measures for the city of Bremen. The focus was on measures such as roof and open space greening and the planting of street trees. The approach included workshops with practitioners to select and specify the measures, which were considered for two implementation scenarios (moderate and ambitious). The evaluation was based on various economic approaches such as damage costs, replacement cost approach and willingness-to-pay studies for social valuation. All costs and benefits were discounted to 2050 and supplemented in a regional input-output model to capture value added and employment effects (Dehnhardt et al. 2020). The analysis provides a clear comparison of the monetary benefits and the investment and maintenance costs until 2025 for the selected measures. In the moderate scenario, the net benefit is around EUR 76 million, and in the ambitious scenario, it is as high as EUR 174 million (Grothmann et al. 2021). The results were also used to model value creation and employment effects for Bremen and the surrounding area. These calculations show that a total of approximately EUR 2.7 million in annual value creation will be generated for the state of Bremen and approximately 55 jobs will be created (Dehnhardt et al. 2020). The decision to carry out the CBA is based on the assumption that it meets four key requirements: Firstly, it enables the costs and benefits of various measures to be systematically weighed up against each other. Secondly, it supports the prioritisation of these measures. Thirdly, it helps to make the advantages of the measures more visible and easier to communicate. And fourthly, it provides a sound basis for legitimising political decisions. A final survey on the likelihood of these objectives being met

by the assessment shows that company representatives and event organisers consider all four uses of the results to be likely (Grothmann et al. 2021, p. 6). However, administrative staff have mixed views on the usefulness of the assessment procedure for prioritisation. For example, the willingness to pay that was surveyed helps to better communicate citizens' priorities to politicians. For decisions in the specialist departments, this classification is considered less relevant and other factors are given greater weight (Grothmann et al. 2021, p. 7).

4.1.2 The cost-effectiveness analysis (CEA)

4.1.2.1 Description of the evaluation method

Another quantitative assessment method for estimating the effectiveness of measures is the CEA. This method is very similar to the CBA, but differs in terms of how benefits are calculated, as these are not measured in monetary terms. Other quantifiable effects, such as the reduction of heat stress or operational flood protection, can also be recorded (BMVBS 2013, p. 17; Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 96). CEA, also known as cost-effectiveness analysis, is used to identify the most cost-effective option for achieving a specific goal by comparing the costs with the expected degree of goal achievement. This also differs from CBA, which can be carried out without any other derived objectives for the measures. The result is a ranking of the options examined according to their economic efficiency, whereby the measure is selected that can achieve the set objective most cost-effectively or that has the best ratio of costs to the degree of objective achievement (BMVBS 2013, p. 17; Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie 2024). CEA is particularly suitable when the costs can be quantified in monetary terms and the effect can be quantified (BMVBS 2013; Dalitz et al. 2023, p. 15). This means that, like CBA, this method is particularly suitable for evaluating individual, local measures (Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie 2024).

4.1.2.1.1 Criteria & indicators

Within the framework of CEA, the two criteria of cost and benefit are used to evaluate the measures, whereby, unlike in CBA, the benefit is defined beyond its monetary value. Costs generally include investment costs, reinvestment costs and running costs such as maintenance costs. Application examples also show that the technical effort, the feasibility in terms of time and transaction costs, for example from politics, citizen participation or urban planning, can also be included in the analysis when evaluating individual measures (BMVBS 2013, p. 15). For example, the City of Jena (Stadt Jena 2012) supplements the classic cost indicators with the transaction costs incurred during project initiation and implementation. In a European guide for local authorities, costs are defined as the material resources required, the costs of human resources in all project phases, and all quantifiable social, environmental or economic disadvantages (Europäische Union 2025b). Future costs are discounted to their present value using a discount rate (Europäische Union 2025b). The benefits of a measure are determined in a CEA depending on the objective set. For example, if the objective is to reduce the number of heat-related deaths, each option can be evaluated based on its potential to reduce heat-related mortality. Both the number of deaths avoided and the percentage decrease compared to the baseline can be considered and compared with the respective costs (Europäische Union 2025b).

4.1.2.1.2 Procedure

When conducting the CEA, several steps must be taken into account. First, a target indicator is defined, whereby a single, non-monetary target indicator – for example, the reduction of thermal stress – is selected (BMVBS 2013, p. 30). Next, a target value is set to measure effectiveness. The next step is to

determine the costs. In most cases, this involves calculating the investment costs, reinvestment costs and ongoing maintenance costs. These costs are discounted over a period of 100 years at a discount rate of 3% per annum, for example, to determine the net present value (BMVBS 2013, p. 46). The effectiveness of the respective measure is assessed on the basis of the selected target indicator. In addition to the quantitative assessment, such as the amount of damage avoided, there is the option of carrying out a qualitative assessment in the categories "low", "medium" or "high". The cost-effectiveness ratio is then calculated by dividing the present value of the costs by the degree to which the target has been achieved (BMVBS 2013, p. 30). All measures examined are compared with each other on the basis of this ratio, and the measure with the most favourable ratio – i.e. the lowest costs per unit of effect – is identified. Sensitivity analyses can also be used in this analysis to check whether changes in the input data influence the final result (BMVBS 2013, p. 30). Participatory stakeholder involvement in the evaluation process is possible, but has so far only been used to a limited extent in practice.

4.1.2.1.3 Practical implementation

The practical implementation of a CEA requires a comprehensive information base and a good understanding of methodology. According to the guidelines of BMVBS (2013), this procedure can also be carried out without special software, although, as with CBA, the use of evaluation software can facilitate the analysis. In the city of Jena, for example, the PRIMATE tool developed by the Helmholtz Centre for Environmental Research (UFZ) was used (Gebhardt et al. 2012; Stadt Jena n.d.). The criteria used for the assessment and their characteristics were determined there by consulting those responsible for planning, implementing and maintaining the measures under consideration and then evaluated (Stadt Jena 2012).

4.1.2.1.4 Critical reflection

The CEA is very similar to the CBA in terms of its methodological structure and implementation. In contrast to CBA, this method also allows the evaluation of measures whose costs are quantifiable but whose benefits are not available in monetarily quantifiable data (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 96). However, measures whose benefits can be evaluated in monetary terms but are measured here on the basis of a specific non-monetary objective can also be taken into account. The method is particularly widespread and well known in the environmental sector. CEA is not suitable for comparing measures from different areas and is only of limited use for comparing non-technical measures (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 96). Furthermore, no transferable data can be found for many evaluation criteria and measures, as much of the information is very context-specific and case-dependent, particularly with regard to the effectiveness of the measures (BMVBS 2013). Furthermore, CEAs usually do not take into account social aspects, feasibility or other side effects (Europäische Union 2025b). This method also shows that uncertainties in the results exist due to various possible climate scenarios and the difficulty of assessing the effects of measures (BMVBS 2013).

4.1.2.1.5 Practical example: cost-effectiveness assessment in the IAWAK-EE project

One example of a project in which a CEA was carried out is the IAWAK-EE project (IAWAK Projekt 2024). The focus here was on measures from various land use areas, such as the introduction of trees and shrubs into agricultural land and the conversion of pine monocultures into mixed deciduous forests. The aim was to investigate the effect of these measures on the landscape water balance, the overheating of areas, biodiversity and flood protection. All sub-areas in the Elbe-Elster district were taken into account for the cost estimate. Investment costs, management costs and opportunity costs (lost profits from alternative use) were included in the analysis. The observation period was 30 years,

with the costs being discounted (Hecker et al. 2025). The effectiveness of the measures was recorded using statistical and hydrological models and compared with the costs incurred. For each combination of measure and plot, the cost-benefit ratio – measured as the reduction in land surface temperature per euro invested – was calculated (Hecker et al. 2025). As the effectiveness was not monetised, it was assessed in relation to the costs. The results of the analysis provided a basis for decision-making for the prioritised selection and implementation of the most cost-effective measures on site (Dalitz et al. 2023; Hecker et al. 2025; IAWAK Project 2024).

4.1.3 The multi-criteria analysis (MCA)

4.1.3.1 Description of the evaluation procedure

A particularly common method for evaluating climate adaptation measures is MCA. In the literature, there has been a shift in focus from purely economic cost-benefit decisions to the consideration of complementary evaluation criteria in order to better prioritise measures (European Union 2025; Lühr et al. 2018; City of Jena 2012). There are initial examples of MCA being used at both municipal and federal level: MCA has been used in countries such as Austria, Belgium and Germany, as well as in the development of the European Adaptation Strategy (Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie 2024; Euopäische Kommission 2021; Hölscher et al. 2025a; Mertens et al. 2013). MCA is not a uniform procedure. Rather, it is usually based on CBA or CEA, whereby additional criteria are taken into account qualitatively in addition to costs and effectiveness or benefits. In practice, the method is adapted to the specific assessment context and the individual criteria are defined and weighted differently. Another special feature of MCA is the fixed involvement of various interest groups – such as stakeholders and experts – in the assessment process (Bavarian State Ministry for the Environment and Consumer Protection 2021, p. 96; Guerrero-Hidalga et al. 2020, p. 3). In addition, MCA not only enables the assessment of individual measures, but in practice it also allows for the analysis of bundles of measures or so-called policy mixes. In research, the assessment of bundles of measures is also possible, for example, using CBA, but in practice it is implemented particularly in MCAs. Examples of this are the ex-ante assessment for the development of the European Adaptation Strategy (Euopäische Kommission 2021) and the ex-ante assessment procedure by the Climate Change and Adaptation Network of Authorities (BNW) in the course of developing APA IV (Hölscher et al. 2025a). This overarching approach allows the MCA to be used as a tool for strategic management and the pursuit of long-term goals. Depending on the selected objective, criteria for the MCA can be selected and defined and weighted according to specific priorities (Euopäische Kommission 2021). Despite the wide variety of designs, it is clear that MCA is particularly suitable for prioritising measures when different and sometimes difficult-to-quantify criteria need to be taken into account. The aim of this procedure is to use a quantitative and/or qualitative assessment to rank adaptation options based on comprehensive criteria (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 96; Dalitz et al. 2023, p. 15).

4.1.3.1.1 Criteria & indicators

Error! Reference source not found. In addition to the criterion of costs, the procedure includes a w ide range of criteria for measuring impact. Table 46 summarises criteria that are particularly common in MCA. The criteria and indicators are taken from procedures that have been carried out and from guidelines and instructions for assessment procedures. It should be noted that the overview is an exemplary selection of criteria and sources taken into account and that other criteria also apply. In an MCA, any number of criteria can be defined and taken into account in the assessment, so that this procedure can be adapted to the assessment context and requirements. Examples of additional criteria include urgency and political and social acceptance (Bayrisches Staatsministerium für Umwelt und

Verbraucherschutz 2021, p. 80). When examining the criteria and indicators, it is also noticeable that operationalisation is rarely described transparently in many procedures and tools.

Table 46 : Overview of common criteria in MCA

Criteria	Indicators	Procedure (examples)
Cost	Includes investment, reinvestment and running costs;	Swiss Federal Office for the Environment (2018); Ex-ante assessment procedure of the BNW (Hölscher et al. 2025a) ; Cost-benefit analysis Singen (2024); Climate adaptation action plan 2030 for Münster (2019) ; KlimA-Lok (2024);
Effectiveness	Contribution to risk reduction, prospects of success, broad impact, sustainability of the impact, degree of urgency	Bayrisches Staatsministerium für Umwelt und Verbraucherschutz (2021) ; BMK Austria (2021); Swiss Federal Office for the Environment (2018); EU Climate Adaptation Strategy (2021); Ex-ante assessment procedure of the BNW (Hölscher et al. 2025a) ; Climate adaptation action plan 2030 for Münster (2019) ; Integrated climate impact adaptation plan for the city of Essen (2023) ; KlimA-Lok (Extrass 2024) ; BMVBS guidelines for decision support in urban climate adaptation (2013); UBA Climate Pilot (2022);
Sustainability	Consideration in the sustainability dimensions of ecology, social issues, and economy and society	Bayrisches Staatsministerium für Umwelt und Verbraucherschutz (2021) ; BMK Austria (2021); European Climate Adaptation Strategy (2021); Ex-ante assessment procedure of the BNW (Hölscher et al. 2025a) ; Cost-benefit analysis Singen (2024);
Interactions	Identification of synergies/conflicts of interest with other measures or policy areas	BMK Austria (2021); Bayrisches Staatsministerium für Umwelt und Verbraucherschutz (2021) ; Ex-ante assessment procedure of the BNW (Hölscher et al. 2025a) ; Cost-benefit analysis Singen (2024); BMVBS decision support guide for urban climate adaptation (2013); KlimA-Lok (Extrass 2024) ;

Feasibility	Institutional requirements, complexity, political support, practicability of implementation, planning effort, number of actors involved, acceptance of the measure	Adaptation Strategy Belgium (2013); Bayrisches Staatsministerium für Umwelt und Verbraucherschutz (2021) ; UBA Climate Pilot (2022);
Flexibility & robustness	Adaptability of a measure to different climate scenarios and changing conditions	Swiss Federal Office for the Environment (2018); Bayrisches Staatsministerium für Umwelt und Verbraucherschutz (2021) ; UBA Climate Pilot (2022);

Source: adelphi's own representation

4.1.3.1.2 Procedure

As mentioned at the outset, the assessment process is usually participatory and adapted to the respective assessment context (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 96). Since MCAs vary greatly depending on the context, objectives and actors involved, there is also diversity in the way they are implemented. At the outset, the assessment procedure is agreed upon and the criteria to be taken into account are defined (BMVBS 2013; Hölscher et al. 2025a). In addition to defining the criteria and indicators, the weighting of the individual criteria is also determined at this stage. There are different approaches to weighting the criteria. Well-known weighting methods include the 100-point method and swing weight[15] (BMVBS 2013). Other practical examples show that weighting is carried out using different percentage weightings. In the city of Singen (2024), for example, the criterion of adaptation needs is weighted at 35%, awareness and synergies at 40% and ecosystem services at 25% in the overall assessment. At the federal level, an ex-ante assessment of potential adaptation measures was carried out by APA IV BNW[16], which focused on the effectiveness of measures. This specific focus is reflected in the double weighting of this criterion (Hölscher et al. 2025a, p. 52). In some application examples, experts and stakeholders are already involved in the methodological development (Hölscher et al. 2025a). Based on the assessment method, an assessment matrix or a tool for carrying out the assessment is then designed. In this process, the individual assessment criteria are operationalised using various indicators and the assessment scales are standardised. In an optional third step, a preliminary selection of the measures to be considered in the assessment process is made and a common information basis for the individual measures is created. The selection can be made in a workshop with subject matter experts – as was done in the cities of Singen and Essen and in the district of Breisgau-Hochschwarzwald – or on the basis of a literature and needs analysis (Hölscher et al. 2025a). The various criteria are then evaluated by the actors selected at the outset, such as experts, stakeholders or external service providers. The evaluation can be both quantitative (e.g. when specifying costs) and qualitative (e.g. assessing effectiveness as high, medium or low). These assessments are then transferred to a standardised rating scale (e.g. values from 1 to 5) and multiplied by the respective weights. Based on the ratings, the measures can then be ranked (BMVBS 2013; Hölscher et al. 2025a; Stadt Singen 2024). In individual MCAs, a sensitivity analysis is

[15] In the 100-point method, the decision-maker allocates 100 points to the various criteria according to their subjective importance and then normalises the weights by dividing them by 100. In the swing weight method, the criteria are first ranked according to their importance; the most important criterion is given 100 points, the other criteria are evaluated in relation to this and also normalised so that the sum of all weights equals 1. Both methods serve to determine the relative importance of criteria in a systematic and comprehensible manner (BMVBS 2013, p. 33 2013).

also carried out and the evaluation is repeated with different data and weightings in order to test the robustness of the ranking (BMVBS 2013; Stadt Jena 2012).

4.1.3.1.3 Practical implementation

Practical examples of MCA application at federal and local level provide valuable insights into the challenges and success factors involved in applying this assessment method. Depending on the specific design of the assessment procedure, the actors involved may require significant time resources (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021; Hölscher et al. 2025a). In the ex-ante evaluation of APA IV measures implemented by the BNW, the network was extensively involved in the development of the methodology. In conjunction with the discursive evaluation process, which took place in several workshops and coordination loops, this led to a high overall time commitment for the actors involved and greater coordination efforts for the process. Early coordination of the capacities of the actors involved is therefore very important. In contrast, assessment processes at the municipal level are often streamlined. Planning and implementation are usually carried out by external service providers (UBA 2022; City of Essen 2023; City of Singen 2024). Furthermore, examples of MCA applications at both the municipal and federal levels illustrate that a cross-thematic exchange between evaluating actors promotes the integration of different perspectives and supports the development of well-founded, consistent solutions. In addition, broad exchange promotes an integrative assessment of benefits and a comprehensive perspective on possible positive and negative side effects. The exchange formats in the assessment process can also promote cooperation between actors beyond the process itself and form an important basis for implementation (expert interviews). Implementation has shown that the discursive process has further refined and optimised the design of the measures, which can contribute to the development of more effective measures . Clear definitions, precise guiding questions and a common information basis regarding the design and understanding of the measures are crucial for consistent evaluation through the participation of different actors. Impact chains and profiles of the measures can be a helpful basis for this (Umweltbundesamt 2022a; Lühr et al. 2018). The creation of detailed profiles, especially in cooperation with the actors responsible for implementation, is also very helpful for implementation (expert interviews).

Discussions with experts from municipal practice have revealed a consistent picture that guidelines and tools for ex-ante assessment in general and for the MCA methodology in particular are not well known. However, comprehensive research shows that initial guidelines and tools for municipal application do exist, such as:

- **UBA Klimalotse**: Klimalotse is a digital tool that supports local authorities in planning and evaluating climate adaptation measures. It provides local authorities with an Excel tool for evaluating climate adaptation measures (Umweltbundesamt 2023b).
- **Urban Adaptation Support Tool:** This European tool supports municipal actors in EU member states in planning and designing climate adaptation. Information and reading material on evaluation procedures are made available to users here (Europäische Union 2025a).
- K**limA-Lok:** This web-based application tool is aimed at local authorities and cities to help them prepare for increasing heavy rainfall and heat events. Measures can be prioritised in this tool. Users can select criteria themselves, add their own key questions and rate them with yes, partially and no (Extrass 2024).
- **INKAS:** The DWD's "Information Portal on Climate Adaptation in Cities" is an interactive online advisory network that can be used to analyse the impact and coverage of measures to reduce summer heat. The tool focuses in particular on urban adaptation measures (Deutscher Wetterdienst n.d.).

4.1.3.1.4 Critical reflection

In summary, it can be said that MCA is an established method at various levels of governance for assessing the effectiveness of adaptation measures. It is characterised by its broad applicability in complex decision-making situations, as it can also be used when not all relevant data can be quantified (Bavarian State Ministry for the Environment and Consumer Protection 2021; Dalitz et al. 2023; Guerrero-Hidalga et al. 2020). Assessments of the complexity and effort involved in implementation vary in the guidelines and practical experience, which can be attributed to the respective design of the MCA (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 96). A major added value of the process lies in the efficient use of existing expert knowledge and the active participation of stakeholders, which can increase the acceptance and relevance of the results (Bavarian State Ministry for the Environment and Consumer Protection 2021, p. 96). Although qualitative assessment by experts and stakeholders allows for comprehensive consideration of a wide range of criteria, this approach also presents various challenges. The subjectivity of assessments, lack of information or indicators, and differing assumptions in the evaluation can lead to inconsistent and inaccurate assessments. Attempts to simplify and standardise different units and criteria can result in a loss of accuracy (Guerrero-Hidalga et al. 2020, p. 3). In addition, it is also difficult to take into account uncertainties in the available data, which can further limit the significance of the results (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 96).

EXCURSUS: TRANSFORMATIVE ADAPTATION & SOCIAL JUSTICE AS THE KEY TO EFFECTIVE MEASURES

Research and practice increasingly show that climate adaptation is only effective and sustainable in the long term if it is socially just (Juhola et al. 2022; Shi et al. 2016). Accordingly, the IPCC also highlights social justice factors as a fundamental prerequisite for "*successful adaptation*" (Intergovernmental Panel on Climate Change 2022, p. 2603).

Against this backdrop, the concept of transformative adaptation is gaining in importance. While incremental adaptation focuses on gradual changes and maintaining the baseline – for example, by raising existing dykes or increasing efficiency – transformative adaptation aims to bring about structural changes to systems, institutions and social conditions. The aim is to address the root causes of vulnerability (Fedele et al. 2019, p. 116). Transformative measures are restructuring, path-changing, innovative, cross-system and effective in the long term (Fedele et al. 2019). Examples of measures, as described by Mahrenholz et al. (2017), include the relocation of dykes, the resettlement of settlements from risk zones, and the establishment of climate-resilient, ecologically and socially sustainable agricultural systems. The aim is to avoid long-term climate risks through preventive, structural changes – rather than simply adapting existing structures.

At the heart of transformative adaptation are also questions of social justice such as "Who bears the costs? Who benefits? Who is heard?" The unequal distribution of risks and resources makes it clear that climate adaptation cannot be planned and implemented independently of social inequalities. Studies such as those by Anguelovski (2023) illustrate that the costs and benefits of adaptation measures are often unevenly distributed within societies. Concepts of environmental justice are based on the assumption that disadvantaged population groups are particularly affected by negative climatic developments and maladaptation. Accordingly, measures must be scrutinised for their social impact. Ex-ante assessments of benefit distribution in adaptation strategies can help to reveal these risks and counteract them (Teebken 2024, p. 4).

Even beyond the issue of social justice, traditional assessments of adaptation measures usually do not take transformative aspects into account. In new assessment approaches – such as the concept of a transformative policy mix developed on behalf of the UBA (Kristof et al. 2023) – additional criteria are applied to established MCA. The following are decisive here:

- **Ideas for change:** attractive ideas for change, lasting change, contribution to the vision
- **Actors & resistance:** e.g. powerful actors available, accessibility of actors, use of resistance
- **Time aspects**: e.g. usable windows of opportunity, time resources of the actors
- **Complexity:** e.g. do actors enable adequate handling of complexity, effective monitoring

In practice, this assessment approach was tested using sponge city measures as an example: with the help of a qualitative assessment based on transformative and classic criteria, it was possible not only to determine the transformation potential of individual measures, but also to derive concrete recommendations for improving or prioritising the instruments. The early identification of potential resistance or supportive actors was particularly helpful in this regard – an aspect that is often neglected in classic policy design (Kristof et al. 2023, p. 25).

