GERMANY

The Economic Case for Investing in Disaster Preparedness and Resilience

Summary Report

TAFF

Technical Assistance Financing Facility
for Disaster Prevention and Preparedness

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Acronym	
AI	artificial intelligence
BCR	benefit-cost ratio
BKK	Federal Office for Civil Protection
BMEL	Federal Ministry of Food and Agriculture
BMF	Federal Ministry of Finance
BMI	Ministry of the Interior
BMZ	Federal Ministry for Economic Cooperation and Development
CPS	Climate Policies Scenario
DRM	disaster risk management
DRR	disaster risk reduction
DWD	German Meteorological Service
EFFIS	European Forest Fire Information System
EU	European Union
EWS	early warning system
GDP	gross domestic product
HHAP	Heat Health Action Plan
HHWS	Heat Health Warning System
km(2)	(square) kilometers
Natech	nature and technology
NHWSP	National Flood Protection Programme
UHI	urban heat island
WBGT	wet bulb globe temperature
WBW	Scientific Advisory Board on Forest Policy

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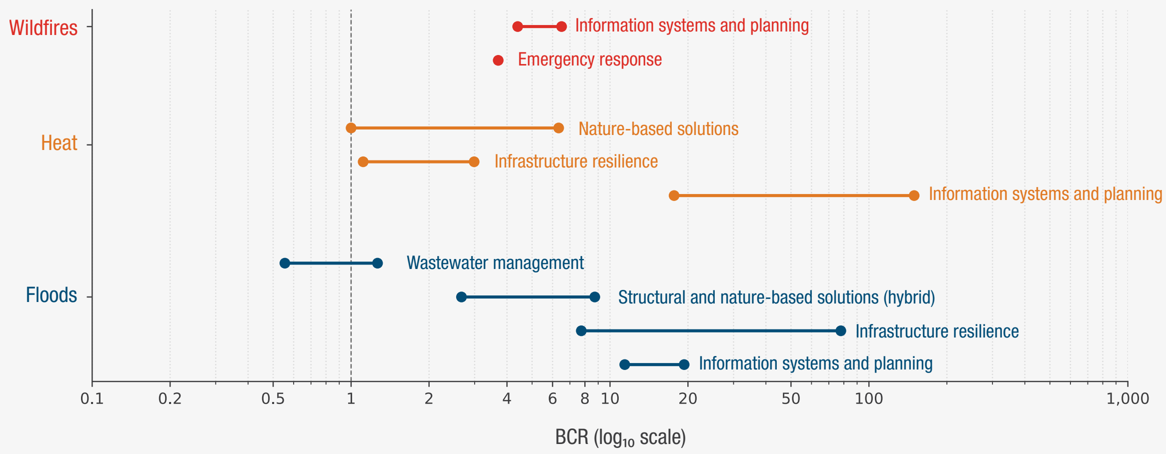
EXECUTIVE SUMMARY

In a rapidly evolving risk landscape, Germany faces the need to enhance its disaster and emergency preparedness capabilities. The country faces rapidly evolving natural hazards. Extreme climate events are already inflicting massive damage, with economic losses estimated to exceed €80 billion in the period from 2018 to 2022 alone.[1] Climate hazards are projected to further intensify, estimated at €280–900 billion by 2050.[2] Yet natural shocks rarely occur in isolation, as technological, public health, economic, and geopolitical factors amplify complex, compound and cascading risks. As global risks—from conflicts and cyber disruptions to extreme weather and resource shocks— increasingly intersect, Germany is confronted with the need to strengthen multi-hazard disaster risk management (DRM) and civil protection systems to manage complex, cascading crises.[3] Modern emergencies often span multiple sectors, overwhelming traditional response mechanisms. From floods that destroy fire stations or disrupt people's access to hospitals to wildfires affecting industrial plants – compounding shocks overwhelm critical infrastructure and essential services, straining the economy and disproportionately affecting vulnerable people.[4]

€2–6
Economic benefits of every €1 invested in resilience

This report presents a strong economic case for investing in disaster and emergency preparedness. Specifically, this report aims to help policymakers identify and prioritize the most urgent and cost-effective opportunities to bolster the country's resilience, thereby improving preparedness not only for climate-related disasters, but for a wide range of future shocks. It also emphasizes the high benefit-cost ratios (BCRs) and multiple benefits of resilience investments that can arise regardless of whether a disaster hits.[5] The report shows that as risks in the country evolve, so too must the solutions, thus requiring continuous efforts to monitor risks and strengthen civil protection capabilities. Investments in Europe consistently demonstrate high economic returns, with benefit-cost ratios (BCRs) ranging from €2–10 per €1 invested.[6] Results from the literature and the new analysis presented in this report show that, in Germany, every €1 invested in disaster preparedness and prevention yields a median economic return of €2–6 for lower-bound and upper-bound estimates, with some individual estimates being as high as €500 (figure 1).[7]

Figure 1. Average benefit-cost ratios (BCR) of wildfire, flood, and heat adaptation measures in Germany



Source: World Bank team.