Taking transformative adaptation and social justice into account in the ex-ante assessment of climate adaptation measures is crucial to ensuring their long-term effectiveness, acceptance and fairness. It makes it possible to identify unequal distributions of benefits and costs at an early stage, to specifically strengthen socially disadvantaged groups and to avoid unintended negative consequences. In this way, measures can be prioritised not only in terms of risk reduction or the achievement of a specific goal, but also taking into account factors such as social sustainability and acceptance.

4.1.3.2 Practical example I: ex-ante assessment to evaluate a policy mix for APA IV

Under the leadership of the UBA, the BNW further developed and tested an ex-ante assessment methodology that was used to evaluate proposed measures for the Action Plan Adaptation (APA) IV (Hölscher et al. 2025a). The focus was on selecting and designing particularly effective policy instruments using a discursive ex-ante assessment procedure. Four key criteria were taken into account: effectiveness, sustainability, interactions and costs. Effectiveness assesses the vulnerability-reducing or resilience-enhancing effect of a measure, sustainability refers to environmental, economic and social aspects, interactions capture synergies and trade-offs between instruments, and the criterion of costs covers all financial expenditures (Hölscher et al. 2025a, p. 57). Each criterion was operationalised through specific indicators, guiding questions and assessment scales. The development and subsequent testing process comprised several steps: First, existing assessment approaches were analysed and methodological building blocks were further developed in a research and conceptualisation phase (Hölscher et al. 2025a, p. 69). Building on this, a multi-criteria assessment methodology was developed in close cooperation with the BNW and operationalised in an Excel-based tool. The assessment was carried out in cluster groups based on the focal points of the climate impact and risk analysis. The results were then collated and evaluated jointly. The measure was developed and evaluated collaboratively within the BNW. The members of the network evaluated the instruments using the methodology developed and documented the results in the Excel tool. The consortium assumed a cross-sectional function to ensure uniform evaluation standards and avoid inconsistencies. Feedback from the network was integrated into the further development of the methodology and the tool. The result of the evaluation process is a joint recommendation of thoroughly tested and evaluated policy instruments to the Interministerial Working Group on Adaptation to Climate Change (IMAA) for inclusion in the APA IV (Hölscher et al. 2025a).

Table 47: Overview of criteria in the ex-ante assessment of the BNW (2024)

Criterion	Description
Effectiveness	Target-compliant effect (risk-reducing, resilience-enhancing), operationalised by three indicators: likelihood of success, broad impact and durability of the effect.
Sustainability	Impact in the three dimensions of sustainability: environment, economy and social aspects, operationalised by areas of impact and key questions (SFA)
Interaction	Recording of interactions within the overall set of proposed measures, operationalised by a matrix that shows positive and negative effects.
Cost	Assessment of costs along a five-point scale with differentiation between cost categories. Initial costs, running costs and transaction costs were taken into account.

Source: own representation by adelphi based on Hölscher et al. (2025a)

4.1.3.3 Practical example II: Cost-benefit analysis of the city of Singen

The city of Singen (Hohentwiel) offers a notable example of the implementation of an MCA in municipal practice. As part of its climate adaptation concept, a multi-stage, methodologically sound procedure was developed that combines qualitative and quantitative elements (Stadt Singen 2024, p. 45). The process, which was supported by an external service provider, initially involved an internal administrative workshop in which 35 measures were selected on the basis of criteria such as benefits, feasibility, responsibility and municipal scope for action. To further narrow down these possible measures, a systematic evaluation was carried out by the external service provider using a cost-benefit analysis. The benefits of the measures were assessed using 14 indicators in the areas of adaptation needs (35%), awareness raising and synergies (40%) and ecosystem services (25%)(Stadt Singen 2024, pp. 46–47). Costs and personnel expenses were also taken into account. Based on the resulting ranking, the 24 highest-rated measures were prioritised and included in the concept. Finally, the analysis was reviewed and discussed with representatives of the city. The final measures were elaborated in comprehensive profiles and included in the municipal participation concept (Stadt Singen 2024). In this example, the evaluation process forms a sound basis for the development of a climate adaptation concept and the selection of climate adaptation measures at the municipal level.

4.1.4 The significance of ex-ante evaluation procedures for adaptation measures in Germany

An examination of the current status quo of ex-ante assessments in research and practice reveals varying degrees of acceptance and implementation of the various procedures. The following is a summary of the findings, particularly with regard to the federal government, the states and local authorities:

The three assessment procedures – CBA, CEA and MCA – comprise different indicators and assessment methods. There is a trend towards increased use of MCA, which usually includes CBA/CEA and can therefore map quantitative and qualitative data. This enables a comprehensive assessment of various criteria and broad application at federal, state and local level. There are initial examples of the implementation of structured procedures at national level, e.g. in Germany, Austria, Switzerland and Belgium, as well as at supranational level in the EU (Bundesministerium Klimaschutz, Umwelt, Energie,

Mobilität, Innovation und Technologie 2024; Euopäische Kommission 2021; Hölscher et al. 2025a; Mertens et al. 2013; Schweizerische Eidgenossenschaft 2020). Assessment procedures are also used in individual municipalities and in flagship projects, e.g. Jenka (Stadt Jena 2012) or RegiKlim (Dalitz et al. 2023; RegiKlim n.d.). Beyond the systematic assessment of the impact of climate adaptation measures, there are also positive effects on the further adaptation process – across federal, state and local levels: direct exchange between different actors during the assessment leads to closer networking and greater identification of the actors and departments with the measures and concepts. Furthermore, practical examples illustrate that ex-ante evaluations can contribute to the adaptation and optimisation of measure design (Hölscher et al. 2025a, p. 70; Stadt Singen 2024, p. 49). Evaluation procedures thus not only enable systematic selection, but also contribute to the qualitative improvement of the measures under consideration.

4.1.4.1 Federal level

In Germany, an ex-ante assessment was already carried out for the development of APA III, which was further developed in a project commissioned by the UBA (Hölscher et al. 2025a, p. 25). Most recently, the assessment procedure was further developed in a UBA project with the BNW, an assessment process was carried out and the results were submitted to the IMAA for inclusion in the APA IV (Hölscher et al. 2025a, p. 26). Twelve of the 20 policy instruments from the assessment process were listed in the APA IV draft, either in full or in part.

4.1.4.2 Federal states

The implementation of assessment procedures at the state level has so far received little attention in research and practice. Exemplary descriptions by experts illustrate that climate adaptation measures in the states were selected discursively in interdepartmental workshops on individual fields of action for inclusion in adaptation strategies. However, according to current knowledge, systematic procedures for assessing the effectiveness of these measures have not been established. Expert interviews show, however, that the importance of assessment procedures and prioritisation is increasing in the federal states.

4.1.4.3 Local authorities

In municipal climate adaptation practice, the establishment of systematic and transparent assessment procedures for prioritising measures has so far been limited. Although the DAS funding programme for climate adaptation managers (KAM) and the development of climate adaptation concepts (Zukunft-Umwelt-Gesellschaft 2021), funding priority A1) generally requires measures to be prioritised, it does not specify the criteria or procedure for this prioritisation. However, it does not specify the criteria or procedure to be used for this prioritisation. Experience reports from various municipalities confirm this assessment: although prioritisation is carried out and key measures are often identified, the prioritisation procedure is usually not presented transparently in the adaptation concepts. It can therefore be assumed that the selection was made on the basis of expert assessments rather than systematic evaluation procedures. Where criteria are specified, these include, for example, urgency, classification as a no-regret measure, adaptation needs based on municipal analyses, and the desired feasibility (e.g. City of Eberswalde, City of Essen, District of Euskirchen; expert interviews). The research and expert interviews consistently show that there is currently little knowledge of ex-ante evaluation procedures at the municipal level.

4.1.4.4 Opportunities and limitations of measurable targets

For CEA and MCA, clearly defined objectives are crucial for verifying the benefits of adaptation measures, as this is the only way to assess their impact in relation to these objectives. This approach is established at the outset in all three assessment procedures. The objectives defined in the DAS thus form a central basis for ex-ante assessments at federal level. At the same time, the DAS also highlights the challenge of making targets measurable using suitable indicators, as illustrated by the economy cluster. Expert discussions on the impact of the defined targets and indicators at state and local level make it clear that these have no direct impact on states and local authorities. Nevertheless, these targets and indicators are assumed to have a certain appeal, particularly at state level. However, the nationwide targets and indicators cannot be easily transferred to the state level, as the expert discussions further show. Rather, specific development processes are necessary to adapt them to the respective state-specific conditions and needs. According to initial assessments, it is assumed that the nationwide targets and indicators will have only a minor influence on the municipalities' own assessment processes.

4.2 Challenges and approaches to the further development of ex-ante assessment procedures

4.2.1 Methodological hurdles in assessing the effectiveness of adaptation measures

There are various methodological challenges involved in the ex-ante assessment of climate adaptation measures. A fundamental problem in assessing the effectiveness of climate adaptation measures is the lack of uniform units of measurement for effectiveness (Guerrero-Hidalga et al. 2020; Owen 2020). In contrast to areas of action such as climate protection, where CO_2 equivalents can be clearly defined and mapped, the benefits of adaptation measures cannot be determined across the board. In practice, in addition to uniform units of measurement, there is also a lack of clearly defined, measurable targets that would enable objective and comparable assessment (expert interviews). Another obstacle is a lack of data, particularly on the costs of inaction (expert interviews; Hölscher et al. 2025a, p. 75). Scenario analyses commissioned by the BMWK illustrate that investments in adaptation measures can significantly reduce or even offset economic damage caused by climate change (Flaute et al. 2022, p. 79). It is estimated that climate change could cost Germany between EUR 280 billion and EUR 910 billion by 2050 if no adaptation measures are taken. However, these estimates are based on macroeconomic models and there is no specific data available on individual measures. In research and in the methodologies described, the benefits are sought on the basis of the damage avoided (BMVBS 2023, p. 28). In practice, this assessment is possible using modelling (BMVBS 2023, p. 28). In the practical examples highlighted here, however, qualitative assessments are usually used or, as in the BREsilient project, damage estimates are carried out in which, for example, the benefits are determined by the retention of greenhouse gases. Damage avoided with the help of individual measures is thus usually determined on the basis of model calculations or expert assessments. Accurately recording the damage avoided by individual measures remains a challenge in practice. In addition, transferable information is not available for all assessment criteria and measures, as much of the data is very context-specific and case-dependent – particularly with regard to assessing effectiveness (BMVBS 2013). Finally, the weighting of different criteria poses a particular challenge, especially when social, environmental and economic aspects have to be taken into account simultaneously (Dalitz et al. 2023).

In addition to these overarching methodological hurdles, comprehensive testing of the MCA at the federal level provides valuable insights into methodological approaches and existing challenges. The application of the assessment procedure in the context of the development of APA IV shows, for example, that the delimitation of the individual sustainability criteria poses a challenge (Hölscher et al. 2025a). Methodological difficulties also arise in the comprehensive assessment of synergies between the various measures and the representation of complex interactions between measures (Hölscher et

al. 2025a). In addition, it is noticeable in this procedure that the widely used criterion of flexibility, which reflects the degree of reversibility and modifiability of measures, was not taken into account. Since greater flexibility does not necessarily mean greater freedom of action for decision-makers to further optimise and adapt the measure (Hölscher et al. 2025a), this criterion was excluded from the further development of the method. The differentiated representation of the positive significance of flexible measures is a methodological challenge in a standardised assessment scale. A central problem with all assessment procedures is the need to take into account uncertainties in estimating the effectiveness of measures (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021; Owen 2020). Due to the comprehensive significance of these uncertainties for the assessment of effectiveness, the following section outlines which uncertainties are relevant and how the various assessment methods deal with them.

4.2.1.1 Uncertainties in assessing effectiveness

A major problem in assessing the impact of adaptation measures is that it is not possible to clearly determine which climate scenario the measures should be geared towards (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021; Owen 2020). However, the significance of these uncertainties varies depending on the assessment concept and context, as measures can be assessed in terms of their objectives rather than directly in relation to climate scenarios, for example. In addition, there are uncertainties regarding the social and political conditions underlying the underlying forecasts (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021; Owen 2020). These uncertainties are also reflected in the data basis: historical data on effectiveness is often used, while reliable information on future developments is lacking (Groth and Nuzum 2016). The presentation of impact chains is one approach to illustrating the mostly indirect effects along the input, output and outcome levels of a measure. However, due to the multi-causality and complexity of the effects of adaptation measures, there are gaps in the chains of effects, making it difficult to clearly identify imitation effects or interactions (Lühr et al. 2018, p. 21). Overall, there are uncertainties regarding both future climate parameters and the effects of climate change in all areas of action, which is why policymakers and society must take these uncertainties into account when selecting and evaluating adaptation measures (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021, p. 80; Lühr et al. 2018, p. 21).

In existing ex-ante assessment procedures, different approaches are taken to reduce uncertainties in the assessment. Across the three assessment procedures considered here, it is emphasised that documentation and transparency regarding existing uncertainties are crucial for the assessment process and the classification of results (Federal Ministry of Transport, Building and Urban Development (BMVBS) 2013, pp. 8, 21). It is also essential that the procedure is easily repeatable so that new scientific findings and climate forecasts can be easily integrated into the assessment (BMVBS 2013; Groth and Nuzum 2016; Umweltbundesamt 2022a).

However, in view of the different assessment methods and application contexts, there are also different ways of dealing with uncertainties and their impact on the significance of the results in the three assessment methods. In quantitative methods – especially in CBA and CEA – sensitivity analyses are often carried out as a final step[17]. Various tools, such as RAT from the Technical University of Munich, also address uncertainties through modelling and sensitivity analyses. The PRIMATE tool, which was used by the city of Jena as an example for prioritisation, takes into account the uncertainties in the input data and the uncertainties caused by the different weightings in the ranking distribution (BMVBS

[17] Sensitivity analyses are procedures used to examine how sensitive the results of an assessment or decision are to changes in individual assumptions or input data. By repeating the assessment with input data that varies as much as possible, it is possible to check whether and, if so, what influence the variation has on the assessment result (BMVBS 2013, p. 29 2013).

2013; Stadt Jena 2012). Remaining uncertainties and individual assessment margins are made transparent in this approach, which is intended to facilitate the identification of compromise solutions. Uncertainties also have different consequences for the informative value of the assessment results of the various methods. For example, when uncertainty is high, CBA can reach the limits of its informative value. In such cases, other assessment methods, such as CEA, may be more compatible with the precautionary principle against extreme damage, as here objectives are derived based on risk prevention considerations and scientific findings, and the aim is then to achieve these objectives as cost-effectively as possible. It should be emphasised that the various models do not provide exact predictions, but rather indicate possible development paths (Schünemann et al. 2024). Sensitivity analyses and the consideration of different models can thus reduce uncertainties in the assessment of effectiveness, but these cannot be resolved in quantitative methods.

When qualitatively assessing the impact of measures, and thus mostly in the case of MCA, it is not possible to calculate the uncertainties. Various factors are taken into account in the methodological implementation in order to reduce uncertainties. In individual procedures, such as the ex-ante assessment for the development of a European adaptation strategy, different climate change scenarios are taken into account (Euopäische Kommission 2021; Hölscher et al. 2025a). However, as the RCP scenario models referred to in the IPCC are difficult to map accurately in a qualitative assessment, a distinction is made here between "low" and "medium" climate change scenarios. Similarly, the BNW assessment procedure takes into account the uncertainty regarding climate pathways and considers an optimistic and a pessimistic climate change scenario exclusively when assessing the effectiveness of measures (Hölscher et al. 2025a, p. 60).[18] At the municipal level, different scenarios are usually not explicitly used as a basis, but rather no-regret or low-regret measures are relied upon, which generally have positive effects regardless of the extent of climate change and increase social tolerance towards climate impacts (Bayrisches Staatsministerium für Umwelt und Verbraucherschutz 2021; Europäische Union 2025a 2025a ; expert interview). However, it is not clear from the interviews how measures are specifically identified as no-regret in municipal practice. Furthermore, municipal practitioners consider the challenge posed by uncertainties in the assessment to be less problematic (expert interviews). In individual multi-criteria assessment procedures, uncertainties are also specifically taken into account through the selection and weighting of appropriate criteria. Flexibility and robustness are used as key criteria, for example with the guiding question: "Does the measure have a positive effect under different climate scenarios?" (Umweltbundesamt 2022a). With a view to avoiding maladaptation, the criterion of path dependency is also emphasised (Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie 2021). In this context, measures that are irreversible or difficult to correct in the event of uncertainty about climatic developments or their effectiveness should be avoided. Key questions include whether a measure can be modified at relatively low cost or reversed if conditions change (Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie 2021, p. 64). In the case of transformative adaptations, complexity is taken into account as an additional criterion (Kristof et al. 2023, p. 18). In addition to the instrument's ability to enable the target group to deal appropriately with complex challenges, existing analyses and scenarios of possible future developments play an important role (Kristof et al. 2023, p. 18).

Overall, the various ex-ante assessments pose a wide range of methodological challenges, which lead to uncertainties in the selection of a suitable method and in the assessment of its impact (Owen et al. 2020). In addition to the methodological challenges, this also includes various practical hurdles that

[18] These two scenarios were taken into account while keeping the description of the measures constant, based on the definition in KWRA 2021. However, the assessment results show only minor deviations between the assessments of effectiveness in the two scenarios (Hölscher et al. 2025a, p. 72). This raises the question of the extent to which abstract climate scenarios can be taken into account in an already complex assessment process.

make it difficult to implement and establish assessment methods. These practical challenges are examined in the following chapter.

4.2.2 Challenges in the practical application and establishment of evaluation procedures

Ex-ante assessments in the field of climate adaptation have so far only been implemented selectively at federal and municipal level. In practice, in addition to methodological obstacles, there are other significant challenges in implementing and integrating assessment procedures. A key problem is the lack of knowledge about suitable procedures and their added value. Knowledge of possible ex-ante assessments of climate adaptation measures is hardly widespread at any level of governance, and the topic has so far only been anchored in a narrow circle of experts. In local authorities in particular, there is little knowledge of assessment procedures and their relevance and benefits, which makes it difficult to integrate them into the selection process for measures (Dalitz et al. 2023, p. 10; Grothmann et al. 2021, p. 9). Building up knowledge also requires considerable time resources and precise guidelines, which are currently lacking. At the state level, the topic is slowly being taken up and the first processes for developing suitable assessment procedures are still in their infancy (expert interviews).

The complexity of the procedures represents a further hurdle, as it is challenging to design comprehensive methods that are practical and applicable. Limited human and financial resources make implementation even more difficult, especially in small municipalities where administrators deal with many issues at the same time and therefore have little capacity for additional evaluation processes (Dalitz et al. 2023; expert interviews). Ex-ante assessments are therefore often outsourced to external service providers, which, however, reduces internal discussion of specific weightings and procedures and requires additional financial resources. The participatory design of assessment procedures is also time-consuming and resource-intensive and hardly affordable for small municipalities (Dalitz et al. 2023, p. 9).

Cooperation with various actors is often described as adding value to assessment procedures, as it enables an interdisciplinary perspective on the impact, increases the acceptance of measures and promotes cross-cutting networks for climate adaptation (Dalitz et al. 2023). In practice, however, this comprehensive participation can be challenging, as climate adaptation is not yet fully established as a cross-cutting issue and, in most cases, there are no established networks to draw on. In addition, the issue of adaptation is often still of secondary importance, meaning that stakeholders must first be mobilised for the issue and the assessment process. When implementing participatory procedures, a common understanding of the objectives of adaptation must first be developed (Dalitz et al. 2023). This shared version and objectives of climate adaptation, as well as a uniform understanding and common assumptions, are particularly important as a basis for reviewing effectiveness. Due to the time and coordination required, the participation of various actors can be challenging.

The inadequate data basis also often makes it difficult to implement assessment procedures. For many measures, there is a lack of reliable data to enable systematic ex ante assessment of impacts and cost-benefit ratios (Dalitz et al. 2023; expert interviews). In addition, systematic ex-post analyses of climate adaptation measures are only carried out to a limited extent. However, these assessments could contribute to a better data basis for a well-founded ex-ante assessment. The selection of suitable data or scenarios can also be challenging in the overall coordination process (Dalitz et al. 2023, p. 9; expert interviews). In addition to the actual availability of data, knowing where to access the relevant data can also be an obstacle. However, this challenge varies greatly depending on the assessment context, e.g. in each federal state, municipality or institution.

Insights from practice also show that the results of assessment procedures have a very different degree of influence on the ultimate implementation of adaptation activities and are taken into account to varying degrees. While at European and national level, such as in the European Climate Adaptation

Strategy or in Belgium, ex-ante assessments play a fundamental role in strategic orientation and the selection of measures, in Germany, for example, they serve to enrich adaptation plans such as APA IV by incorporating individual measures that have been tested in the assessment process. At the municipal level, on the other hand, the results often have a different function: they primarily support the informed selection of measures for adaptation concepts, as the example of Singen shows, and can serve as an initial basis for designing implementation (expert interviews). In practice, however, measures are rarely implemented based solely on their ranking in the cost-benefit assessment. Rather, factors such as financial conditions, available funding windows, personnel capacities, the personal interest of climate adaptation managers (KAM) and cooperation with other departments determine which measures are actually implemented (expert interviews). Often, projects that are already planned or can be easily supplemented by adaptation measures are implemented. Visible, quickly implementable measures ("low hanging fruits") are also preferred in order to achieve and demonstrate short-term successes (expert interviews). Overall, a key obstacle, especially in municipal practice, is that prioritisation based on structured methodology and transparent criteria often has only a limited influence on actual implementation.

EXCURSUS: THE ROLE OF CLIMATE ADAPTATION MANAGERS (KAM) IN LOCAL AUTHORITIES

The KAM position was newly created in Germany in 2022 in response to the growing importance of municipal climate adaptation and has been systematically eligible for funding since the update of the federal funding guideline "Measures for Adaptation to the Consequences of Climate Change" (2021)(Zentrum KlimaAnpassung n.d.). This funding via the German Adaptation Strategy (DAS) forms an important basis for financing, but in funding priority A1 it only covers temporary job funding for two years. In addition, there are alternative financing options, such as European ERDF funds (e.g. in the city of Singen) or the municipal guideline, as in the example of the city of Münster.

Depending on the financing model and the corresponding funding guidelines, the main tasks of the KAM include, in particular, the development and implementation of a climate adaptation concept. In funding priority A1, the development of the concept is supported and there is the possibility of receiving follow-up funding within the framework of DAS funding for the implementation of the developed concept. The role of the KAM is not yet firmly established in many municipalities and depends heavily on the availability of funding and political will. The fixed term of this newly created position has various implications for the tasks and role of the KAM. For example, the fixed term leads to considerable time pressure in the development of the adaptation concept. For KAMs, who often have little experience of working in administrative structures, the time available for familiarisation, networking within the administration and developing the concept is very limited (expert interviews). This can make it difficult to integrate an evaluation process, for example. There is also a risk of knowledge loss when a KAM leaves the administration after two years, as the hoped-for spillover effect often fails to materialise and the originally intended continuation after the end of the project is only partially successful. Since it is usually unclear at the beginning of the concept development how the implementation is to be financed and structured, the topic is often given low priority (expert interviews).

The respective funding guidelines and the structural anchoring of the position – for example, as a staff unit or within a specialist department – influence the role, tasks and scope of action of the KAM. In general, KAMs pool knowledge and expertise on climate adaptation in the municipality and shape the framework for the development process of adaptation concepts. They take on a coordinating and initiating role, particularly in the conception phase: they develop the climate adaptation concept together with the relevant administrative departments and prioritise measures. Through their coordinating role in the development of the concept, KAMs can initiate and establish evaluation procedures (expert interviews).

Expert interviews reveal that even though comprehensive prioritisation is the responsibility of the individual technical experts, KAMs play a key role, particularly with regard to synergies, conflicts and interactions between measures. In the implementation phase, the focus of the KAM's role is on activating and networking actors, accompanying measures and providing support in practical implementation. They act as multipliers and contact persons for internal and external consultation. As described above, the implementation of the measure is usually guided less by the impact assessment carried out beforehand and more by pragmatic factors such as available financial resources and funding or internal administrative cooperation. The aim is also to integrate climate adaptation measures into measures that are already planned, thus taking advantage of windows of opportunity for adaptation. The networks established during the assessment process and the detailed profiles can be of great added value here (expert interviews). KAMs create commitment and continuity by regularly monitoring and steering implementation and reporting to management. Since the measures are usually implemented by the administrative departments already specified in the planning stage, the influence of KAMs on the prioritisation of measures is reduced here. Overall, the role and effectiveness of KAMs is strongly influenced by the support they receive from their superiors and mayors, as well as by their own personality and networking within the administration (expert interviews). The role of KAMs is central to the coordination of this cross-cutting issue, but their impact is strongly influenced by the structural and financial conditions mentioned above.

4.2.3 Research gaps in ex-ante assessments of adaptation measures

The methodological and practical hurdles in the development, implementation and establishment of ex-ante assessments highlight the comprehensive need for further development of assessment procedures. The difficulties described also show that there is a considerable need for research into both methodological issues and practical application.

4.2.3.1 Data basis

There is a pressing need for research into the data basis for ex-ante assessments of climate adaptation measures. Often, there are no complete building or energy registers, and the local effects of climate change are also inadequately recorded in some cases (expert interviews). This makes it considerably more difficult to estimate investment requirements and assess the effectiveness of planned measures. There is a great need for more precise estimates of the impact of climate adaptation measures. To this end, the systematic processing of ex-post assessments as a basis for future ex-ante analyses is an important field of research. When researching measures, different framework conditions should be taken into account in order to obtain as comprehensive a picture as possible of their impact. Measures at all levels of governance should also be considered. Based on these findings, attempts can be made to determine reference values for specific contexts, which can facilitate practical implementation in guidelines. Another major methodological challenge is mapping the costs of inaction. Initial aggregated data is available at international and national level (Flaute et al. 2022), but this cannot yet be used for regional assessment concepts. An important approach is the implementation of a national damage register in which damage occurring nationwide as a result of extreme weather events is recorded in a structured and uniform manner (Oberpriller et al. 2025). Research into scalable data and operationalisable indicators represents an important contribution to sound assessment procedures and also serves as a supporting argument for climate adaptation (expert interviews; Juhola et al. 2022).

4.2.3.2 Uncertainties in assessment

Another key area of research concerns dealing with uncertainties in the assessment process. The planning and assessment of climate adaptation measures involves considerable uncertainty, for example with regard to future climate scenarios, cost developments and political framework conditions. Existing procedures therefore attempt to reduce these uncertainties and at the same time present them transparently (see Chapter 4.2.1.1). The methods used include, for example, the inclusion of multiple scenarios, the development of flexible concepts that are regularly updated, and the application of iterative assessment approaches. Based on the procedures described here, there are differences in the consideration of uncertainties in qualitative and quantitative procedures. However, the respective assessment contexts – for example, whether federal or local government – also influence the extent to which uncertainties limit the informative value of assessment results and how uncertainties are dealt with methodologically. Studies on the consideration of uncertainties should take greater account of both the assessment contexts and the actors involved. The BNW's testing of the MCA indicates that taking pessimistic and optimistic climate scenarios into account leads to hardly any deviations in the assessments (Hölscher et al. 2025a, p. 15). Interviews with experts also make it clear that precise climate scenarios are not taken into account in practice. Based on these exemplary results, it is important to investigate for which assessment contexts the consideration of different climate scenarios represents added value and how these scenarios can be consistently used as a basis for the assessment. Overall, research into computational and methodological approaches to reducing uncertainties is a key prerequisite for precise and reliable assessment procedures.

4.2.3.3 Modular structure

A key methodological research need lies in the further testing of assessment procedures and the development of modular assessment systems that can take into account different sectors, the diversity of measures and different assessment scales. The respective starting point, regional conditions and socio-economic aspects must be integrated into the assessment. The development of quantifiable, comparable measurements and assessment scales for the effectiveness of measures is considered to be of central importance.

4.2.3.4 Impact structures and innovative approaches

A research gap exists in the lack of impact structures or systematic representations of various effects in the context of municipal climate adaptation measures. Impact structures or impact chains serve to illustrate the various effects of measures along the levels of input, output and outcome (Hölscher et al. 2025a; Lühr et al. 2018). This form of mapping can also be used to illustrate uncertainties along the impact chain. Impact analyses have so far been little used in the field of climate impact adaptation, although they are likely to make valuable contributions to adaptation to climate change. Research into innovative approaches for capturing impact structures, with the aim of illustrating non-mono-causal relationships, represents another field of research (Lühr et al. 2018, p. 9).

4.2.3.5 Maladaptation

The assessment process for developing Austria's National Climate Adaptation Strategy highlights the significant risk of maladaptation, which is also emphasised by the IPCC (Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie 2024; Intergovernmental Panel on Climate Change 2023, p. 101). With a focus on reducing maladaptation, criteria such as the increase and/or shift in vulnerability, conflicts of interest with climate protection and ecological and social sustainability, path dependencies, negative competitive effects and inefficiency are used here (Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie 2021, p. 59). These criteria are already partially taken into account in individual MCAs. However, due to the increase in maladaptation, it is particularly important to examine (IPCC 2022, p. 27) the extent to

which the aspect of shifting vulnerabilities can be taken into account and operationalised in ex-ante assessment procedures.

4.2.3.6 Transformative adaptation

The assessment of transformative climate adaptation is a relatively new field of research, and research on transformative adaptation (see info box "Excursus: Transformative adaptation & social justice as the key to effective measures") is still in its infancy in practice. An exemplary study examining the transformative nature of adaptation measures is the UBA study by Kristof et al. (2023). The extent to which the criteria listed here can be transferred to other assessment contexts and procedures, and the extent to which additional value can be gained by integrating further criteria, should be investigated in further research activities.

4.2.3.7 Assessment procedures in multi-level governance

There is a significant need for research into the specific requirements for evaluation procedures at different levels of governance. In particular, there is little information available on the status quo in the federal states and the requirements and obstacles for evaluation procedures at this level. This study has provided initial insights into the current state of ex-ante evaluations at the municipal level. Nevertheless, comprehensive research on municipal practice is also necessary in order to obtain a systematic overview of the status of the application of evaluation procedures in German municipalities. On this basis, existing obstacles and success factors can be comprehensively identified and recommendations for action for broader and sustainable anchoring can be derived. Particular attention must be paid to smaller municipalities and districts, as there is a particular need for research into practical procedures and support services in these areas.

4.2.3.8 Significance of European funding programmes

A study of individual municipalities suggests that applying for EU funding or European awards, e.g. as part of the European Climate Award, could encourage ex-ante evaluation of measures. The importance of European funding and awards for the establishment of systematic evaluation procedures has been little researched to date, and a larger-scale study is needed to test this hypothesis. In addition, there is a need for research into how funding mechanisms – for example, through the targeted linking of funding to benefit assessments – can support the application and further development of assessment approaches in municipal practice.

4.2.3.9 Integration of new technologies

The rapid development of new technologies and AI-supported programmes is leading to a variety of research needs for the integration and improvement of ex-ante evaluation procedures. The increasingly frequent development of digital twins of cities or federal states makes comprehensive data from various subject areas easily accessible. This raises the question of whether and to what extent their integration enriches the basis for evaluation and whether scenario analysis is improved in terms of the flexibility and robustness of measures. For example, there is a need for research into easier data preparation and availability of data through AI tools. It is also necessary to investigate the extent to which AI-based programmes can contribute to easier handling for users of complex assessment tools. Fundamental insights are needed into the acceptance and integration of AI into existing assessment processes. As in other areas of application, the ethical, legal and social implications of AI use must be critically examined, particularly with regard to the assessment of the social and environmental impacts of adaptation measures.

4.3 Recommendations for the further development and establishment of effectiveness assessments of adaptation measures

4.3.1 Methodological developments

The ex-ante assessment methods currently in use have various shortcomings and challenges. Research into and application of these methods are still in their infancy, and there is a significant need for further methodological development. The methodological development of existing assessment methods is an important next step in order to be able to estimate the impact of climate adaptation measures even more accurately and to further align the methods with the various needs of practical application.

Two fundamental aspects that should be considered in further development are the ease of repeatability of the assessment and the alignment of the methods with different assessment contexts. It should be easy to repeat an assessment in order to take appropriate account of new information and evolving risks (Environmental Protection Agencies Network 2025, p. 9; Kristof et al. 2023). The specific design of an assessment procedure depends largely on the respective objectives, context and available resources. The development of a uniform standard assessment procedure is therefore only possible to a limited extent. Further research should examine the extent to which assessment procedures can be designed in a modular way so that they can be easily adapted to the needs and capacities of the assessors.

The assessment procedures presented all have uncertainties in their results (see Chapter 4.2.1.1). As previously indicated, there is still a great need for research into the methodological handling of uncertainties (see Chapter 4.2.3.2). In addition to reducing uncertainties, for example through better data bases that are applicable to the local level and individual measures, further research should be conducted into the significance of uncertainties in prioritisation in practice and how these can be presented in a transparent and easily understandable manner. Here, too, it is important to link the further development of the methodology closely to practical needs. In addition, a consistency check of the evaluation results of the instruments has proven useful in practice (Hölscher et al. 2025a; Kristof et al. 2023). Particularly when several actors are involved in the assessment, there is a risk that criteria and indicators will be understood differently or that individual aspects will be weighted differently in the respective assessments. A consistency check of the assessment results can therefore reduce uncertainties and subjectivity in the methodological process.

A major challenge of existing assessment methods lies in the complexity of their practical application. There is a crucial need to further align assessment methods with practical application. This study highlights the current lack of knowledge in practice and the limited resources available to potential users (expert interview). The procedure should be as low-threshold and methodologically easy to understand as possible, especially with regard to the municipal level. The procedures should be tested in practice and tailored to the needs of users in the various administrative structures. This focus is crucial in order to bring ex-ante assessment procedures from scientific development and exemplary testing into broad practice.

Further methodological development should aim to evaluate adaptation measures not only individually, but also in their entirety. The effectiveness of individual measures depends heavily on which other measures are also implemented. The effect of a package of measures differs significantly from the sum of the effects of the individual measures it contains. In addition, adaptation measures often only become effective when they are implemented in combination. Therefore, considering different packages of measures or policy mixes often provides more meaningful insights than

evaluating individual measures. This aspect has only been considered sporadically in research to date and has not yet been implemented systematically or in a practical manner. Initial approaches that take this evaluation component into account have been integrated into the ex-ante evaluation procedure for APA IV measures. There, positive or negative interactions and synergy effects between individual measures were analysed. However, here too, the effectiveness assessment was only carried out for individual measures and not for alternative configurations of a possible policy mix. Further research is needed here to develop methods for evaluating packages of measures or policy mixes for climate adaptation. This is also relevant for the assessment of transformative adaptation instruments and policy mixes: many adaptation measures only have a transformative effect in combination with other measures. The entire policy mix should also be considered with regard to its transformative potential.

The assessment of adaptation measures in terms of their transformative potential is a relatively new field of research. The research by Kristof et al. (2023) is an example of how transformative adaptation can be operationalised and assessed ex ante. At the same time, this study highlights important research needs that need to be addressed in order to further develop methods for transformative climate adaptation. In order to be able to evaluate individual criteria on an even more sound basis, methods for assessing transformativeness should be further developed. In this area, too, only initial methodological approaches are available so far, so that further development of this young field of research would be an important next step (Kristof et al. 2023, p. 27). One possible approach here would be to develop checklists or sub-criteria. Further refinement of the methods could also improve the scaling of the individual criteria. It should be examined whether an overall point score without specific weighting of individual criteria and a parallel view of the balance lead to the best result in terms of a suitable transformative policy mix, or whether weighting adapted to the individual case is necessary (Kristof et al. 2023).

With regard to the assessment methods presented in this study, it is clear that there is a specific need to further develop the methodology, the criteria considered and the operationalisation. For example, in practice, there is a need to be able to map not only the cost estimates for one-off investments but also the long-term maintenance and operating costs of a measure (expert interview). According to expert statements, a major added value of such further development is that it makes these long-term costs visible. This would allow them to be better taken into account in funding programmes, especially at the municipal level. The anchoring of long-term maintenance and operating costs thus represents a significant gain and a possible incentive for municipal application. In the case of the MCA in particular, there is a need for further development with regard to the integration and operationalisation of individual criteria, such as flexibility or synergy and conflicts (see Chapter 4.2.1). Further research should focus on existing procedures, findings and gaps and develop them further in additional research projects with a view to creating a user-friendly design and broad application.

4.3.2 Recommendations for anchoring assessment procedures in practice

In addition to further methodological development, it is particularly important to promote the implementation of suitable assessment procedures in practice. Based on expert interviews and literature research, recommendations for broad application were identified.

An important aspect that can support application in practice is the provision of tools and handouts (expert interviews). Interview partners emphasise the need for practical, easily understandable guidelines or handouts that map the various modules of a standard evaluation process and explain the corresponding tools for implementation. One innovative idea is to prepare assessment procedures not only as text documents, but also as software tools. At the beginning, users could fill out a questionnaire that asks, for example, about the duration of the process, available resources or groups of actors involved. The tool would then issue a recommendation on the design of the assessment procedure,

including the methodology. This could be particularly helpful in selecting the appropriate method, thus facilitating entry into the process. Detailed information bases should also be anchored in advisory centres and services, for example at the Climate Adaptation Centre (ZKA), which advises local authorities and social institutions on climate adaptation issues and offers relevant training courses. Federal states could also act as multipliers and provide support services for local authorities, and an advisory centre based at the UBA to support federal states and local authorities would also be conceivable.

In order to anchor assessment procedures more broadly, it is recommended that assessment procedures be mainstreamed into guidelines, funding programmes and individual laws (Environmental Protection Agencies Network 2025 2025 ; expert interviews). The inclusion of MCA to support informed decision-making in the Building Code could also promote climate-resilient urban land-use planning and should be examined. It is also important to ensure policy coherence so that adaptation measures do not conflict with other nationwide sustainability strategies (Environmental Protection Agencies Network 2025, p. 9). For the EU, the promotion of guidelines for ex-ante assessment procedures is recommended in order to strengthen development and consistency in the Member States. This recommendation is also transferable to the federal system in Germany (Environmental Protection Agencies Network 2025, p. 10). Such guidelines can help the federal states to proactively assess their adaptation strategies and reduce the effort required to develop a suitable method for the federal states. However, the expert interviews also made it clear that individual practitioners do not consider mandatory ex-ante assessments to be beneficial if they are not backed up by additional financial and information resources. As this is seen as a major risk and could place an additional burden on local authorities, the voluntary nature of assessment procedures is emphasised.

Financially, the anchoring of evaluation procedures should be further strengthened by integrating them into federal and state funding guidelines. Based on further research findings and the development of practical guidelines for different target groups, systematic implementation in funding programmes should be examined. For example, the prioritisation process in the DAS funding programme could be further refined and strengthened by comprehensive information and support services. Other funding programmes should also be examined for the possibility of integrating ex-ante evaluation procedures. It is important that this anchoring is accompanied by IT support and sufficient resources. At the municipal level, external service providers are often called upon for support. To ensure that implementation is feasible given the limited human resources in the municipalities, appropriate calculations must be made for the funding. Linking funding to the expected benefits of measures is also a recommendation from practice. Alternatively, it is also conceivable that bonus points could be awarded in funding programmes for the application of assessment procedures.

Existing research and expert interviews identify municipal implementation as key to climate adaptation. However, climate adaptation is not currently a mandatory task and, due to severely limited resources in local authorities, is being addressed and implemented in very different ways. The UBA's local authority survey and expert discussions make it clear that there is a need for a "climate adaptation officer" who acts across departments (Friedrich et al. 2024a). KAMs play a special role in this regard, as their cross-departmental perspective enables them to take a holistic view of adaptation measures, prepare their results for all relevant departments and facilitate the balancing of interests (expert interviews; Grothmann et al. 2021, p. 16)(see Chapter 4.2.2). Assessment procedures can only be carried out if sufficient personnel and financial resources are available. However, fixed-term contracts for staff can be an obstacle, as knowledge about the process is lost and the implementation of measures is not guaranteed from the start of concept development. In the expert interviews, emphasis was therefore placed on establishing climate adaptation as a joint task and securing long-term staffing for climate adaptation, also with regard to the systematic evaluation of measures.

As many actors have only limited knowledge and experience with the implementation of assessment procedures to date, the promotion of exchange formats represents a further important step towards sharing knowledge and experience and removing obstacles. This is recommended both at federal level – for example with regard to knowledge transfer from European member states – and at state and local level (Environmental Protection Agencies Network 2025, p. 10 2025; expert interviews). Highlighting good examples of how assessment procedures are carried out can also make an important contribution in view of the limited knowledge available. Identifying and preparing such examples and embedding them in information centres would be another important step towards demonstrating how they can be easily applied and inspiring others to follow suit.

5 Conclusion

The analysis of financing requirements for climate adaptation in Germany clearly shows that the investment needs are already considerable today and are likely to increase further as climate change progresses. Various estimates and models – from empirical bottom-up approaches to macroeconomic top-down models – consistently indicate that the annual financing requirements are likely to run into the tens of billions. Detailed sectoral analyses, such as those for water management, show particularly high investment requirements for individual areas. Added to this are administrative costs for implementing legal requirements and urban development measures that have often been overlooked to date, which – depending on their scope – can also accumulate to considerable sums.

At the same time, there is a high degree of uncertainty in all quantitative and qualitative estimates. The diversity and dispersion of the figures, as well as the heterogeneity of the sectors, make it clear how difficult it is to produce a reliable calculation. The cross-cutting nature of climate adaptation makes it difficult to clearly allocate costs, as many measures address several objectives at the same time and are often intertwined with other policy areas. The methodological approaches chosen also have specific strengths and weaknesses: bottom-up methods allow for a detailed examination of individual measures, but only capture cross-cutting effects and indirect costs to a limited extent. Top-down models can map macroeconomic relationships, but are limited to selected adaptation measures and often do not integrate all relevant factors such as construction cost dynamics or synergies with other policy areas. Overall, all available figures are subject to uncertainty, which is why reliable statements on specific needs can only be made to a limited extent.

In light of these developments, public budgets face a multitude of challenges: acute liquidity requirements arise from extreme weather events and the associated damage repairs; long-term costs result from necessary adaptation investments; and in extreme cases, there is a risk of excessive debt if high damage costs limit the financial scope for financing existing debts. However, how innovative financing instruments – such as catastrophe bonds, parametric insurance, climate-resilient debt clauses, resilience bonds or local climate funds – can contribute to risk mitigation and long-term financing in conjunction with existing mechanisms has only been investigated to a limited extent and remains a key area of research. The practical effectiveness and scalability of these instruments in the German context is still open and requires further empirical testing and evaluation.

In view of limited resources and growing risks, it is also essential to use the available funds as efficiently and effectively as possible. The systematic prioritisation of adaptation measures is therefore becoming increasingly important. Ex-ante assessment methods such as cost-benefit analyses (CBA), cost-effectiveness analyses (CEA) and multi-criteria analyses (MCA) provide a methodological basis for assessing the benefits, efficiency and social acceptance of measures in a structured and transparent manner. While CBA and CEA focus primarily on quantifiable costs and benefits, MCA allows for the consideration of a wide range of criteria, including qualitative ones. This method, which is particularly widespread in practice, is especially suitable for complex decision-making situations with different objectives and uncertainties, but requires the context-specific adaptation of assessment methods and the weighting of the selected criteria. In practice, participatory and context-specific approaches are increasingly being chosen, which increase the acceptance and relevance of the results.

Nevertheless, considerable challenges remain: the limited availability of reliable assessment data, uncertainties due to different climate scenarios and complex chains of effects, and the additional resources required to carry out structured assessment procedures make broad application difficult, especially at the municipal level. There is a particular need for research into the systematic recording

of the costs of inaction, the integration of social justice and transformative aspects into assessment procedures, and the development of modular, practical tools and exchange formats. The assessment of policy mixes and the consideration of multi-causal effects are further key areas for development.