Note: BCR ranges are aggregated and averaged from numerous case studies and analyses, including from scientific literature and original analysis conducted for this report. Where BCR exceeds 1, the benefit of an intervention exceeds the costs (e.g., an intervention with a BCR of 2 has benefits exceeding costs by a factor 2).

Table 1. Summary of key recommendations for strengthening multi-hazard preparedness

Actors and sectors	Recommendations and priority policy actions
Strengthen resilience against compound, cascading multi-hazard risks	
Key sectors: DRM, civil protection, building and infrastructure	**Enhance multi hazard-risk informed planning** through vulnerability and benefit-cost analytics, cross-sectoral contingency planning, resilience of infrastructure and buildings
Key sectors: DRM, civil protection	**Strengthen multi-hazard information and early warning systems** through enhancing notably situational awareness and community preparedness
Prevent increase of flood exposure and impacts	
Key sectors: Infrastructure, civil protection, transportation, water	**Enhance comprehensive flood protection measures**, prioritizing underprotected areas and strengthening infrastructure and critical services, using green/grey solutions
Key sectors: Building and infrastructure, spatial planning	**Support flood resilient settlement development** by enforcing risk informed land use, spatial planning, building regulations, and incentivizing insurance uptake
Key sectors: DRM, civil protection	**Enhance public preparedness to floods**, by promoting contingency planning of civil protection and critical infrastructure systems and enhancing FEWS effectiveness
Ensure awareness and preparedness against extreme heat	
Key sectors: Infrastructure, urban planning, health, civil protection	**Enhance local heat prevention and preparedness** guided by city-level Heat Health Action Plans for heat reduction measures and response planning
Key sectors: Civil protection, health, buildings, legislation	**Tackle heat-related productivity and health impacts, including** heat protection equipment, labor protection regulations, retrofitting buildings and enhancing HEWS
Support wildfire resilience of forests, people and assets	
Key sectors: DRM, civil protection, building and infrastructure	**Manage wildfire exposure of settlements and infrastructure** by identifying high-risk settlements and assets, and enhancing preparedness and contingency planning
Key sectors: Environment, forestry	**Enhance wildfire resilience of forests and ecosystems** by implementing ecosystem management and wildfire prevention measures in exposed areas
Key sectors: DRM, civil protection	**Strengthen wildfire preparedness and effective response** through scenario planning for natural-technological hazards, enhancing rapid detection and public awareness

Source: World Bank Team

The complex intersection of natural and technological (Natech) hazards presents a significant and escalating national security concern for Germany's highly industrialized landscape. Critical infrastructure is highly exposed to multiple hazards, with thousands of kilometers of roads and powerlines exposed to landslide, flood, and wildfire hazards.[8] Germany also has Europe's largest wildland-industrial interface area and a high concentration of hazardous industrial sites,[9] with high potential for cascading Natech disasters. The 2019 Brandenburg fires, which affected a biogas park and led to large-scale evacuations, and chemical contaminations caused by the 2021 flood are reminders that these threats are real.[10] Proactive resilience investments—in early warning, awareness raising, integrated crisis coordination, and resilient infrastructure—but also enhanced coordination across federal, state and local levels are essential to prevent catastrophic future losses, safeguard people, maintain essential services, and preserve public trust.