Overall, the analysis makes it clear that effective and sustainable climate adaptation requires an integrated strategy. This strategy must systematically address financing gaps, actively manage fiscal risks, and base the prioritisation of measures on a solid assessment foundation. However, the multitude of unanswered questions and the high demand for research make it clear that many of the instruments and procedures currently under discussion need to be further developed and empirically tested before they can be implemented broadly and effectively. This is the only way to ensure that limited resources are used in a targeted manner to effectively limit the economic, social and environmental risks of climate change and strengthen the resilience of society.

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Appendix A: Profiles of innovative financing mechanisms

7.1 Levying (local) taxes for climate protection and adaptation

Classification: new instrument/extension of an existing instrument?

New instrument that builds on existing approaches.

Definition and basic principle

The increasing challenges posed by climate change require significant investment in municipal climate adaptation. Given the particular importance of local measures to tackle the climate crisis (Brand et al. 2023), municipalities are faced with the task of tapping into additional sources of funding. Local taxes for climate adaptation offer an approach that increases the financial scope of municipalities to finance adaptation measures. The levies do not necessarily have to follow the polluter pays principle, which would be difficult to apply in the context of supraregional climate risks anyway, but can also be specifically levied on individuals who would particularly benefit from the local measures implemented. Local levies for climate adaptation are municipal financing instruments that serve to generate earmarked revenue for climate adaptation measures. A distinction must be made between legal and political earmarking: legal earmarking enshrines the exclusive use of revenue for climate adaptation in law and creates maximum planning security, but is subject to strict constitutional admissibility requirements. Political earmarking, on the other hand, allows for greater flexibility in budget planning and easier implementation, but offers less binding force and can be adjusted if political priorities change. The choice between the two approaches depends on the desired degree of legal certainty and the desired scope for flexibility. The levies comprise various approaches: land sealing levies targeting the sealing of soil, extended precipitation water fees for sustainable rainwater management, broad climate adaptation levies for local investments on site, and specific project levies for targeted adaptation measures such as flood protection. At the same time, depending on its design and the chosen assessment basis, the instrument can provide incentives for behaviour that reduces local climate risk, for example by promoting unsealing or sustainable rainwater management.

How it works

The way local levies for climate adaptation work varies considerably depending on their design. In the case of land sealing levies, a levy is imposed on sealed areas, calculated on the basis of the actual sealed land area. The proceeds can be earmarked for unsealing measures and climate-friendly infrastructure. The amount of the levy is based on the external costs caused by sealing, such as increased flood risks or urban heat islands.

Extended precipitation water charges represent a further development of the existing split wastewater charge[19]. While the current precipitation water charge in the 15 largest German cities ranges between EUR 0.50 and EUR 2.00 per square metre of sealed area (Deckert 2025), an extended version could generate additional funds for climate adaptation measures. This would take into account not only the

[19] This separates the previously standard wastewater charge into a sewage charge and a rainwater charge.

costs of wastewater disposal, but also those of sustainable rainwater management and climate protection.

Broad climate adaptation levies can be designed as a flat-rate levy per inhabitant or as a percentage surcharge on existing municipal levies. These funds can flow into an existing or newly created municipal climate adaptation fund, from which various measures can be financed (see fact sheet on local climate funds; Keusen and Radic-Capuani 2024). Specific project levies, on the other hand, are levied for concrete adaptation projects, such as decentralised flood protection or the implementation of sponge city concepts.

The assessment is usually based on objective criteria such as area size, degree of sealing or population figures. Modern technologies such as satellite imagery and geographic information systems enable precise recording of the assessment criteria. Reductions or exemptions are conceivable for proven climate adaptation measures, such as the installation of green roofs, infiltration systems or cisterns.

Advantages and areas of application

Local taxes for climate adaptation offer several key advantages. They enable direct and earmarked financing of climate adaptation measures, thereby alleviating the often precarious financial situation of local authorities. The polluter pays principle leads to a fairer distribution of costs, as those who exacerbate climate change-related risks also bear the costs (Schep et al. 2022).

The steering effect is another important advantage. The financial burden of environmentally harmful activities creates incentives for more climate-friendly behaviour (Schep et al. 2022). For example, a land sealing levy can motivate the preservation of unsealed areas or the reduction of existing sealing. At the same time, such levies strengthen municipal financial autonomy and reduce dependence on federal and state subsidies.

Local taxes for climate adaptation are primarily used at the municipal level. Municipalities and cities can use these instruments to finance measures such as the creation of green spaces, the installation of blue-green infrastructure or flood protection. The local level of taxation allows both taxes and the measures financed by them to be adapted to local economic and climate-related conditions.

Counties can take on a coordinating role and finance cross-cutting climate adaptation measures that extend beyond the boundaries of individual municipalities (Völker et al. 2024). This is particularly relevant for measures in the area of water management or regional green networking. The 294 German districts cover 96% of the federal territory and 68% of the population, giving them a key role in comprehensive climate adaptation (Völker et al. 2024).

The federal states contribute to the creation of uniform legal frameworks and, through their respective local tax laws (for an overview, see Grupp and Stelkens n.d.), lay the foundation for local taxes that municipalities can levy.

The federal government has a coordinating and framework-setting role. With the Climate Adaptation Act of 2023, it has created binding guidelines for climate adaptation at all federal levels for the first time (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz 2023a). In addition, the federal government can use tax incentives to promote the introduction of local taxes and increase their acceptance. For example, the federal government could introduce a new special expenditure provision in the German Fiscal Code (Abgabenordnung) whereby contributions and levies paid by residents or companies in a municipality to finance climate adaptation measures are fully deductible as special or operating expenses. At the same time, the Fiscal Equalisation Act could stipulate that each municipality receives a 20% surcharge on its key allocations for every euro levy generated. On the one hand, this means that the funds flow directly into municipal budgets, and on the

other hand, the effective burden on taxpayers is reduced thanks to the tax advantage. Example: A municipality levies EUR 100,000 in climate adaptation levies – it receives EUR 100,000 in its budget plus a EUR 20,000 bonus allocation. The paying companies or private households can claim the full amount of their levies as tax deductions, which could reduce resistance to additional levies.

Challenges and limitations

The introduction of local taxes for climate adaptation faces considerable legal challenges. German municipal tax law is subject to strict constitutional requirements that limit the levying of new taxes (Keusen and Radic-Capuani 2024). In particular, the requirement for special factual justification and compliance with the principle of equivalence[20] can complicate the design. The distinction from existing federal and state taxes and levies must be taken into account, as must municipal revenue sovereignty (Baumann 2024).

Social acceptance is another key challenge. New levies often meet with resistance from the population, especially when the effects of climate change are not yet immediately apparent (Heitfeld and Thiele 2024). In an economic context, differences in the tax burden can cause companies to relocate in the medium term, which has a negative financial impact on the original company locations (see Chapter 3.1.2). Communicating the necessity and benefits of such taxes therefore requires comprehensive public relations work and citizen participation and should also highlight the economic advantages that can result from the implementation of adaptation measures (see Chapter 3.1.2.5).

Practical implementation poses complex administrative challenges. Assessing the levies requires precise data collection, for example on degrees of sealing or climate risks. The data must be collected consistently, stored and updated regularly, as a lack of precision in the assessment basis could impair the acceptance of the levies and their optimal design. The establishment of appropriate administrative structures and staff training also incur additional costs; last but not least, suitable enforcement instruments must be developed to ensure proper collection.

Distribution effects can also lead to social injustices. Since low-income households suffer disproportionately from the financial consequences of climate change (Staude 2025), new levies for climate financing represent an additional burden that could affect, for example, low-income individuals who live in areas with high levels of soil sealing or who do not have the means to make climate-friendly adaptations. Social gradation or hardship provisions are therefore conceivable, but these increase the complexity of the instruments. The extent of the distributional effects depends, on the one hand, on the distribution of local climate risks among residents and, on the other hand, on the specific design of the respective levy. These differ both in terms of the indicators they are linked to (i.e. who has to pay them and to what extent) and in terms of who benefits from the measures implemented and to what extent.

Examples

Internationally, there are already various approaches to local taxes that directly or indirectly benefit climate adaptation purposes. In Switzerland, various cantons are using differentiated incentive systems for rainwater management that promote disconnection from the sewerage system (Infoplattform Schwammstadt n.d.).

In Catalonia, the regional government has been operating a climate fund since 2020, which is financed by revenue from a newly introduced CO_2tax on vehicles registered in Catalonia (Catalan Government 2020). The climate fund, which is intended to facilitate the implementation of measures and strategies

[20] The equivalence principle states that only costs necessary for the fulfilment of the public task may be taken into account when levying charges.

for climate protection and adaptation, is used, for example, to promote the use of renewable energies, decentralise energy networks, promote energy-efficient housing and sustainable mobility, and achieve water savings. It thus offers a successfully implemented practical example of an additional levy that also finances climate adaptation measures.

Various approaches are already established or under discussion in Germany. The split wastewater charge, which bills sewage and rainwater separately, is now standard in most German municipalities. Depending on the municipality, it ranges between EUR 0.50 and EUR 2.00 per square metre of sealed area ; Bremen, for example, has been charging a rainwater fee of EUR 0.83 per square metre since 2024 (Deckert 2025). Thirteen of the 16 federal states currently levy water abstraction charges; only Hesse, Thuringia and Bavaria have not yet introduced such a levy on the abstraction, extraction or use of groundwater or surface water (streams, rivers, lakes)(Bund für Umwelt und Naturschutz Deutschland e.V. 2025).

Municipal support programmes for decentralised flood protection already demonstrate how earmarked funds can be used for climate adaptation. Dortmund provides EUR 250,000 annually for flood and inundation protection measures for private properties, with a maximum subsidy of EUR 1,000 per property and an income limit of EUR 75,000 in taxable income for individuals or EUR 150,000 for jointly assessed or legal entities (Stadt Dortmund n.d.). The city of Passau has increased its subsidy rate for decentralised flood protection to up to 85% of the costs in 2024 ; in addition, the exclusion of ancillary buildings such as garages has been lifted and the maximum subsidy amount increased (Stadt Passau 2024). However, these programmes have so far been financed mainly from general budget funds or donations.

The new property tax C, which can be introduced in Germany from 2025, offers local authorities the opportunity to set a higher assessment rate for undeveloped but buildable land (Augustin 2024). Although primarily intended to combat speculation in building land, it can also contribute indirectly to climate adaptation if its revenues are used for climate-adapted settlement development.

Conclusion and outlook

Local levies for climate adaptation are a promising instrument for strengthening the municipal financing basis for necessary adaptation measures. They combine the polluter pays principle with the direct financing of climate adaptation and create incentives for climate-friendly behaviour. The various design options – from land sealing levies and extended rainwater fees to project-specific levies – offer municipalities flexible approaches to tapping into additional sources of financing.

However, successful implementation requires overcoming considerable legal, political and practical challenges. Clear legal frameworks, social acceptance and administrative capacities are prerequisites for the effectiveness of such instruments. Social distribution effects should be taken into account and appropriate compensation mechanisms created.

The growing importance of climate adaptation suggests that local levies for climate adaptation will become more relevant in the coming years. Pilot projects and gradual introductions can help to gain experience and create acceptance. Integration into existing systems such as property tax or wastewater charges can reduce administrative costs and facilitate implementation.

In the future, technical advances in data collection and processing could increase the precision and efficiency of such levies. At the same time, there are synergies with other policy areas, such as digitalisation or social urban development, which can further strengthen the effectiveness and acceptance of local levies for climate adaptation.

Further reading

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7.2 Catastrophe bonds (cat bonds)

Classification: new instrument/extension of an existing instrument?

New instrument in the German context, based on international approaches.

Definition and basic principle

Catastrophe bonds (also known as cat bonds) are special securities that enable governments, public insurers and other institutions to protect themselves against the financial consequences of natural disasters. Unlike traditional bonds, where repayment depends primarily on the issuer's solvency, repayment of catastrophe bonds is linked to the occurrence of certain natural events such as storms, earthquakes or floods (Wagner 2018b).

Investors receive an attractive interest rate for purchasing catastrophe bonds, which reflects the risk of the investment. If a predefined catastrophe occurs during the term, this money is used in whole or in part to cover the damage incurred; investors lose some or all of their investment. If no catastrophe occurs, investors receive their money back plus the agreed interest. For the issuer, this means that the necessary capital is immediately available when needed – and there is no risk of the money being unavailable in the event of damage because it was already provided when the bond was issued (Wagner 2018b). Cat bonds thus transfer part of the economic risk posed by natural disasters to the financial sector and provide additional capital to deal with the consequences of climate change.

For the public sector, cat bonds offer the advantage of helping to reduce budgetary risks and providing rapid financial resources after a disaster (Environmental, Social and Governance Initiative 2020). Unlike traditional loans, whose premiums and provisioning obligations are reflected in the borrower's budget, the use of catastrophe bonds does not lead to additional debt, as the bond is not issued by the sponsor itself but by a special purpose vehicle (see below) and payments are made directly from the investors' capital (Financial Protection Forum 2021).

How it works

Cat bonds are structured using complex financial architectures involving several actors and transaction levels. The issuer (sponsor) first establishes a legally independent *special purpose vehicle* (SPV). This outsourcing protects the bond against the sponsor's potential insolvency, meaning that the main risk for investors lies solely in the occurrence of the insured catastrophe (Bucher 2025).

The special purpose vehicle issues the cat bonds to institutional investors and invests the capital paid in highly liquid, secure securities such as government bonds or money market instruments (Wagner 2018b; Steiger 2024). The proceeds from this reinvestment are used to finance the interest payments made to the investors in the cat bond. Interest is paid during the term of the cat bond and is not reclaimed even in the event of a claim. Since cat bonds generally offer higher interest rates than secure securities, the sponsor covers this gap by paying a premium to the special purpose vehicle (Bucher 2025 2025 ; see Figure 11). An example illustrates this: a cat bond is issued with an interest rate of 8%; the capital paid in is invested securely at an interest rate of 3%; the sponsor pays the missing 5% required to refinance the interest to investors as a premium.

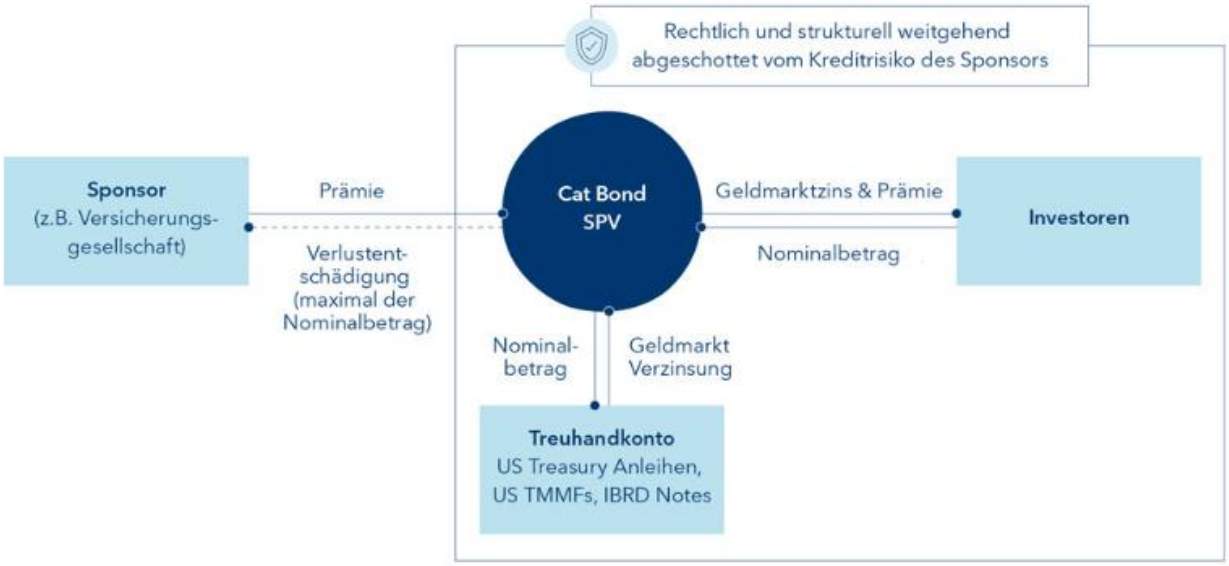

Figure 11: typical cat bond structure(aus Steiger 2024)

The key mechanism of a cat bond is the trigger mechanism, which defines the conditions under which a payout is made. A payment event occurs when a qualifying event occurs within the specified risk period (Twelve Securis and J. Safra Sarasin 2025; Wagner 2018b). A distinction is made between different types of triggers (Bucher 2025) :

- **Indemnity** triggers: these are based on the sponsor's actual losses and thus offer the best protection against basis risk[21], but require prior measurement of losses and are therefore relatively slow. As a rule, a so-called *attachment point* is set, above which a partial payout is triggered, as well as an *exhaustion point*, upon reaching which a full payout of the bond capital is triggered.
- **Parametric triggers:** these are based on objectively measurable parameters such as wind speed or earthquake magnitude and enable faster payouts as soon as these parameters have been objectively measured as having been exceeded or not reached, but they carry a higher basis risk (see profile on parametric insurance).
- **Index-linked triggers:** these are based on the total amount of insured losses across the entire insurance industry due to a natural event. Here, too, thresholds are set for partial and full payouts. These triggers are particularly suitable for globally operating reinsurers, whose own losses are usually closely correlated with the overall market, and offer a compromise between speed and basis risk.

Advantages and areas of application

Cat bonds are an instrument that has been extensively tested internationally for over 25 years, with a global market volume of approximately USD 50 billion (Bundesverband Alternative Investments e.V. 2024). The large amount of existing references and experience means a comparatively low risk for first-time users, as they can draw on extensive data and best practices.

Cat bonds offer several strategic advantages for public budgets and government actors, making them a valuable tool for fiscal resilience. The primary advantage lies in the rapid and predictable provision of

[21] A basis risk exists when the actual amount of damage is greater than the maximum compensation amount of the insurance instrument (see also profile on parametric insurance;Wagner 2018a).

liquidity after catastrophic events(Environmental, Social and Governance Initiative 2020). While traditional insurance often requires months of claims settlement processes, cat bonds can pay out within days to weeks after the trigger event (Steiger 2024).

Cat bonds offer local authorities and federal states the opportunity to diversify their risk financing and reduce their dependence on the traditional reinsurance market. This is particularly relevant in view of the rise in reinsurance prices and reduced capacity following major loss events in recent years (Schier 2024). Although local authorities in Germany are already fully protected against climate damage by the federal and state governments (see Chapter 3.2.1), the independent issuance of cat bonds can offer relevant advantages for local authorities: it creates a clear risk calculation, improves budget planning and can be realised with low own risk thanks to federal guarantees. In addition, it opens up access to institutional private capital and, despite the premiums to be paid, may be cheaper than taking out emergency loans in the event of a disaster.

The individual selection of triggers and parametric thresholds for each cat bond product makes cat bonds a flexible instrument that can be adapted to regional or local characteristics. The transparency and predictability of cat bonds can also significantly support the budget planning of public authorities. Since all parameters are clearly defined in advance, municipalities and states can calculate precisely what financial resources will be available in the event of specific events (Ossenbrink 2025). This planning security enables a more efficient allocation of budget funds and, when applied correctly, reduces the need for costly emergency loans.

The federal government has a central coordinating role in the implementation of cat bonds. Similar to the recommendations for parametric insurance (see fact sheet), the standardisation of cat bond structures, the provision of validated climate data as a basis for parametric triggers and the development of a supportive regulatory framework are the responsibility of the federal government. The ECB and EIOPA have already made specific recommendations for increased use of cat bonds to close the European insurance gap for natural disasters (Europäische Zentralbank 2024). In addition, the federal government could act as a co-sponsor, similar to resilience bonds (see also fact sheet on the state as the insurer of last resort). The creation of tax incentives for investors is also conceivable, for example by granting tax credits on capital invested in cat bonds.

For agriculture, the European Commission forecasts climate-related losses of EUR 40 billion annually by 2050, recommending cat bonds as an essential tool for closing the insurance gap (González Peláez et al. 2025). This underscores the potential for sector-specific applications in Germany as well.

Cat bonds also enable the coverage of previously uninsurable risks. Similar to parametric insurance, they can cover non-damage business interruptions[22] or systemic risks that are excluded from traditional insurance (see fact sheet on parametric insurance). The free use of payouts gives public authorities the flexibility to finance not only direct damage, but also consequential damage and preventive measures (Environmental, Social and Governance Initiative 2020) .

Challenges and limitations

The implementation of cat bonds is associated with several structural challenges that have limited their use in the German public sector to date. The basis risk is the most fundamental challenge. It describes the risk of a deviation between the actual amount of damage and the compensation payments from the Cat Bond(see Wagner 2018a). With parametric triggers, this deviation can be significant, especially if the selected parameters do not adequately reflect individual risk exposures

[22] This refers to losses in revenue that are not directly attributable to a damaging event, but rather to factors such as interrupted supply chains or official orders (Pollak 2024).

(World Bank 2022). However, this risk would be covered by existing federal and state aid for municipalities in the event of a disaster (see Chapter 3.2.1) – although in this case, the advantage of cat bonds in ensuring rapid payouts would only apply to part of the required funding. Cat bonds should therefore be seen as an additional instrument for quickly generating liquidity to reduce the fiscal risks posed by climate damage to public finances, with any gaps being covered by existing hedging mechanisms. The use of parametric triggers not only requires careful selection of parameters tailored to the individual insurance case, but also inevitably requires the availability of the necessary high-resolution, up-to-date data, which could be provided by the federal government (see profiles on parametric insurance and CRDCs).

The complex structure of cat bonds generates high transaction costs, which means that cat bonds only make economic sense above a certain minimum volume (Reitmeier et al. 2025) and makes access difficult for smaller municipalities and countries. Cat bonds issued by government agencies rather than insurance companies in particular require considerable expertise in areas such as disaster modelling, law and capital market transactions, which also makes it difficult to use this instrument and can be a problem, especially in municipalities with limited human resources (see Klimaschutz Kommune 2025).

Examples

International experience shows the potential for national and supranational applications. Since 2014, the World Bank has issued more than US$4.8 billion in cat bonds for member states through its Capital-at-Risk Notes programme (World Bank 2022). Countries such as Mexico, Jamaica and the Philippines are already successfully using cat bonds to hedge their budgets against natural disasters (Financial Protection Forum 2021).

The German cat bond market is in an early stage of development, but is already showing promising applications in the public sector. In 2024, Versicherungskammer Bayern (VKB), Germany's largest public insurer, issued a cat bond with a volume of EUR 175 million and a three-year term through its Irish special purpose vehicle "King Max Re DAC"(Konzern Versicherungskammer 2024). This demonstrated for the first time the feasibility of cat bonds for public insurers operating primarily in Germany. The King Max Re bond covers the four main natural hazards of storm, hail, flood and earthquake (Konzern Versicherungskammer 2024) and offers investors a risk premium of 5.4% (finanzen.net 2025). The trigger is set at EUR 900 million in damages, with an upper limit of EUR 1.1 billion EUR (Evans 2024).

Conclusion and outlook

Catastrophe bonds are increasingly establishing themselves as a relevant instrument for strengthening the fiscal resilience of public budgets against climate-related extreme events. The first German issues by Versicherungskammer Bayern and SV SparkassenVersicherung (Verband öffentlicher Versicherer 2025) successfully demonstrate their applicability for the German public sector and set important precedents for further issuers.

The strategic advantages of cat bonds – rapid provision of liquidity, risk diversification and planning security – address key challenges posed by climate-related budgetary risks. Support from European institutions and the World Bank creates favourable conditions for market expansion.

However, structural developments are necessary for successful implementation in Germany. The federal government should take on a coordinating role in standardising cat bond structures and promote regulatory clarification. The provision of validated climate data as a basis for parameters and the development of tax incentives could accelerate market development. Technological advances in climate modelling and digitalisation promise to reduce basis risk and transaction costs (Financial Times 2025).

The integration of cat bonds into comprehensive risk financing strategies, combined with parametric insurance and traditional instruments, can significantly strengthen the resilience of the German public sector to climate risks. Building the necessary capacity and expertise in public administrations is a crucial factor in this regard.

Further reading

- The World Bank (2022): **Building Sovereign Financial Resilience in Middle-Income Countries: Factsheet 5 (English)**. Washington, D.C. Available online at https://documents1.worldbank.org/curated/en/099050306222242278/pdf/P1637800d3753c0f60be4a03472b063ccf0.pdf

- Bucher, Florian (2025): **Insurance-Linked Securities: A Guide to ILS and Cat Bonds with a Focus on Germany**. Bundesverband Alternative Investments e.V. (BAI). Bonn. Available online at https://www.bvai.de/fileadmin/Veroeffentlichungen/BAI_Publikationen/Studien/BAI_ILS_2025_DE.pdf

7.3 Resilience bonds with a focus on prevention

Classification: new instrument/extension of an existing instrument?

Extension of a new instrument (catastrophe bonds)

Definition and basic principle

Resilience bonds with a focus on prevention are innovative financing instruments that represent a further development of conventional catastrophe bonds (cat bonds) and are specifically designed to finance proactive investments in climate-resilient infrastructure. Unlike traditional catastrophe bonds, which primarily serve as an insurance instrument for damage that has already occurred, resilience bonds combine risk transfer with preventive measures to avoid damage (Vaijhala and Rhodes 2018). The basic principle is based on monetising avoided losses through a so-called "resilience rebate" – a discount mechanism that quantifies the difference between expected losses with and without resilient infrastructure measures and uses it as a source of financing for preventive projects (Vajjhala and Rhodes 2019).

Resilience bonds as a financing instrument were developed in 2015 by the organisation re:focus to bridge the gap between limited public resources and the growing need for resilient infrastructure (Vajjhala and Rhodes 2019). Resilience bonds function as hybrid instruments that provide both disaster protection and project financing for prevention measures, thus pursuing a systemic approach to strengthening climate resilience (Sivaprasad et al. 2024).

How it works

Resilience bonds with a focus on prevention work on the basis of a two-stage financial model that combines traditional catastrophe bonds with infrastructure financing. First, the instrument is structured like a conventional catastrophe bond: a sponsor (typically a public institution) establishes a *special purpose vehicle* (SPV) that issues the bond. Investors receive regular interest payments and their capital back at the end of the agreed term, unless a predefined disaster event occurs (Vajjhala and Rhodes 2019 2019 ; see fact sheet on catastrophe bonds).

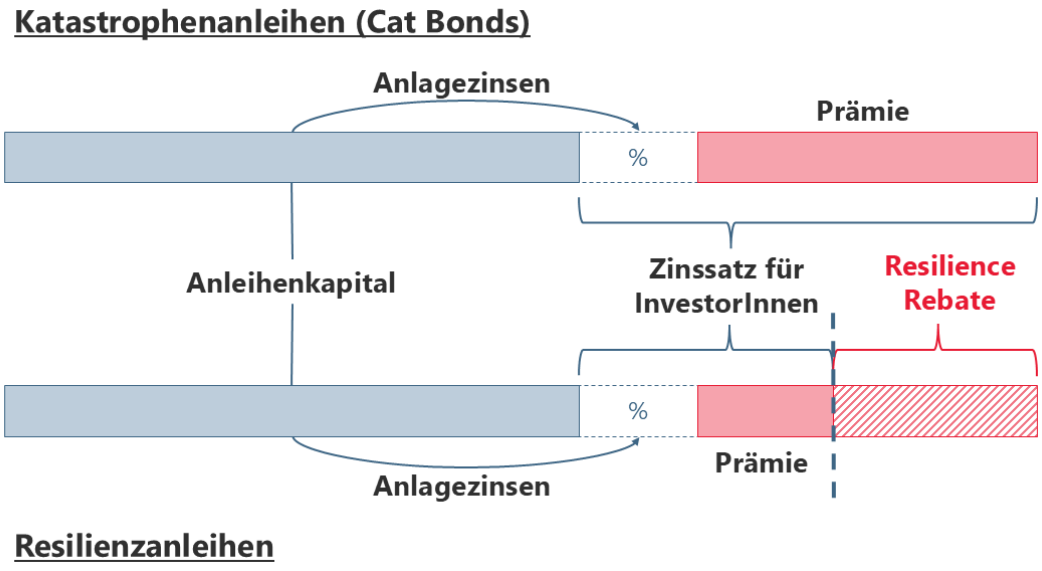

Figure 12: Structural comparison of catastrophe bonds and resilience bonds (not to scale)

The key difference lies in the integration of a "resilience rebate" structure (see Figure 12). Disaster modelling is used to calculate two scenarios: the expected losses under the baseline and the expected losses after implementing a resilient infrastructure measure. The difference between the two scenarios is recorded as the quantified benefit of the prevention measure (Vaijhala and Rhodes 2018). These avoided losses lead to a reduction in the insurance premium for the sponsor, resulting in lower interest rates being paid to investors; at the same time, however, the prevention measures also reduce the risk of a disaster occurring, which would mean the (partial) loss of the investment for investors. The difference in the premium amount is returned to the sponsor as a so-called resilience rebate and can be used to finance resilience-building infrastructure projects (Vajjhala and Rhodes 2019).

Payment is made in two stages: firstly, sponsors receive the resilience rebate to finance the project during the term of the bond; secondly, in the event of a disaster, a rapid payout is made for emergency and reconstruction measures (Vaijhala and Rhodes 2018). Trigger mechanisms can be structured parametrically (based on measurable parameters such as wind speed or earthquake magnitude) or damage-based (based on modelled losses)(World Bank 2022).

Advantages and areas of application

Resilience bonds with a focus on prevention offer several key advantages for the fiscal resilience of public budgets. A major advantage lies in the combination of preventive risk reduction and reactive disaster protection, which provides both ex-ante investments in resilient infrastructure and ex-post liquidity for emergency measures (Vajjhala and Rhodes 2019). This enables public institutions to plan their spending more strategically and reduce costs in the long term, as preventive measures are typically more cost-effective than reactive reconstruction measures (Larrain Bascunan et al. 2020). In the event of damage, they offer the same advantages as cat bonds: they provide funds very quickly (if implemented appropriately), create planning security and transfer part of the climate risks from the issuing households to the financial market (see fact sheet on catastrophe bonds).

These instruments significantly expand access to capital for climate adaptation measures by appealing to institutional investors who would not normally invest in traditional infrastructure projects (Sivaprasad et al. 2024). By connecting with capital markets, larger volumes of financing can be mobilised than would be possible through conventional public budgets or development banks alone (Financial Protection Forum 2021). The multi-year maturity of typical bonds (3-5 years) offers price stability and planning security for large-scale infrastructure projects (Motlagh et al. 2024).

At the municipal level, resilience bonds are particularly suitable for large infrastructure projects such as coastal protection measures, flood management or resilient transport systems. These instruments enable cities to reduce their dependence on government transfer payments and invest independently in preventive climate adaptation (Vaijhala and Rhodes 2018). At the country level, resilience bonds can enable the financing of regional structures and networks to strengthen resilience to climate impacts and coordination between different municipalities.

The federal government plays a central coordinating role in the implementation of resilience bonds. First, it is responsible for creating a regulatory framework that could provide tax incentives for investors (e.g. in the form of tax credits on capital invested in resilience bonds) and ensure legal certainty for the issuance of such instruments. The provision of standardised climate data and risk modelling tools is essential for calibrating the bonds and is primarily the responsibility of the federal government (see profiles on parametric insurance and catastrophe bonds). In addition, the federal government could act as a first guarantor or co-sponsor to strengthen capital market confidence in these new instruments and reduce transaction costs for downstream issues (see also the fact sheet on the state as the insurer of last resort). Pilot projects and the development of standardisation frameworks would accelerate market development and establish best practices.

Challenges and limitations

The implementation of resilience bonds with a focus on prevention faces several structural and technical challenges. A key limitation is the basis risk (Wagner 2018a), which is present here in two forms: on the one hand, a coverage gap may arise if the actual damage is greater than the underlying assumption of the amount of damage without adaptation measures; on the other hand, there may also be a discrepancy between the modelled losses avoided through adaptation measures and the actual damage prevention effects. Quantifying the resilience rebate requires precise disaster modelling, which is much more difficult to achieve for complex, systemic infrastructure projects such as green stormwater management systems or nature-based solutions than for clear-cut measures such as dykes or coastal protection structures (Vajjhala and Rhodes 2019).

High transaction costs represent another significant barrier. The development and issuance of resilience bonds requires extensive legal documentation, risk modelling by specialised agencies and the involvement of various financial market players. Transaction costs already represent a barrier to entry for catastrophe bonds (Reitmeier et al. 2025) ; the modelling component of resilience bonds increases this factor significantly. These high fixed costs make smaller projects uneconomical and favour large infrastructure projects, which could lead to smaller municipalities being disadvantaged. Similar to municipal K-CLOs (see profile), bundling, e.g. in municipal associations, would be conceivable here in order to exploit economies of scale and reduce transaction costs per municipality.

Coordinating the timing of infrastructure project cycles and capital market requirements is also proving to be complex. While catastrophe bonds typically have maturities of 3-5 years, resilient infrastructure projects can require development and construction times of up to a decade. This discrepancy makes it considerably more difficult to optimally structure the financing instruments and potentially limits their scope of application.

Another important limitation on the use of resilience bonds is the current lack of standardised assessment frameworks and taxonomies for resilience projects, which increases the modelling costs of individual projects while making it more difficult for investors to compare and evaluate them. The federal government could play a key role here in creating uniform standards and instruments.

Another key aspect, as with catastrophe bonds, is the incentive problem: as long as local authorities can count on unconditional assistance from the federal and state governments in the event of damage, they lack the economic pressure to take on the complex structuring and interest costs of resilience bonds – unlike private insurers, which benefit directly from risk transfers. Approaches to conditioning state aid, for example through mandatory proof of prevention or graduated subsidy rates, are conceivable in principle, but politically very complex. Positive incentives for local authorities to hedge their risks could be provided by the federal and state governments, for example in the form of subsidy bonus models, if local authorities finance a certain proportion of their climate adaptation investments through resilience bonds; surcharges on the premium rates to be paid by local authorities would also be possible.

Examples

Although resilience bonds were developed as a concept back in 2015, most concrete implementations are still in development or in pilot phases. re:focus partners have validated the framework and have been working with various partners from the insurance industry and capital markets since 2017 on the first market launch (Vaijhala and Rhodes 2018). The focus has so far been primarily on large public infrastructure projects in North America, particularly in climate-vulnerable cities such as San Francisco, Houston and Miami (Vaijhala and Rhodes 2018).

In the international development context, climate adaptation bonds were issued by the Asian Infrastructure Investment Bank (AIIB) in 2023, which have structural similarities to resilience bonds. The first issue of 500 million Australian dollars was specifically earmarked for projects in which at least 20% of the financing is used for climate adaptation (Asian Infrastructure Investment Bank 2023). The Asian Development Bank is pursuing a similar approach, issuing green bonds worth USD 132 million in 2019 to explicitly finance resilient infrastructure projects such as climate-adapted transport systems and flood protection measures (Qadir et al. 2021).

The European Bank for Reconstruction and Development (EBRD) has developed a structured approach to climate resilience bonds that encompasses three categories: climate-resilient infrastructure (water, energy, transport), climate-resilient business and commercial operations, and climate-resilient agriculture and ecological systems (European Bank for Reconstruction and Development 2019). Although these do not yet fully integrate the Resilience Rebate structure, they demonstrate the practical feasibility and willingness to implement adaptation-oriented bond instruments.

Conclusion and outlook

Resilience bonds with a focus on prevention address a key challenge in climate finance: closing the gap between limited public resources and the exponentially growing need for preventive climate adaptation (Mazzai 2024). By combining risk transfer and project financing, they create incentives for proactive investments in resilience, thereby overcoming the traditional problem that prevention measures are difficult to justify politically and financially, even though they are more cost-effective in the long term (Vaijhala and Rhodes 2018).The increasing frequency and intensity of climate-related extreme events is driving demand for instruments such as catastrophe and resilience bonds from both the public and private sectors (Mazzai 2024; Reitmeier 2024). Capital markets are showing growing interest in sustainable and climate-resilient investments (Colom 2025), which creates the basis for scaling up resilience bonds. Integration into the broader green bond market, which had already mobilised nearly USD 3 trillion by March 2025 (Demski et al. 2025), could promote additional liquidity and standardisation.

Technological advances in climate modelling, earth observation and data analysis may improve the accuracy of underlying risk modelling in the future, thereby reducing basis risk. Artificial intelligence and machine learning could, in particular, simplify the assessment of more complex, systemic resilience measures and expand the scope of application of the instruments (see also profiles on parametric insurance solutions and CRDCs).

However, successful market development requires coordinated efforts in standardisation, regulation and capacity building. It is essential to build expertise among both public issuers and investors. The development of internationally harmonised taxonomies for resilience investments could strengthen the comparability of and confidence in these instruments (Feiková 2025). Pilot projects and gradual expansion to different risk types and geographical regions will be crucial for the long-term establishment of resilience bonds as a standard instrument of climate finance.

Further reading

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- Qadir, Ujala; Pillay, Kamleshan; Creed, Anna; Boulle, Bridget; Tukiainen, Krista; Lala, Olumide et al. (2021): **Green Bonds for Climate Resilience. State of Play and Roadmap to Scale**. Edited by Global Centre on Adaptation. Climate Bonds Initiative. Available online at https://gca.org/wp-

content/uploads/2021/10/Green-Bonds-for-Climate-Resilience_State-of-Play-and-Roadmap-to-Scale.pdf

7.4 Climate-resilient debt clauses (CRDCs)

Classification: new instrument/extension of an existing instrument?

New instrument

Definition and basic principle

The occurrence of climate-related damage events can significantly limit public budgets' ability to meet existing debt servicing and credit obligations. Climate-resilient debt clauses (CRDCs) are an innovative financial instrument that can be integrated into debt agreements to enable a temporary suspension or deferral of principal and interest payments in the event of natural disasters or extreme weather events. The basic principle of CRDCs is based on *ex-ante* agreed conditions under which normal debt servicing can be interrupted. These clauses identify specific trigger events such as storms, floods, droughts or other climate-related events, upon the occurrence of which the agreed payment suspension is activated automatically or upon request (Cravero et al. 2025). The World Bank's CRDC product also covers public health emergencies, particularly pandemics and epidemics (Navarro-Martin 2024).

How it works

In order to implement CRDCs, appropriate clauses must be agreed and contractually stipulated when designing a debt instrument. In 2022, the International Capital Market Association (ICMA) published a standardised template for CRDCs, which was developed by a working group convened by the British government (Cravero et al. 2025). This ICMA term sheet specifies a number of characteristics for CRDCs (Cravero et al. 2025) :

- **Range of events covered**: a series of exogenous events (i.e. events beyond the control of authorities) with negative economic impacts on the borrower (e.g. earthquakes, tsunamis, droughts, floods and pandemics).
- **Triggers for CRDCs**: must be jointly determined in advance by both parties. A combination of parametric triggers that can be measured independently and proxy triggers (based on statements by relevant authorities or organisations) is conceivable; triggers must be reliable and verifiable in a timely manner, independently verifiable and not influenceable by either party[23].
- **Conditions for deferral of payment**: these primarily include the duration of the deferral; the number of permissible deferrals; clarification as to whether the deferral applies only to interest, to the principal to be repaid, or to both; and the repayment terms. A one-year deferral is set as the standard by the ICMA, with up to two years of deferral possible. Repayment can be deferred up to three times, taking into account the total term of the debt instrument. The deferred debt can be repaid using one of the following methods:
    - It is added to a so-called bullet loan ([24]) and repaid as a one-off payment with higher interest rates upon expiry;
    - They are added pro rata, i.e. proportionally to the remaining term, to future instalment payments;
    - They are repaid within up to three years after the trigger event, but within the original loan period.

[23] Further details on the necessary characteristics of parametric triggers can be found in the profile on parametric insurance solutions.

[24] In the case of a bullet loan, the entire loan amount is repaid at the end of the loan period without any instalment payments being made beforehand (Corporate Finance Institute 2024 2024).

If one of the covered events, e.g. a drought, occurs and triggers a specified trigger (e.g. precipitation falling below a threshold value or a state of emergency being declared by a competent authority as a result of a drought), the relevant debt instrument is deferred in accordance with the terms of the contract. The deferral can be extended according to specified criteria (e.g. prolonged drought). At the end of the deferral period, the deferred debt is repaid according to the specified terms; there is no debt forgiveness.

Advantages and areas of application

Unlike traditional *ex-post* debt restructuring procedures, CRDCs offer the advantage of a predefined, legally secure "breathing space" for the households concerned, which does not require time-consuming renegotiations but opens up financial leeway in a timely manner by releasing funds earmarked for debt repayment (Cravero et al. 2025). Activation is based on objectively measurable parameters or declarations by relevant authorities, which ensures legal certainty and rapid liquidity relief (Cravero et al. 2025). An important feature of CRDCs is what is known as net present value neutrality for creditors, as payments are merely deferred but not waived (Cravero et al. 2025) ; they therefore neither change the debtor's debt level nor generate a loss for the creditor. In the event of a disaster, CRDCs also help to reduce the default risk on other credit obligations, etc., thereby avoiding penalty fees and other follow-up costs (Cravero et al. 2025).

While CRDCs have so far been discussed primarily in international development contexts, their application in the German federal context would also be conceivable. For the practical integration of CRDCs, a clear distinction between market-financed debt and compensation payments is necessary. The former includes bonds and loans in which CRDC clauses can be directly embedded (see profiles on catastrophe bonds and resilience bonds). The latter concerns the existing federal transfer system (sales tax distribution, financial equalisation, federal supplementary grants, municipal financial equalisation; see Chapter 3.2), which could be supplemented by parametric adjustment mechanisms. In the event of damage, the deductions calculated on the basis of the previous year's economic performance of a donor country affected by a damaging event could be reduced or postponed from the sales tax distribution in order to create temporary financial leeway. In order to ensure full payment to the recipient countries, the federal government could pay funds into a climate compensation fund, which would act as a liquidity reserve to compensate for the difference resulting from a reduction in a donor country's VAT deduction. In subsequent years, the VAT deduction of the donor state in question would be slightly increased, thus offsetting the fund subsidy; in the long term and overall, the net burden on the donor state would remain neutral.

The integration of CRDCs into the German fiscal equalisation system would offer considerable advantages for the fiscal resilience of state and local government budgets. The most important advantage is the immediate liquidity relief after climate-related damage events. Affected states and municipalities could use the funds otherwise earmarked for debt servicing in bonds or similar instruments, or additionally provided in the fiscal equalisation system, directly for emergency measures, reconstruction and disaster relief. Past extreme weather events in Germany, such as the floods in North Rhine-Westphalia and Rhineland-Palatinate in 2021, have shown that rapid financial assistance is essential in dealing with immediate damage and supporting affected people and local authorities (Bundesministerium des Innern und für Heimat and Bundesministerium der Finanzen 2022).

CRDCs would also increase financial planning security for states and municipalities, as they provide *ex-ante* defined relief mechanisms. In contrast to ad hoc government aid, which is subject to political negotiation processes and is delayed (e.g. in the case of the 2021 floods; Bundesministerium des Innern und für Heimat and Bundesministerium der Finanzen 2022), CRDCs offer automated, legally enshrined support. This reduces uncertainties in budget planning and enables states and

municipalities to pursue longer-term investment strategies. In this sense, CRDCs as an instrument of damage financing can also make an indirect contribution to climate adaptation financing by increasing financial leeway for resilient reconstruction. The federal government would play a central coordinating role in the implementation of CRDCs. This includes the standardisation of trigger mechanisms, for example based on data from the German Weather Service and the Federal Office for Civil Protection and Disaster Assistance. The federal government could also provide the necessary technical infrastructure for data collection and processing and create a legal framework for the implementation of CRDCs in federal financial relations, similar to what the United Kingdom has done with the IMCA template for CRDCs (Cravero et al. 2025). Within this framework, the characteristics of the instrument could be tailored to the German context. In addition, the federal government could act as a reinsurer or guarantor for extreme damage cases (see profile on the state as the insurer of last resort), for example by guaranteeing the liquidity of the Climate Compensation Fund, which would thus ensure the stability of the financial equalisation system even in the event of parallel extreme events in several donor countries or supra-regional damage events.

Challenges and limitations

The use of parametric triggers requires that appropriate parameters be selected for the extreme weather events covered and that these be underpinned by spatially and temporally high-resolution, accurate, objective and up-to-date data (see fact sheet on parametric insurance solutions). Since CRDCs have so far been used primarily in the Global South and established parameters such as hurricane strength are not relevant in the German context, new indicators for the German context must be defined before CRDCs can be applied in Germany.

A structural problem with the application of CRDCs in the German federal system arises from the geographical distribution of climate-related risks in Germany (see for example Umweltbundesamt 2022b). Climate risks are unevenly distributed geographically, which could mean that certain states or municipalities would systematically benefit from CRDCs more often than others. It is also in the nature of the instrument that CRDCs can have their greatest impact on highly indebted households, while economically better-off households have less need for the additional financial leeway that CRDCs can create. This could exacerbate existing conflicts between donor and recipient households in fiscal equalisation. Furthermore, embedding CRDCs in existing structures would further increase the already high complexity of the federal financial system.

Conclusion and outlook

Climate-resilient debt clauses are an innovative instrument for strengthening fiscal resilience against climate-related financial risks. Their implementation in the German fiscal equalisation system would be an important building block for a climate-adapted federal financial architecture and would offer affected states and municipalities rapid, predictable relief in times of crisis.

Embedding CRDCs in the German fiscal equalisation system would be a highly complex political undertaking, involving not only the establishment of a climate equalisation fund but also adjustments to the entire fiscal equalisation architecture. Against this backdrop, it would be conceivable to initially integrate CRDCs into selected new federal climate financing instruments or to implement voluntary pilot projects with states or municipalities.

In the long term, CRDCs could become part of a more comprehensive reform of federal financial relations that also integrates other innovative instruments such as cat bonds (see fact sheet). The growing experience of international organisations with CRDCs, in particular the World Bank (Navarro-Martin 2024) and regional development banks (Cravero et al. 2025), offers valuable insights for implementation in Germany.

Further reading

- Cravero, Maura; Gonzalez Esquinca, Karla D.; Peres, Taarika (2025): **Climate-resilient debt clauses: a primer for FiCS members**. Climate Policy Initiative. Available online at https://www.climatepolicyinitiative.org/publication/climate-resilient-debt-clauses-a-primer-for-fics-members/

7.5 Expansion of local climate funds

Classification: new instrument/expansion of an existing instrument?

Expansion of an existing instrument: Municipal climate funds, which have so far mainly supported projects to reduce emissions, will be expanded to finance climate adaptation measures. This will establish climate adaptation as an equal goal alongside climate protection and strengthen local resilience to climate impacts.

Definition and basic principle

The expansion of local climate funds means that existing funds at the municipal level will in future support not only climate protection projects but also adaptation measures. Projects that reduce local risks from climate change – such as sponge city concepts, greening, early warning systems or renaturation – are eligible for funding. The aim is to increase the scope for municipalities to pursue forward-looking climate policies and to motivate more actors to participate actively.

A climate fund mobilises resources that can be used to implement specific climate projects locally. This instrument gives local stakeholders such as foundations, associations, companies and residents the opportunity to participate by making a financial contribution or launching their own projects. So far, this financing instrument has primarily aimed to tap into and provide new funds for local climate protection. There is great potential here to also anchor the issue of climate adaptation and thus finance and implement local adaptation projects.

Various funds from the public and private sectors can be used to finance a climate fund. Voluntary contributions from the business community, companies, foundations and private individuals make up a significant proportion of this.

How it works

The main function of a local climate fund is to finance projects that contribute to the municipality's ongoing measures to reduce emissions or adapt to climate change and that are implemented directly on site.

Within the framework of their self-government guarantee, local authorities can set up climate funds and finance them from general budgetary resources. The majority of existing climate funds are financed – at least in part – from local authorities' own resources. This means that local authorities allocate funds (on a one-off or annual basis) from their budgets to the climate fund, which uses them to support local projects. These funds are earmarked for a specific purpose and are approved via the local authority budget.

The funds of local climate funds come from a mixture of public and private sources. In addition to municipal budget funds and contributions from municipal companies, voluntary donations from citizens, companies and foundations are particularly important. Revenue from accommodation taxes, concession fees or compensation payments can also be contributed (Keusen et al. 2022).

Locally formulated funding guidelines can be used to define thematic priorities, such as greening buildings, unsealing surfaces or heat protection. Specific target groups can also be identified, such as social institutions, schools or non-profit organisations. Municipal mandatory tasks or profit-oriented projects are excluded from funding by local climate funds.

The fund may be administered by the local government, a municipal enterprise or an association. Most climate funds are managed by the administration, which facilitates the use of existing structures and

expertise. It is crucial that the fund's sphere of influence remains limited to the municipal area. Inter-municipal funds jointly supported by several municipalities are also possible. In these cases, too, it should be ensured that funding is used exclusively for projects in the region, i.e. within the joint area of activity. Alternatively, an association can act as the sponsor, which can increase acceptance, especially in the case of established organisations (Altenburg and Sommer 2022; Keusen and Radic-Capuani 2024).

Advantages and areas of application

Expanding local climate funds to include support for adaptation measures brings numerous advantages and opens up a wide range of applications. First, such a fund strengthens the capacity of local authorities to take action by providing additional funding for projects that specifically address local climate change challenges. By involving different stakeholders – from citizens and businesses to associations and foundations – it not only broadens the financial base, but also promotes social engagement in climate adaptation and climate protection. The participatory nature of the instrument ensures that climate protection and adaptation are perceived as a collective task, which strengthens the sense of self-efficacy and belonging within the community.

A local climate fund makes it possible to implement projects that have an immediate impact on the local area and improve the quality of life of the population, for example through the greening of roofs and facades, the expansion of early warning systems or the renaturation of areas. The visibility and tangibility of these measures help to increase acceptance of climate adaptation and raise awareness of the challenges of climate change. In addition, the local economy, tourism and community life also benefit from the funded projects, as these are often linked to regional value chains. Integration into existing local government structures also enables relatively uncomplicated and rapid implementation, so that the fund can have a quick impact and be adapted to new challenges as needed.

Challenges and limitations

A key hurdle is that structurally weak municipalities in particular often have limited budgetary resources, which makes it difficult to provide own funds for the fund. In such cases, financing may depend heavily on donations and voluntary contributions, which in turn are subject to economic fluctuations and therefore do not provide a reliable basis for planning. This can mean that the fund's funding opportunities are not available to the same extent every year, making long-term project funding difficult (Keusen et al. 2022).

In addition, the successful implementation of a local climate fund requires a clear legal and organisational structure. It must be ensured that the fund's sphere of influence remains limited to the municipal area and that the funding criteria are defined in a transparent and comprehensible manner. The inclusion of new areas of responsibility such as climate adaptation can also mean additional administrative work, especially if the local authority is responsible for the fund and the necessary human resources have to be provided. Finally, the effectiveness of the instrument depends largely on strategic funding planning and continuous public relations work. Without a long-term perspective and continuous commitment ( ), there is a risk that the fund will not be able to fully develop its impact and will lose the trust of local actors.

Examples

There are already numerous examples of local climate funds in Germany. Two examples are described below:

- **Göttingen Climate Fund**:
  This fund specifically promotes not only traditional climate protection measures, but also projects aimed at adapting to the consequences of climate change. Particularly noteworthy is the "Water and Greening" funding module, which helps Göttingen citizens to better prepare their buildings and properties for heavy rainfall and heat waves. Eligible measures include the installation of upstands and speed bumps to protect against flooding, the installation of pressure-tight doors and the construction of cisterns for rainwater harvesting. In addition, greening measures such as the unsealing of surfaces and the planting of roofs and facades are financially supported in order to improve the urban climate and mitigate the effects of heat(Stadt Göttingen o. J.).

- **Climate Fund of the Nuremberg Metropolitan Region**:
  The Climate Fund of the Nuremberg Metropolitan Region is a practical example of a participatory and transparent approach to financing climate protection and sustainability projects at the regional level. The fund is financed by a broad mix of different sources: in addition to membership fees, third-party funds such as subsidies, as well as voluntary payments and donations from private individuals, companies and local authorities, contribute significantly to the provision of funds. This diversified financing model makes it possible to actively involve both the regional economy and civil society in the design and implementation of climate protection and adaptation measures. Transparent reporting on the use of funds also ensures a high degree of traceability and trust among all parties involved(Metropolregion Nürnberg o. J.) .

Conclusion and outlook

In recent years, local climate funds have established themselves as an effective instrument for local climate projects. They make it possible to respond specifically to local needs and challenges and to actively involve the local population and businesses in the financing and implementation of climate protection and adaptation measures. The combination of public, private and civil society funding mobilises additional resources that go beyond traditional budgetary approaches. In future, climate funds could serve even more as a platform for innovation and social cohesion by involving new actors, using digital participation formats and creating targeted synergies with other support programmes. In this way, they not only contribute to achieving climate neutrality and adaptation, but also strengthen democratic participation and the future viability of local authorities.

7.6 Resilience assessment of infrastructure investments

Classification: new instrument/extension of an existing instrument?

The mandatory resilience assessment for infrastructure investments is a new instrument that has not yet been established in this systematic and comprehensive form in the German planning and funding context. It goes well beyond established procedures by prescribing the binding and verifiable integration of climate adaptation and resilience in all phases of public investment, thus creating an innovative basis for climate-proof and future-proof infrastructure.

Definition and basic principle

Climate change is already affecting long-lasting infrastructure such as bridges, railway lines and power stations, and these effects are likely to increase in the future. They therefore require special planning. Future climate developments should also be taken into account in construction methods, for example for railway tracks, rather than past values. It is therefore essential to clearly identify and specifically promote climate-resilient and climate-friendly infrastructure (DG REGIO 2025).

A resilience assessment is not a financing instrument in the strict sense, but rather a tool that aims to systematically integrate climate adaptation into the breadth of public infrastructure investments. This should result in public funds being geared more strongly towards climate adaptation requirements from the outset, ultimately leading to an increase in investments in climate adaptation and climate-adapted infrastructure projects.

The resilience assessment evaluates the extent to which planned or existing infrastructure projects are resilient to the effects of climate change. The aim is to identify and assess climate risks at an early stage in the planning process and to minimise them through appropriate adaptation measures. The approach is based on European standards such as the European Commission's Climate Resilience Check (European Commission: Directorate-General for Climate Action 2021), but should be tailored to the specific requirements in Germany. In this way, resilience is integrated not only into explicit climate adaptation projects, but into all public investments, reducing long-term damage from extreme weather events or creeping changes. Mandatory, verifiable documentation of each step of the resilience assessment creates transparency and traceability for funding and approval authorities and plays a crucial role in justifying investment decisions (DG REGIO 2025).

How it works

As part of the resilience assessment, project promoters carry out a climate risk and vulnerability analysis under the supervision of the competent authorities. This involves a two-stage process: a screening (preliminary assessment) and an in-depth analysis. The first stage involves an initial assessment, in which an initial climate check is carried out to identify climatic stressors (e.g. heat, heavy rain, flooding) and a decision is made as to whether an in-depth analysis is necessary. The second stage then involves a more detailed risk and vulnerability analysis to assess the exposure and sensitivity of the infrastructure and to develop and evaluate adaptation options. The results are documented and serve as a basis for the selection, planning and implementation of measures that reduce the residual risk to an acceptable level. The definition of an "acceptable level of risk" depends on the level of risk that the project sponsor is willing to accept. For example, there may be project components that are classified as non-essential infrastructure, where the costs of adaptation measures exceed the benefits of risk avoidance. In such cases, it may be reasonable to accept the failure of non-essential infrastructure under certain circumstances. Compliance with the resilience assessment is checked by approval authorities and is to be made a prerequisite for funding by funding bodies (European Commission: Directorate-General for Climate Action 2021).

Advantages and areas of application

The resilience test helps public contracting authorities to make investments future-proof and sustainable. It helps to avoid bad investments and increase the service life and functionality of infrastructure. Economically, it can therefore lead to a reduction in future damage and repair costs. The tool is particularly relevant for long-term large-scale infrastructure projects, which are generally durable and will be exposed to a changing climate, increasingly accompanied by extreme weather events, for many years to come (European Commission: Directorate-General for Climate Action 2021).

Infrastructure investments in Germany will play a significant role in the coming years, particularly in light of the planned special fund for infrastructure and climate neutrality. With the special fund pursuant to Article 143h of the German Basic Law, the German government is providing up to EUR 500 billion until 2045 for key future projects, particularly in the areas of transport, energy, digitalisation and climate protection. This year, EUR 37.2 billion is already earmarked for expenditure. According to the special fund's economic plan, a further EUR 84.8 billion is to be committed as commitment appropriations for the coming financial years (Deutscher Bundestag 2025b).

In the context of the special fund in particular, it is therefore essential that the allocation of funds and the associated investment decisions consistently promote the climate resilience of infrastructure projects. Given the enormous sums involved and the long-term impact of the projects being funded, there is a risk that, without systematic consideration of climate risks and vulnerabilities, new infrastructure will be created that will no longer be able to cope with the challenges of climate change in just a few decades. Mandatory resilience testing ensures that risks such as extreme weather, flooding or heat are identified at an early stage and taken into account in planning. This ensures that public investments not only address short-term needs, but also enable sustainable, safe and economical operation in the long term. The resilience assessment thus contributes significantly to maximising the impact of the special fund and driving forward the transformation to a sustainable, resilient infrastructure in Germany.

The sectoral fields of application for this instrument are also diverse: In addition to the transport sector, where there is an investment backlog of EUR 48.3 billion (2024) in municipal road and transport networks alone (KfW Research 2025a), resilience assessments should also be applied in the energy sector, the water sector and municipal services (e.g. schools).

Challenges and limitations

Key challenges include the availability and quality of climate data and the uncertainties involved in modelling future developments. In addition, the relevant authorities need to build up expertise, as in many places there is a lack of knowledge about how to properly implement resilience assessments. This requires extensive training and further education measures. At the same time, there is a shortage of human resources needed to carry out and monitor the assessments, which are already in short supply.

Another key obstacle is the lack of clear legal guidelines and the fact that resilience assessments have not yet been sufficiently integrated into procurement and planning processes. Introducing such assessments also leads to increased bureaucracy and prolongs the duration of approval processes. At a time when there is a strong political demand for less bureaucracy and faster procedures, considerable resistance to the practical implementation of mandatory resilience assessments is to be expected. The question also arises as to whether and to what extent the requirements for resilience assessments should be standardised, e.g. for dealing with residual risks. For public infrastructure projects, it would be necessary to define clear and uniform specifications in the form of appropriate standards and guidelines for the requirements of a resilience assessment.

Examples

One example of such a resilience assessment is the European Commission's Climate Resilience Check, mentioned above. It sets out a procedure for ensuring that climate considerations are taken into account throughout future investments and the development of infrastructure projects. This enables various EU funds such as InvestEU, the European Regional Development Fund (ERDF), the Cohesion Fund (KF) and the Just Transition Fund (JTF), as well as private investors, to make informed decisions about projects (DG REGIO 2025).

According to Article 73(2)(j) of Regulation (EU) 2021/1060, infrastructure investments supported by the ERDF with an expected lifetime of at least five years must be climate-resilient. If a project is classified as such infrastructure under ERDF funding, a climate resilience assessment is carried out. The climate compatibility assessment consists of two pillars (climate neutrality and climate resilience) and begins with a self-assessment by the applicants. For this purpose, an Excel tool for assessing climate compatibility is used, which must be completed in full and submitted to the responsible bank (Leipe et al. 2024; Ramboll Deutschland GmbH 2024).

Conclusion and outlook

The resilience assessment could be a key instrument for ensuring the long-term viability and sustainability of public infrastructure investments in times of climate change. It enables climate risks to be identified at an early stage and minimised in a targeted manner, thereby avoiding misguided investments and subsequent damage. Even though its introduction and implementation are associated with challenges such as increased costs, a lack of legal requirements and the need for capacity building, the long-term benefits outweigh these disadvantages. In the coming years, resilience assessment is expected to become even more relevant due to the importance of major investment programmes such as the "Infrastructure and Climate Neutrality" special fund. It will be crucial to design the instrument in a practical manner, build up expertise and make the processes efficient in order to meet both the requirements of climate adaptation and the need for rapid, effective investment. In this way, resilience assessment can make a significant contribution to the transformation towards a sustainable, resilient infrastructure in Germany.

7.7 Integration of climate protection and climate adaptation into horizontal fiscal equalisation

Classification: new instrument/extension of an existing instrument?

This is an extension of an existing instrument, as the horizontal fiscal equalisation instrument already exists and is being supplemented here.

Definition and basic principle

The integration of climate protection and adaptation into horizontal fiscal equalisation represents an innovative further development of existing fiscal equalisation mechanisms, in which climate-related factors are systematically included in the redistribution of public funds between local authorities of equal rank. Horizontal fiscal equalisation basically serves to balance out differences in financial strength between states and between municipalities (within the respective federal state) in order to ensure that tasks are performed appropriately (Bundesministerium der Finanzen 2025a). The integration of climate-related elements extends this principle to take into account climate protection and adaptation needs as a new dimension of needs-based fairness.

The basic principle is based on the recognition that climate protection and climate adaptation, as tasks for society as a whole, have different effects on local authorities, creating both additional (financing) requirements and financing burdens (Döring et al. 2024). While traditional financial equalisation operates on the basis of horizontal equalisation between the federal states based on financial strength and equalisation indices (Scherf 2023) and municipal financial equalisation is based in principle on tax revenue and a fictitious/calculated financing requirement, a climate-oriented expansion would introduce additional parameters for the assessment of climate change-related services and requirements. These could include:

- Different adaptation needs due to (unavoidable) climate risks, such as coastal protection in northern Germany or heavy rain prevention on slopes. These needs do not correlate with population figures, on the basis of which the existing equalisation is calculated (see Chapter 3.2), and would therefore have to be recorded separately.
- Compensation for special adaptation measures when a municipality (or federal state) takes measures that also benefit surrounding local authorities, such as natural flood protection of a riverbed that effectively protects several municipalities.
- Compensation for climate protection contributions that benefit society as a whole, such as emission-reducing projects by a municipality that have positive effects beyond the region. The scope of the impact would imply federal government participation in the financing. An alternative would be to set up a separate "climate resource pool" within the horizontal financial equalisation system, from which funds would be made available specifically for climate protection and adaptation-related projects.

The climate impact approach discussed in North Rhine-Westphalia for municipal fiscal equalisation pursues a results-oriented approach in which CO_2 savings are used as a uniform impact measure for automatic payments (Döring et al. 2024). This *results-based financing* approach could serve as a model for the operationalisation of climate-related transfers. In order to be able to evaluate adaptation measures uniformly in this context, the *Adaptation Benefits Mechanism* of the African Development Bank can serve as an international model, enabling a standardised evaluation of climate adaptation measures through the certification of measurable adaptation benefits(African Development Bank 2025).

How it works

Climate protection and adaptation can be integrated into horizontal fiscal equalisation through various mechanisms. A key component would be to expand the financial strength index to include climate adaptation needs resulting from varying vulnerability to climate risks (see Kahlenborn et al. 2021). Factors such as flood risk, heat risk or extreme weather events could be taken into account as additional needs indicators. At the same time, the tax capacity measurement could be modified to take into account climate protection and adaptation costs in order to compensate local authorities that suffer revenue losses as a result of ambitious climate policies, for example when areas are designated as protected areas and can no longer be used commercially, which reduces the municipality's tax revenue. This is in line with the concept of internalising opportunity costs, as already implemented in Portugal and France in ecological fiscal equalisation reforms (López-Laborda et al. 2023). However, since opportunity costs are difficult to calculate empirically and are considered "alien to the system" in conventional fiscal equalisation by, for example, Döring et al. (2024), a separate module would have to be created within the fiscal capacity index to reflect these effects in a transparent and comprehensible manner.

Another approach would be performance-based allocations based on actual climate protection or climate adaptation achievements. Suitable indicators could be selected on the basis of the "Orientation Framework for Effective Climate Protection Targets in Municipalities" published by the UBA (Wachter et al. 2024) and could include, for example, the reduction of municipal final energy demand, the expansion of local renewable energy production or the climate neutrality of municipal facilities. The climate impact approach from the North Rhine-Westphalian discussion offers a concrete model in which tonnes of CO_2equivalents saved serve as a uniform impact measure (Döring et al. 2024). Based on the African Development Bank's *Adaptation Benefits Mechanism*, criteria could also be developed to evaluate climate adaptation measures in an impact-based and standardised manner (see below) in order to compare the extent to which individual countries and municipalities have implemented appropriate adaptation measures and to reward them in the course of fiscal equalisation.

Advantages and areas of application

The integration of climate-related elements into horizontal fiscal equalisation offers considerable potential for all federal levels. At the municipal level, it would create reliable and predictable funding for climate protection and adaptation measures that goes beyond the temporary funding programmes that have been common practice to date (Döring et al. 2024). Municipalities that perform above average in terms of climate protection or adaptation would be compensated accordingly, creating incentives for ambitious climate policy (López-Laborda et al. 2023).

At the state level, this would have the advantage of systematically taking into account different climate needs and contributions in horizontal redistribution. States with high climate risks or special protection measures (such as forest conservation or moorland protection) would be given appropriate consideration (Droste et al. 2017).

The federal government would have to take on a central coordinating role in implementation. This includes developing uniform standards for the evaluation of climate measures, providing validated climate data and creating the legal framework. The federal government could also initiate pilot projects and promote the development of appropriate evaluation methodologies.

The instrument could be used particularly in areas where clear metrics are available, such as CO_2 savings in climate protection, land indicators in nature conservation and moorland protection, and vulnerability indicators in climate adaptation. International experience shows that indicators must be easy to monitor, collected uniformly, reliable and as stable and predictable as possible in order to avoid significant financial fluctuations on the recipient side (Busch et al. 2021).

Challenges and limitations

A major challenge lies in the fundamental conflict between the cross-cutting nature of climate protection/climate adaptation and the requirements of fiscal equalisation for clear, measurable indicators. Municipal fiscal equalisation is traditionally based on *ex-post* measurable, past-oriented data, whereas climate protection and climate adaptation are future-oriented and difficult to define (Döring et al. 2024). This problem requires innovative solutions.

Empirical needs assessment is another key challenge. Objective, scientifically sound indicators must be developed to ensure that climate-related factors are integrated in a manner that is constitutionally sound.

Legal hurdles also arise from the constitutional requirements for fiscal equalisation schemes. The Federal Constitutional Court requires appropriate and comprehensible justification for all redistribution factors (Gerhards et al. 2020).

Political feasibility is complicated by the complex interests of various local authorities. While some municipalities and states would benefit from climate-oriented redistribution, others would suffer fiscal disadvantages. This requires careful political consideration and possibly transitional arrangements.

An additional risk lies in the unconditional nature of fiscal equalisation transfers (López-Laborda et al. 2023) – taking climate protection and adaptation into account when allocating funds does not guarantee that the additional funds will actually be used for climate purposes, which could compromise the effectiveness of the instrument. To prevent misuse, allocations can be linked to specific performance or outcome targets, such as the submission of audited proof of use, compliance with climate protection and adaptation standards, or the documented achievement of specified milestones. In addition, earmarked funding pools and automated recovery mechanisms in the event of non-compliance with clear requirements offer greater legal certainty and transparency, ensuring that funds are actually used for climate protection and adaptation.

Examples

International models for integrating ecological factors into fiscal equalisation systems can already be found in various countries. Portugal and France have successfully integrated ecological elements into their municipal fiscal equalisation systems, taking forest protection and nature reserves into account as factors (López-Laborda et al. 2023). In Germany, too, the climate and forestry allowance in North Rhine-Westphalia is already an example of rewarding ecosystem services in municipal fiscal equalisation (Döring et al. 2024).

López-Laborda et al., (2023) calculated for the Basque Country for the years 2016-2019 that comprehensive integration of sustainability indicators into local fiscal equalisation systems would have resulted in less sustainable municipalities, especially cities, losing up to 5% of their per capita allocations, while small and particularly sustainable municipalities would have increased their per capita allocations by up to 13%.

In Germany, the climate impact approach proposed by Döring et al. (2024) is being discussed as an innovative alternative to conventional subsidy programmes. This would compensate municipalities based on actual CO_2 savings achieved and could be implemented through various fiscal equalisation channels (see above).

The *Adaptation Benefits Mechanism (ABM)* of the African Development Bank (2025) demonstrates how standardised assessments of climate adaptation measures can work. *Certified Adaptation Benefits* are issued based on measurable social, economic and environmental benefits and can serve as a model for

results-oriented climate finance. The criteria for certification include, for example, the following points:

- Transparency and traceability: The methodology must disclose how adaptation benefits are measured and verified.
- Measurability and verifiability: Adaptation successes must be substantiated with clear, quantifiable indicators wherever possible.
- Additionality: The measure must not be *business as usual*, but must go beyond legal requirements and common practice.
- Stakeholder participation: Affected groups and relevant actors must be involved.
- Social and environmental compatibility: Potential negative impacts must be assessed and minimised.
- Monitoring and reporting: Procedures for ongoing review and reporting must be put in place.

A clear example of this is the first project certified under the ABM, "Promoting the use of a solar-powered, climate-friendly cold storage system for storing seed and ware potatoes in Kenya" (Adaptation Benefit Mechanism 2022). In the Kenyan counties of Nakuru and Nyandarua, a total of 100 on-farm cold storage silos are to be installed in cooperation with GIZ, which will be operated by a solar PV system with green cooling technology (R290 refrigerant). At the same time, 180 members of local cooperatives will be trained in maintenance, quality assurance and data collection.

To quantify the adaptation benefits, a baseline scenario and an activity scenario (with adaptation measures implemented) were modelled. In the baseline scenario without cooling technology, an average of 29% of the 700 tonnes of stored potatoes are lost each year, leaving only 550 tonnes in good quality. In the activity scenario, the cooling system reduces losses to 5%, and 665 tonnes can be sold in good quality. This corresponds to a saving of 115 tonnes per year. Economically, this leads to a reduction in storage losses from an average of USD 28,296 per year in the baseline scenario to USD 6,615 per year in the activity scenario, which corresponds to a saving of USD 21,681 per year. For the project, it was determined that one adaptation benefit (AB) corresponds to one USD saved; thus, an annual profit of 21,681 ABs (325,217 over the project period) was recorded for the project. Every three months, independent auditors will collect sensor data and carry out manual spot checks; the results will be published in monitoring reports every six months.

Conclusion and outlook

The integration of climate protection and adaptation into horizontal fiscal equalisation is a promising instrument for systematically anchoring climate policy goals in the federal financial architecture. It offers the potential to create lasting incentives for ambitious climate policy that go beyond conventional support programmes, while taking into account different regional needs and performances.

However, successful implementation requires overcoming significant technical and political challenges. The development of robust assessment methodologies that meet both scientific requirements and constitutional standards is crucial. The participatory approach proposed for the further development of the climate impact approach could also be effective here .

In future, technical advances in data collection and analysis could lay the foundations for a more precise assessment of climate performance. The development of uniform standards at European level could enable additional synergies. The integration of climate-related factors into fiscal equalisation should be seen as a building block of a comprehensive reform of climate financing that intelligently combines various instruments.

Further reading

- Döring, Thomas; Gerhards, Eva; Thöne, Michael (2024): **Climate approach and multi-year tax capacity in municipal fiscal equalisation in North Rhine-Westphalia**. FiFo Report No. 34. Available online at https://www.fifo-koeln.org/images/aktuelles/2024/FiFo-Bericht_34_Klimaansatz-KFA.pdf

- African Development Bank (2025): **Adaptation Benefits Mechanism Guidebook**. Available online at https://main.abmechanism.com/download/336/publications/40872/abm-guidebook-2025.pdf

- López-Laborda, Julio; Montes-Nebreda, Andoni; Onrubia, Jorge (2023): **Going green through local fiscal equalisation**. Foundation for Applied Economic Studies (FEDEA). Available online at https://documentos.fedea.net/pubs/dt/2023/dt2023-07.pdf

7.8 Municipal Climate Collateralised Loan Obligations (K-CLOs)

Classification: new instrument/extension of an existing instrument?

K-CLOs can be classified as an innovative combination of existing securitisation instruments: formally, they resemble traditional *collateralised loan obligations* (CLOs), but are specifically structured for green or climate-related municipal investments. They thus represent a logical further development of both the green bond logic and the CLO approach.

Definition and basic principle

K-CLOs are structured financial instruments in which municipal climate loans are bundled and securitised. As with traditional *asset-backed securities* (ABS), similar loan receivables – e.g. for municipal investments in renewable energies or building renovations – are pooled. The receivables are transferred to a *special purpose vehicle* (SPV), which divides them into several tranches and issues them as securities to investors.

According to Di Filippo et al. 2021), there are two main forms of green securitisation: (1) transactions whose underlying assets – i.e. the loans – are directly "green", and (2) transactions in which the proceeds from the sale of securities flow exclusively into green projects. Both models are consistent with the *Green Bond Principles* (Di Filippo et al. 2021).

The European Banking Authority emphasises that green securitisation has great potential to support the financing of the transition to climate neutrality – especially for small-scale projects with standardised loans such as energy efficiency or PV systems(Europäische Bankenaufsichtsbehörde 2022). Similar structures could also become relevant for certain climate adaptation measures in the future, provided that corresponding loan portfolios – for example, for investments in climate-resilient infrastructure, sponge city concepts or coastal protection – can be made sufficiently standardised, scalable and economically viable.

Transactions are considered sustainable if both the underlying portfolio and the use of the funds are consistent with environmental objectives such as those of the EU taxonomy (Europäische Bankenaufsichtsbehörde 2022). According to Di Filippo et al. (2021), typical target areas for green securitisation are solar energy, energy-efficient buildings, sustainable mobility and climate-resilient infrastructure at the municipal level.

How it works

Municipal CLOs (K-CLOs) function like traditional structured finance by dividing the loan portfolio into senior, mezzanine and junior tranches. The senior tranche receives repayments first and is considered low risk; the junior or equity tranche carries the highest default risk but is compensated by higher returns (Di Filippo et al. 2021).

The mezzanine tranche is risky, but less so than the equity tranche – it is often only placed with the help of public guarantees, for example from national promotional banks or the EIB, in order to mobilise private capital for green projects (Europäische Bankenaufsichtsbehörde 2022; Di Filippo et al. 2021).

Securitisation is carried out via a legally independent special purpose vehicle (SPV), which takes out the loans, divides them into securities and forwards the cash flows from the loans to the investors (Climate Bonds Initiative 2018; Europäische Bankenaufsichtsbehörde 2022). The SPV enables the aggregation of small loans, e.g. from the municipal sector, into a tradable overall instrument. According

toClimate Bonds Initiative (2018), this is a crucial mechanism for attracting institutional investors to small-scale, low-threshold green projects that would otherwise have no access to the capital market.

Advantages and areas of application

K-CLOs can offer numerous advantages. By bundling even small individual loans, the financing of municipal climate investments – for example in renewable energies, thermal insulation or coastal protection – is becoming affordable on a large scale for the first time (Climate Bonds Initiative 2018). This gives institutional investors access to a standardised financial product that is linked to clearly defined environmental targets. It is particularly significant that K-CLOs create scope for further lending: as is customary with other asset-backed securities, securitisation transfers the credit and default risk proportionally to investors. This relieves the capital base of the originating bank or municipality and enables new lending – an effect that has been demonstrated, for example, in the US PACE sector (*Property Assessed Clean Energy* – a financing model in which building owners refinance investments in energy efficiency or climate adaptation through their property tax)(Di Filippo et al. 2021).

In addition, government guarantees can reduce financing costs and improve ratings. Public reinsurance, for example through national development banks or supraregional institutions, can facilitate placement, especially for risky tranches. Studies show that municipal consortia with state guarantees have access to more favourable terms (Climate Bonds Initiative 2018). For example, Nordic local government financing agencies (LGFAs) that had received national development mandates have so far issued around USD 9.5 billion in green bonds to finance local sustainability projects (Climate Bonds Initiative 2018).

At the federal level, the government could provide support, for example through central climate data services, standardised assessment frameworks (such as the EU taxonomy), tax incentives – such as withholding tax reductions for foreign investors on interest and coupon payments, temporary partial exemptions from capital gains tax for investors liable for tax in Germany, or investment allowances for institutional investors investing in K-CLOs for the first time – and regulatory clarifications. According to experts, pilot programmes and pool guarantees for municipal projects with fluctuating credit ratings could be particularly effective (Climate Bonds Initiative 2018). The areas of application for K-CLOs extend beyond traditional infrastructure measures (water, energy, mobility) to include social climate resilience and urban climate funds. Overall, K-CLOs open up an additional source of private financing for municipal climate protection – as a useful supplement to traditional instruments such as tax revenues or promotional loans.

Challenges and limitations

Despite their potential, K-CLOs are associated with considerable challenges. The market for green securitisation in Germany is still "underdeveloped", which is attributed to legal uncertainties, reputational risks and a lack of financial incentives, among other things. For example, there is currently no financial advantage over non-green securitisations – a so-called greenium – that would give issuers a measurable cost advantage when placing their securities (True Sale International and Bankenverband 2024; Di Filippo et al. 2021). As a result, issuers lack motivation to launch green securitisations. In addition, many existing transactions do not have an official green label, which leads to transparency problems and lower investor confidence (True Sale International and Bankenverband 2024).

Another problem is structural complexity: setting up a special purpose vehicle (SPV), tranching the securities, meeting rating requirements and complying with legal prospectus requirements are both time-consuming and costly (True Sale International and Bankenverband 2024).

In the municipal sector in particular, the question arises as to the availability of homogeneous loan portfolios and the incentive structure for banks. KfW emphasises that green municipal loans are often unattractive to banks at present because they involve low margins and high regulatory costs (Brand and Steinbrecher 2021).

Legally, K-CLOs are subject to general EU securitisation regulations – for example, with regard to risk retention, transparency requirements and possible prospectus obligations (Europäische Bankenaufsichtsbehörde 2022). In addition, a specific EU standard for green securitisation has not yet been developed (True Sale International and Bankenverband 2024). Finally, it must be ensured that the use of funds is actually consistent with climate adaptation goals. Otherwise, there is a high risk of greenwashing, which can significantly undermine the credibility of the instrument (Di Filippo et al. 2021).

Overall, the implementation of K-CLOs therefore requires a high degree of regulatory clarity, technical expertise and trust on the part of the actors involved.

Examples

Practical examples of K-CLOs in the narrow sense are still rare. Nevertheless, international pilot projects demonstrate their feasibility in principle. For example, the Inter-American Development Bank (IDB) is planning a multi-billion green loan CLO programme in collaboration with the World Bank to securitise sustainable corporate and infrastructure loans. At the same time, the World Bank has begun to launch its own structured financing products and has approved a new, investor-friendly CLO structure for mobilising private capital (Lewis 2025).

The World Bank Group and the International Finance Corporation (IFC) are also working on structured financing models such as green CLOs and synthetic securitisations to mobilise private capital for climate and energy projects in developing and emerging countries (Lewis 2025).

A concrete example from Germany is the green synthetic securitisation by Landesbank Baden-Württemberg (LBBW) in cooperation with the European Investment Bank (EIB) in autumn 2023. The EIB undertook to guarantee a mezzanine tranche of EUR 175 million, thereby relieving LBBW of regulatory constraints and enabling it to grant EUR 350 million in new loans for wind and solar energy projects. This transaction enabled the bank to build up a new loan portfolio focusing on climate protection and energy security projects (Europäische Investitionsbank 2023).

Although these examples currently mainly concern corporate or subsidised climate protection projects, they demonstrate the fundamental transferability of the CLO model to municipal contexts – including in the area of climate adaptation, provided that standardised loan portfolios and suitable framework conditions can be created. For example, structures could be envisaged for financing measures to combat heat, heavy rainfall or to improve the resilience of critical infrastructure, whose economic returns can be made transparent and investable.

Conclusion and outlook

Municipal climate CLOs are a promising instrument for mobilising private capital for municipal climate protection and adaptation. They allow numerous smaller climate projects – for example, in the areas of energy efficiency, sustainable mobility or water management – to be bundled into a structured collective vehicle. This creates an accessible, standardised product that can also be attractive to institutional investors with an ESG focus (Di Filippo et al. 2021).

Similar to green bonds, K-CLOs could thus help to close the "green gap" in public infrastructure financing. However, the practical implementation of such structures in Europe is still in its infancy. In

addition to suitable project portfolios, a successful market ramp-up requires binding standards for green securitisation (e.g. based on the EU taxonomy and the proposed green bond standards), tax incentives and targeted support from authorities (Europäische Bankenaufsichtsbehörde 2022).

Pilot projects are crucial to building confidence in the instrument. Analysts expect that with the increasing standardisation of ESG criteria – for example, in relation to impact reporting, transparency and use of proceeds – demand for green ABS products (including CLO structures) will also rise significantly (Di Filippo et al. 2021). Experience from North America and multilateral development banks already shows that securitisation can be an effective mechanism for transforming heterogeneous climate projects into marketable securities.

If Germany were to set up pilot projects – supported by a central data infrastructure, funding programmes and risk mitigation by the federal government – K-CLOs could play a key role in municipal climate financing in the coming years.

7.9 Parametric insurance

Classification: new instrument/extension of an existing instrument?

New instrument

Definition and basic principle

Parametric insurance is an innovative insurance solution in which policyholders and risk carriers agree on one or more parameters and a payout structure depending on whether certain thresholds are exceeded or not reached before the contract is concluded. Unlike traditional insurance policies, which are based on complex damage calculations, parametric insurance uses predefined parameters to determine the insured event and trigger the benefit(Marsh GmbH 2025). Parameters can cover a wide range of possible measurements: while so-called weather index insurance focuses purely on weather-related indicators (e.g. precipitation, temperature, wind speed), parametric insurance can include other objectively measurable indicators, such as earthquake magnitude, water levels or crop yield indices (Kovacevic 2024).

How it works

Parametric insurance is based on location-specific evaluations of defined parameters. If a contractually agreed threshold is exceeded or not reached, this trigger automatically results in the contractually agreed claim payment. The insurer settles the claim without proof of damage or assessment; only the sensor measurements triggering the coverage must be verified (Glinskis and Murphy 2025).

Advantages and areas of application

An important advantage of parametric insurance is the quick and uncomplicated settlement of claims, which can take place within a few days or weeks (Glinskis and Murphy 2025). This is particularly important for local authorities and federal states, which have to bear large financial expenses for emergency aid and repairs within a short period of time in the event of a disaster. It also reduces administrative costs and the effort involved in claims settlement processes, as there is no need to keep individual records of damage incurred (Glinskis and Murphy 2025).

Another advantage is the high adaptability of parametric insurance, as the selection of parameters, the setting of thresholds and the corresponding agreement on compensation can be tailored to the individual insurance claim (Marsh GmbH 2025).

Since all contract parameters are clearly defined in advance, parametric insurance is also transparent for all parties involved in terms of its effect and application. The use of publicly available data, such as weather data, also contributes to transparency compared to conventional insurance solutions (Glinskis and Murphy 2025).

Parametric insurance could close coverage gaps that exist in the context of conventional insurance solutions. For example, so-called non-damage business interruptions can be insured, which are not due to property damage but, for example, to supply chain interruptions or official instructions (Pollak 2024). While traditional insurance policies usually require prior property damage as a prerequisite for payment, parametric insurance is based on the agreed threshold being reached. Policyholders are free to use the funds distributed, which allows for greater fiscal leeway and compensation not only for direct damage but also for consequential damage. This flexibility in the provision of aid is cited as a major advantage in international contexts (Kinderhilfswerk der Vereinten Nationen 2024).

Parametric insurance was originally developed to insure regions of the world against environmental and climate damage that were previously underinsured because, for example, they did not have accurate valuations of their insurable assets or were difficult for loss adjusters to access (Sowers and Michel 2022). The deliberately low threshold of the instrument can also help in German contexts to compensate for existing differences between municipalities and states in terms of data availability, accessibility and economic conditions, which would be significant in traditional insurance solutions.

In this context, the federal government would play a leading role in coordinating and standardising parametric insurance solutions for climate impacts. In particular, the central provision of validated climate data and other relevant data is essential for the use of this instrument (see below). The federal government would also be primarily responsible for designing a regulatory framework that could, for example, provide tax incentives for the use of parametric insurance and thus reduce the fiscal risks for the public sector. For example, reduced insurance tax rates (around 5% instead of the regular 19%) could apply to municipal policyholders. In addition, the federal government could initiate pilot projects for implementation, such as regional parametric insurance pools based on the natural disaster damage pool of public insurers (Verband öffentlicher Versicherer 2022). Within the framework of coordination between the federal levels, the federal government has another important fundamental responsibility in the context of climate financing.

Challenges and limitations

The use of parameter thresholds as triggers for insurance payments fundamentally carries the risk that, if the threshold is narrowly missed, any damage that may occur will not be covered by the insurance (Glinskis and Murphy 2025). To counter this risk, it may be advisable to use parametric insurance in conjunction with traditional insurance, which still allows for payouts in such cases on the basis of a damage assessment.

The effectiveness of parametric insurance as protection against climate damage also depends on whether the agreed sum insured is in reasonable proportion to the actual costs of the damage incurred (known as basis risk). Parametric insurance is modelled against the expected consequences of a specific environmental risk, so that an inappropriate selection of parameters can result in the insurance sum paid out not adequately covering the actual damage incurred (Broberg 2020). In order to ensure meaningful insurance cover, it is therefore essential to select appropriate parameters and to be aware of the possible consequences of exceeding them. A suitable parameter should be publicly available to both parties, objective and not subject to influence by either party; in addition, sufficient historical data should be available to assess the risks associated with the respective parameter (Marsh GmbH 2025).

The basis for selecting meaningful parameters is the availability of the relevant data. In a survey conducted by the industry portal Reinsurance News, the industry experts questioned identified this as a major obstacle to the wider use of parametric insurance (HZ Insurance 2024). The data must be continuously updated and supplemented with new research findings. In order to reflect the consequences of climate change, it is not enough to rely solely on historical data – the use of advanced modelling tools is also essential in order to be able to accurately assess future developments. This point is also currently considered by experts to be an obstacle to the implementation of parametric insurance, as is a lack of knowledge about parametric insurance among both professionals and consumers (HZ Insurance 2024; Kreft et al. 2022).

In the German context, there is also the question of the interaction between parametric insurance and existing state aid mechanisms. As already mentioned in the fact sheet on resilience bonds, local authorities often lack the economic incentive to cover their own risks as long as unconditional support is provided by the federal and state governments. If parametric insurance were simply to replace

public recourse funds, there would be little incentive to take out parametric insurance, which involves ongoing premium payments. To overcome these obstacles, government aid could be linked to co-payments and the purchase of parametric insurance. Possible instruments could include:

- Mandatory proof of municipal prevention measures or co-payments when claiming public funds.
- Graduated subsidy rates linked to a minimum proportion of parametric cover.
- Bonus models for subsidies, such as increased grants if local authorities cover a defined proportion of their climate adaptation investments through parametric products.
- Surcharges or discounts on premium rates depending on prevention standards and parameter ratings.

Such conditioning of government support would address the incentive problem, strengthen municipal risk prevention and ultimately reduce the fiscal burden in the event of a disaster.

Examples

Parametric insurance is already being used internationally to insure countries in the Global South against the consequences of climate change. Since the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Climate Agreement ruled out legal liability of industrialised nations for climate damage, parametric insurance offers an approach to establishing economic protection without having to prove causality for the damage incurred(Horton 2018).

As part of UNICEF's Today and Tomorrow Initiative, a parametric insurance solution has been developed to reduce the protection gap for vulnerable children and young people against climate and disaster damage and to accelerate the provision of financial aid. It is based on the Child Cyclone Index (CCI), which maps the impact of high wind speeds on children at the national level. WTW (formerly Willis Towers Watson) monitors cyclone activity on behalf of UNICEF and compiles event reports that measure the CCI; when the specified threshold is reached, the insurance sum is paid out to the affected UNICEF country offices. Payment is made within 36 to 72 hours after the cyclone has left the area (Kinderhilfswerk der Vereinten Nationen 2024).

Conclusion and outlook

Parametric insurance solutions are an innovative and promising tool for strengthening the fiscal resilience of public budgets against the effects of climate change. They offer fast, transparent and flexible solutions for hedging climate-related risks that are difficult or impossible to cover with traditional insurance products. However, their use requires accurate, up-to-date data, the right choice of parameters and the use of modelling tools that are as accurate as possible for climate impacts. Parametric insurance is not usually a stand-alone solution, but should be used in conjunction with traditional insurance and other hedging measures (Kreft et al. 2022).

Parametric insurance is becoming an increasingly important market instrument (Glinskis and Murphy 2025), allowing experience to be gained in various contexts and reducing the potential risks for early adopters. In the future, technical advances (e.g. AI, machine learning) could increase the accuracy of the underlying parameters and help to align insurance coverage and claims amounts and further close existing coverage gaps (Sowers and Michel 2022).

Further reading

- Glinskis, Emmalina; Murphy, Daniel (2025): **How parametric insurance is building climate resilience**. World Economic Forum. Available online at https://www.weforum.org/stories/2025/01/what-is-parametric-insurance-and-how-is-it-building-climate-resilience/

- Kreft, Sönke; Sandholz, Simone; Bulut, Samet Sevket; Mirwald, Magdalena; Kohler, Dirk (2022): **Climate risk insurance: Potential as a strategic instrument for climate adaptation in Germany**. Published by the Federal Environment Agency (UBA). Dessau-Roßlau (Climate Change, 13/2022). Available online at https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/cc_13-2022_klimarisikoversicherung.pdf

7.10 Reformed federal supplementary grants with climate forecast factor

Classification: new instrument/extension of an existing instrument?

Federal supplementary grants (BEZ) are a key instrument of federal fiscal equalisation in Germany. They serve to provide additional support to financially weak states after the distribution of VAT shares (Art. 107 GG). Against the backdrop of increasing climate risks, the question arises as to whether the BEZ could be expanded to include a climate-related component. The aim would be to strengthen the fiscal resilience of the states to climate impacts and to incentivise preventive adaptation measures. International and academic discussions suggest that fiscal equalisation systems could in principle be suitable for taking climate and environmental policy objectives into account (Daniela Kletzan-Slamanig et al. 2023; Droste et al. 2017; OECD 2024).

Definition and basic principle

In 2023, the total volume of federal supplementary grants amounted to around EUR 10.2 billion, which was used to support twelve recipient countries (Bundesministerium der Finanzen 2024). The current system already includes various forms of support for financially weak states from the federal government, including general federal supplementary grants, special-needs BEZ and specific compensation payments, for example for structural unemployment or low municipal tax revenue (Bundesregierung 2023a).

The idea of reformed federal supplementary grants with a climate forecast factor is based on the fundamental principle that climate-related risks and their fiscal impact could be systematically integrated into the distribution of federal funds to the states. The climate forecast factor would serve as an additional component for determining the financial requirements of the states, taking into account both preventive climate adaptation measures and reactive damage management.

The instrument could be based on scientific findings. The climate forecast factor could take into account regional differences in climate exposure, vulnerability and adaptation capacity and translate these into a transparent distribution system. Central to the concept is the recognition that climate change is already having a significant impact on public budgets.

How it works

The reformed federal supplementary grants with a climate forecast factor (KPF) could be based on a three-part model approach that integrates both ex-ante forecast data and ex-post damage experience. This three-part approach is an independent proposal, but it builds on existing scientific work on climate risk and cost assessment (KWRA 2021; Flaute et al. 2022).

Climate risk component (KRK)

This component would be based on the scientific assessment of regionally differentiated climate risks. The results of the climate impact and risk analysis (KWRA) could be used as an initial basis. The analysis identifies key hazards such as heat, drought, heavy precipitation and flooding, as well as their geographical distribution, and assesses them qualitatively according to exposure, sensitivity and adaptation capacity. However, this qualitative classification is not sufficient for transfer to a fiscal equalisation system. It would need to be supplemented by quantitative data on probability of occurrence, damage levels and regional impacts ( ), for example through economic modelling as in Flaute et al. (2022) or through indicators from climate impact research.

Adaptation requirement component (ABK)

This component would not cover the risks themselves, but rather the financial expenditure required to counter these risks. While the KRK would describe the risk situation, the ABK would translate this into a concrete need for action and investment. This could be based on both already identified and prospective climate adaptation measures in the areas of infrastructure, land use, health and urban development. The DAS 2024 defines sector-specific impact targets for this purpose for the first time (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz 2024). The needs assessment could be based on standardised cost estimates derived from national and international comparative studies. According to a recent analysis by the Federal Environment Agency, climate-related federal expenditure in 2023 already amounted to around EUR 3.7 billion, with an increase to around EUR 5.4 billion in 2024 (Hölscher et al. 2025b). These figures illustrate the growing need for public funding in the area of climate adaptation.

Damage experience component (SEK)

This component would take into account historically recorded climate-related damage and thus reflect the actual regional burden. However, the introduction of such a component would only make sense in the context of a comprehensive reform of the existing compensation mechanisms (e.g. through a reorganisation of special funds or disaster relief). Otherwise, there would be a risk that higher damage in the past would automatically lead to higher allocations from federal funds – regardless of whether disaster relief had already been provided by the federal government or the community of states.

In addition to existing insured and uninsured damage data, a national extreme weather damage register maintained by the Federal Environment Agency could serve as a central data source in the future. This register was designed in 2024 on behalf of the UBA to systematically and continuously record and evaluate climate-related damage in Germany (Oberpriller et al. 2025).

According to a study commissioned by the BMWK, direct climate damage in Germany between 2000 and 2021 amounts to around EUR 145 billion, with over 55% of this damage occurring since 2018 (Flaute et al. 2022). Such data forms the basis for making the loss experience component transparent and comparable and for adequately reflecting long-term trends.

Calculation formula

The climate forecast factor could be calculated using the following basic formula:

$$\mathbf{KPF = \alpha \times KRK + \beta \times ABK + \gamma \times SEK}$$

Where:

- KPF = climate forecast factor
- KRK = Climate risk component
- ABK = adaptation requirement component
- SEK = Damage experience component
- α, β, γ = weighting factors (with $\alpha + \beta + \gamma = 1$)

An example weighting could be 40% for KRK, 35% for ABK and 25% for SEK. However, the weightings should be determined on the basis of scientific recommendations and political objectives.

Advantages and areas of application

- The reformed federal supplementary grants with a climate forecast factor could offer several significant advantages over the existing system and other financing approaches for climate adaptation. A key advantage of the climate forecast factor would be its potential preventive effect, provided that the calculation methodology takes into account the adaptation efforts of the federal states. Although high climate exposure would initially increase financial requirements and thus allocations, regional damage experience and vulnerability indicators could be reduced in the long term through successful adaptation measures. This would create an indirect incentive. States that invest early in climate adaptation and resilience can reduce their future damage exposure and vulnerability. Although this would reduce allocations from the loss experience component, it would also reduce the fiscal burden on the countries themselves.
- This development is visible in rolling calculations of the climate forecast factor and can lead to more stable, predictable allocations instead of relying on short-term increases in damage compensation.

This would be in line with the economic assumption that preventive measures are more efficient in the long term than dealing with climate-related damage after the fact. In this way, the climate forecast factor could combine risk orientation with a medium to long-term incentive for prevention, as countries develop a financial interest in reducing their vulnerability. Setting the climate forecast factor for several years would also contribute to greater planning security for countries and municipalities. Since many climate adaptation measures require long-term investment and implementation horizons – particularly in the areas of infrastructure, urban development and health – a reliable and predictable financing basis is needed. Studies show that uncertainties about funding periods and the availability of funds are currently key obstacles to effective adaptation (Flaute et al. 2022; Döring et al. 2024).

The introduction of a climate forecast factor could enable risk-adequate funding allocation by taking into account regional differences in climate exposure, vulnerability and adaptation capacity. In contrast to traditional project-based funding instruments, the concept of indicator-based, objective funding allocation would offer considerable efficiency gains. By eliminating time-consuming application and review procedures, resources could be deployed in a more targeted and timely manner. According to Flaute et al. (2022), many municipalities would like to see less project-based and more flat-rate, structural funding approaches, as these allow for more flexible and needs-based use of funds.

The reformed federal supplementary grants with climate forecast factor could be applied at all federal levels: the federal government would assume the role of financier, standard-setter and data provider. The development of the climate forecast factor, the provision of scientific data (e.g. KWRA, climate damage database) and the monitoring of success would fall within its remit. At the same time, the study by *Flaute et al. (2022)* makes it clear that the quantification of climate damage and adaptation costs is subject to considerable uncertainty. If such a factor is to be integrated into a financial equalisation system, a uniform nationwide data basis and assessment standards are therefore required – a further indication that the federal government would have to assume central responsibility for data provision and methodological harmonisation. The federal states would be the primary recipients of the funds and would use them in accordance with their specific climate exposures and adaptation requirements. At the same time, they would be responsible for coordinating with local authorities and monitoring the implementation of regional climate adaptation strategies. Local authorities would be primarily responsible for the concrete implementation of adaptation measures. The German Association of Towns and Municipalities estimated the annual municipal investment requirement for climate adaptation and protection to be at least EUR 8 billion (DSTGB, cited in Flaute et al. 2022). The federal supplementary grants could help to close this funding gap.

Challenges and limitations

The introduction of reformed federal supplementary grants with a climate forecast factor would entail a number of institutional, technical and legal challenges that would need to be carefully addressed. A key challenge is the limited availability of high-quality, regionally differentiated data on climate risks, adaptation needs and damage experiences. Uninsured damage in particular is often inadequately documented, even though it has been shown to account for a significant proportion of total damage (Flaute et al. 2022; Kahlenborn et al. 2021). In addition, data quality varies considerably between federal states, particularly with regard to small-scale vulnerability indicators and municipal adaptation capacity. At the same time, there are considerable uncertainties in climate projections. The climate science basis is subject to high model and scenario uncertainties, which affect the forecasting of future damage. Scenario analyses show, for example, a range of expected climate-related costs of EUR 280 to 900 billion by 2050 (Flaute et al. 2022). These uncertainties affect the precision and reliability of the calculation models for the distribution of funds.

Another challenge is the question of attributing damage caused by extreme weather and determining the extent to which it is caused by climate change. This causal attribution of climate-related damage poses a methodological problem. Not all extreme weather events can be clearly attributed to anthropogenic climate change (Kahlenborn et al. 2021). Damage is often caused by multiple factors, which makes it difficult to objectify and legitimise compensation mechanisms.

Another potential risk is a moral hazard effect, whereby individual countries rely on federal funds and thus make fewer investments of their own in climate protection. This could lead to inefficient use of resources. In addition, the complexity of the instrument would require considerable administrative resources for its technical implementation. The combination of several types of data (forecasts, exposure indicators, damage data), the development of a transparent calculation model and coordination between the federal government, the states and local authorities require a high degree of standardisation and institutional capacity. The instrument could entail long-term financing risks. Rising damage costs due to increasing extreme weather events could lead to a significant increase in the federal government's funding requirements. Without appropriate budgetary control, this could lead to crowding-out effects in other policy areas or jeopardise the sustainability of the federal budget (Flaute et al. 2022; Bräuer et al. 2009).

The introduction of a climate forecast factor in the distribution of federal supplementary grants would require an amendment to the Fiscal Equalisation Act. In addition, the constitutionality of differentiated funding allocation based on climate-related criteria could be subject to judicial review. Article 107(2) of the German Basic Law does not currently provide for the consideration of ecological criteria. The explicit anchoring of the climate adaptation dimension would therefore have to be secured legislatively and constitutionally (Döring et al. 2024; Bundesregierung 2023a).

Examples

As the reformed federal supplementary grants with climate forecast factor have not yet been implemented, there are few practical precedents that can be directly applied. However, experience from related approaches can be used for the conceptual design:

- **Climate impact approach in municipal financial equalisation (NRW)**
  In North Rhine-Westphalia, a research project developed a so-called climate impact approach that incorporates greenhouse gas reductions at the municipal level as a basis for assessment in fiscal equalisation. This was the first indicator- and impact-oriented mechanism to be tested (Döring et al. 2024).
- **Climate and forestry allowance (§ 16 GFG NRW)**
  The state of North Rhine-Westphalia grants municipalities a lump sum for municipal forest

areas in order to reward their climate protection function. The fiscal significance is limited, but it shows that climate-related elements can be integrated into fiscal equalisation systems (Landesregierung Nordrhein-Westfalen 2024).

These examples illustrate that the integration of climate-related criteria into fiscal equalisation systems is fundamentally feasible, but that a nationwide instrument such as the reformed federal supplementary grants would be uncharted territory. A more detailed description of the climate impact approach can be found in the separate fact sheet "Climate impact approach".

Conclusion and outlook

The addition of a climate forecast factor to the federal supplementary grants represents an innovative approach to strengthening fiscal resilience to climate-related risks. By systematically taking climate risks, adaptation needs and historical damage data into account in the context of fiscal equalisation, both preventive and reactive elements could be anchored in the distribution of funds.

The key advantages could include greater planning security, the promotion of preventive investments in climate resilience, and risk-adjusted allocation of funds based on objective and differentiated criteria. The instrument would make it possible to distribute the fiscal burden resulting from climate change more fairly between the federal government and the states, thereby cushioning the long-term financial burden on regions that are particularly affected. However, implementation would involve complex challenges. Data availability and quality, uncertainties in climate modelling, constitutional demarcation issues and administrative requirements are key limitations that necessitate gradual implementation. A learning-oriented, iterative approach appears to be sensible in this context. For the future, therefore, targeted further development of data infrastructure, governance structures and indicator-based calculation models would be necessary. In the long term, the reformed federal supplementary grants with a climate forecast factor could become a key component of a climate-proof fiscal policy that, in addition to fiscal stability, also has climate policy steering effects.

Further reading

- Döring, Thomas; Gerhards, Eva; Thöne, Michael (2024): **Climate approach and multi-year tax capacity in municipal financial equalisation in North Rhine-Westphalia**. FiFo Reports No. 34. Institute for Public Finance at the University of Cologne. Available online at: https://www.fifo-koeln.org/images/aktuelles/2024/FiFo-Bericht_34_Klimaansatz-KFA.pdf

- Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (2024): **German Strategy for Adaptation to Climate Change 2024**. Berlin. Available online at: https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Klimaanpassung/das_2024_strategie_bf.pdf

7.11 The state as the insurer of last resort

Classification: new instrument/extension of an existing instrument?

The concept of the state as the insurer of last resort represents a new approach in the German context. Until now, the insurance system has not provided for a defined, mandatory role for the state as a reinsurer for extreme risks. The state is therefore not necessarily the last resort for climate risk protection. However, it is increasingly intervening to provide support for insurance cover, particularly when private insurance companies reach their limits.

Definition and basic principle

The concept of "the state as the ultimate insurer" refers to a multi-level insurance system in which the state acts as a last resort for extreme loss events when the capacities of private insurers and reinsurers are exhausted. This state fallback position acts as a final risk buffer in a tiered chain of insurance solutions. The system is based on the principle of the "ladder of intervention", in which various actors assume risks in ascending order: primary insurers, reinsurers and finally national insurance systems.

The European solution for managing natural disaster risks proposed by the European Central Bank (ECB) and the European Insurance and Occupational Pensions Authority (EIOPA) in December 2024 exemplifies this concept at the supranational level. The two-pillar system includes, as a last resort, an EU-wide public-private reinsurance scheme and an EU public disaster financing fund financed by contributions from Member States. While national and subnational governments are generally expected to cover most of the losses to public assets in the event of a disaster, a European public disaster fund would create additional immediate capacity by providing financial support to governments in the event of particularly severe disasters, thereby supporting efforts to rebuild infrastructure (Europäische Zentralbank and European Insurance and Occupational Pensions Authority 2024).

How it works

The system works by distributing the burden of losses across different risk levels. In the first level, private primary insurers bear the basic risks, i.e. losses from disasters with a low impact, which account for the vast majority of climate-related events. The second tier comprises private reinsurers, which assume the excess risk of primary insurers in the event of disasters with a greater impact (Haubner 2009). In the third tier, national government insurance schemes provide additional reinsurance capacity for events with an even greater impact. Under the concept proposed by the ECB and EIOPA, a European public-private reinsurance system would offer private (re)insurance companies additional reinsurance against risk-based premiums for the most severe loss events affecting privately insured losses (Europäische Zentralbank and European Insurance and Occupational Pensions Authority 2024).

At the German level, the state would assume the remaining extreme risks as the "insurer of last resort" in the fourth and highest tier, for example in particularly exposed locations with excessive damage potential. Here, the state must provide additional cover when the capacities of private market participants are exhausted, in addition to damage to public infrastructure and the costs of disaster management (Umweltbundesamt 2022c). This state protection typically takes the form of so-called "stop-loss guarantees" or "default guarantees", whereby the state bears damages above a defined threshold (Neininger 2025; Becker and Oslislo 2022; Versicherungswirtschaft heute 2025).

Advantages and areas of application

Climate change poses fundamental challenges to the existing insurance system, as extreme weather events become more frequent and intense, increasingly calling into question the insurability of damage. Even today, many risks can no longer be adequately covered due to rising premiums or a lack of insurance offerings in particularly risk-exposed regions, leading to a growing insurance gap. If the problems of insurability continue to worsen, a fundamental reform of the insurance system could have a stabilising effect (Allianz 2025). The state system as the insurer of last resort offers advantages for the stability of the insurance market and social resilience. The state's fallback position allows private insurers to take on even extreme risks in a calculable manner, as the so-called tail risk is borne by the state (Evans 2023). This can ultimately lead to lower risk premiums for policyholders and increase the availability of insurance cover.

The state has unique prerequisites for this role: sovereign tax collection powers, long-term financing capacity and the ability to spread risk over generations. Thanks to its high creditworthiness, the state can finance damages that would drive private actors into insolvency (Nguyen 2009).

The scope of application extends across all federal levels. At the local level, cities and municipalities can benefit from more stable insurance markets as systemic risk is reduced. States can establish national insurance systems backed by government guarantees. At the European level, final protection can be provided through the concept proposed by the ECB and EIOPA of an EU-wide public-private reinsurance scheme and a public EU fund for disaster financing.

Challenges and limitations

A key challenge is to design a state reinsurance offering in such a way that it stabilises the private insurance market without replacing it. It should be prevented that the necessary risk signals in the premiums are lost as a result of state coverage. If all risks of private assets are ultimately transferred to the state, this would hardly lead to an improvement over the current situation and could create false incentives for prevention and risk awareness.

As with other protection mechanisms, the central problem of moral hazard would remain: if policyholders rely on government assistance, the incentives for private provision and risk reduction decrease. This can lead to underinsurance, which ultimately increases the burden on the government. The expectation of state aid can also tempt private insurers to make more careless risk assessments (Bayrisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie 2020; Becker and Oslislo 2022).

Thus, similar to other protection mechanisms, the implementation of a government insurance of last resort can also entail considerable fiscal risks. Climate change-related increases in damage can lead to incalculable burdens on public finances and insurers (Darley 2025). Germany already has a national debt of over EUR 2.5 trillion, which limits the fiscal scope for additional guarantees (tagesschau.de 2025).

Systemic risks arise from the concentration of extreme risks in the state. Simultaneous major loss events can overwhelm even state financing capacities. In this case, a European fallback option, as proposed by the ECB and EIOPA, could be a supplement to minimise the risk.

Examples

Internationally, there are various models of state protection as a last resort for insurance. Since 1982, the French Système CatNat has been a comprehensive state-backed system for natural disaster damage. The Caisse Centrale de Réassurance (CCR) acts as a state reinsurer with an unlimited state

guarantee for natural disaster damage. The system achieves a high insurance density of 98%, with average annual premiums of only EUR 26, which initially appear very low (Zentrum für Europäischen Verbraucherschutz e.V. 2023). These favourable conditions are mainly due to the solidarity-based (rather than risk-based) principle and the role of the strong state reinsurer. However, the French CatNat system is also increasingly the subject of criticism: the contributions of the insured are not calculated according to individual risk, but are levied as a statutory levy, which currently amounts to 12% of the property insurance premium and is set to rise to 20% in 2025 – a response to the increasing deficits caused by climate change and extreme weather. In addition to this levy, the costs of regular building insurance must still be borne, meaning that the actual financial burden on policyholders is significantly higher than the often-cited average of EUR 26 (Gesamtverband der Versicherer 2024). A comparison with risk-based premiums in Germany therefore falls short.

In Germany, Extremus Versicherungs-AG has been successfully implementing a state-backed special insurance scheme for terrorist risks since 2002. The state covers losses above EUR 2.52 billion up to a total capacity of EUR 8.5 billion per year. This structure enables insurance cover for major risks that would otherwise be uninsurable (Ponzel 2022; Nodorf 2022).

Further international examples can be found in smaller countries such as those in the Caribbean, where regional insurance pools with state participation cushion extreme weather risks. The Caribbean Catastrophe Risk Insurance Facility (CCRIF) shows how state co-financing can enable parametric insurance solutions (Caribbean Catastrophe Risk Insurance Facility 2022).

Conclusion and outlook

The concept of the state as the insurer of last resort represents a possible complement to private insurance markets in order to ensure societal resilience against extreme risks. In view of the increase in damage caused by climate change, a government fallback position is becoming increasingly indispensable. The increasing frequency and intensity of natural disasters is already overwhelming private insurance capacity in some cases. Nevertheless, the concept requires further in-depth analysis in order to comprehensively examine potential risks and long-term sustainability for society and the insurance industry.

Further reading

- European Central Bank & EIOPA (2024): **Towards a European system for natural catastrophe risk management**. Available at: https://www.ecb.europa.eu/pub/pdf/other/ecb.climate-insuranceprotectiongap_EIOPA202412~6403e0de2b.en.pdf
- Kreft, Sönke; Sandholz, Simone et al. (2022): **Climate risk insurance: Potential as a strategic instrument for climate adaptation in Germany**. Federal Environment Agency (UBA). Available at: https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/cc_13-2022_klimarisikoversicherung.pdf

Appendix B: Anonymised overview of the experts interviewed

Table 48 : Anonymised overview of the persons interviewed, divided into stakeholder groups

Stakeholder group	Number of persons interviewed
Municipal stakeholders	9
Actors from state and federal institutions	6
Actors from academia	3