Floods remain Germany's costliest extreme weather event and require a stepping up of integrated flood risk management strategies and accelerated civil protection capabilities in underprotected areas. Flood damage totaled an estimated €71 billion between 2000–21, with the 2021 flash flood accounting for over €40.5 billion.[11] Climate change is projected to increase the frequency of extreme events, particularly heavy rain flooding in urban and central areas. Settlement growth increased in areas with extreme flood risk by 9.5 percent between 2016 and 2025, while many municipalities (*Gemeinden*) exhibit insufficient levels of structural flood protection (dikes).[12] Upgrading protection infrastructure in underprotected communities may take years, highlighting the urgent need for enhanced flood preparedness and civil protection measures. Flood exposure also puts civil protection infrastructure and services at risk, as demonstrated during the 2021 Ahrtal floods, with cascading effects on health, education, and emergency response capacities. An exposure analysis undertaken for this report indicates that several thousand fire and police stations, as well as health care facilities are located in flood zones. Flood adaptation measures are highly cost-effective (with median benefits exceeding costs by a factor of 2.25 to 7.6), including soft measures like early warning systems (EWS) and last mile communication, returning up to €45 for every €1 invested.[13] Yet, as 46 percent of early warning recipients during the 2021 Ahrtal floods did not know how to react, interventions are urgently needed to enhance public preparedness and risk information.

Extreme heat is a rapidly intensifying public health and productivity threat, particularly in urban areas, demanding the nationwide scaling up of high-yield adaptation measures. The 2018 and 2019 heat events caused an estimated €34.9 billion in losses and contributed to over 15,000 deaths.[14] Projections indicate that the seven largest German cities alone could see approximately 1,080 heat-related deaths annually by 2100 under current climate mitigation policies.[15] In 2025, only about 25 out of several thousand municipalities have a Heat Health Action Plan in place, and most municipalities have limited experience and track records of implementing such plans. Action is needed to strengthen the effectiveness and reach of the national Heat Health Warning System (HHWS), which can yield returns on investment of up to around €199 for every €1 invested, and targeted urban greening based on high-resolution heat modeling. Ultimately, fully integrating heat adaptation into urban planning, health policies, labor protection, and civil protection strategies across all levels of government is crucial for building climate-resilient cities that can protect their populations and economies in a hotter climate.

Wildfire risk is escalating rapidly across Germany, necessitating targeted investments in early detection technology and long-term forest resilience to protect highly exposed critical assets. The 2025 fire season recorded the largest annual area burned in history (over 5,400 hectares).[16] A high share of critical assets—including thousands of kilometers of road networks and power lines and 36 percent of emergency-response facilities (police stations, fire stations, education facilities, and health care facilities)—is in areas of high to very high wildfire hazard.[17] Quantitative analysis confirms the economic case for proactive investment: the automated FireWatch early detection system yields an estimated BCR of €3 for every €1 invested today, projected at €4 or €7 under future warming scenarios.[18] With a BCR of 3.7, rapid aerial suppression also offers a high return, preventing up to €27,400 in combined damage and response costs per incident. Technological investments need to be coupled with a shift from vulnerable monoculture to climate-smart forests for resilience. Wildfire risk management requires a sustained, multilevel investment strategy that prioritizes cost-effective interventions and long-term forest adaptation to prevent escalating climate risks.

Strengthening emergency preparedness and civil protection while building infrastructure and ecosystem resilience provides a robust path forward, delivering tangible benefits both in the presence and absence of disasters. Germany has a solid policy and institutional foundation for emergency preparedness, but needs to accelerate the implementation of strategies and investments, including at local level with support from national level agencies. New evidence presented in this report highlights the economic value of investments that strengthen critical networks, emergency services and community preparedness against climate shocks and complex events. Preparedness measures bridge prevention and response, addressing compound risks, improving early warning reach, and enforcing spatial planning. Policy should also prioritize resilient infrastructure through vulnerability-informed prevention, contingency planning, and stronger civil protection capacity. Designing protection measures should consider a mix of gray and green measures in sectoral plans—such as urban greening and nature-based solutions—to maximize long-term benefits, recognizing these require cross-stakeholder cooperation and have long lead times.

With escalating climate impacts and future cumulative climate costs projected to reach up to €900 billion by 2050, proactive investment in multi-hazard resilience is an economic imperative for Germany. Effective civil protection is not just about natural hazards: it is a cornerstone of national resilience in the face of overlapping risks. To identify concrete priorities towards this objective, this report draws on a host of new analyses and on a systematic review of the existing literature. The resulting recommendations for enhancing resilience (Table 1) are not only urgent in the face of rapidly evolving risks, but also make economic and political sense as they help to safeguard people, critical assets, and economic productivity. Overall, the benefit-cost ratios presented in this report provide an indication of the strong economic case for investing in resilience that can be expected on average in Germany, though it cannot replace detailed risk-informed investment appraisals for specific contexts and cases.

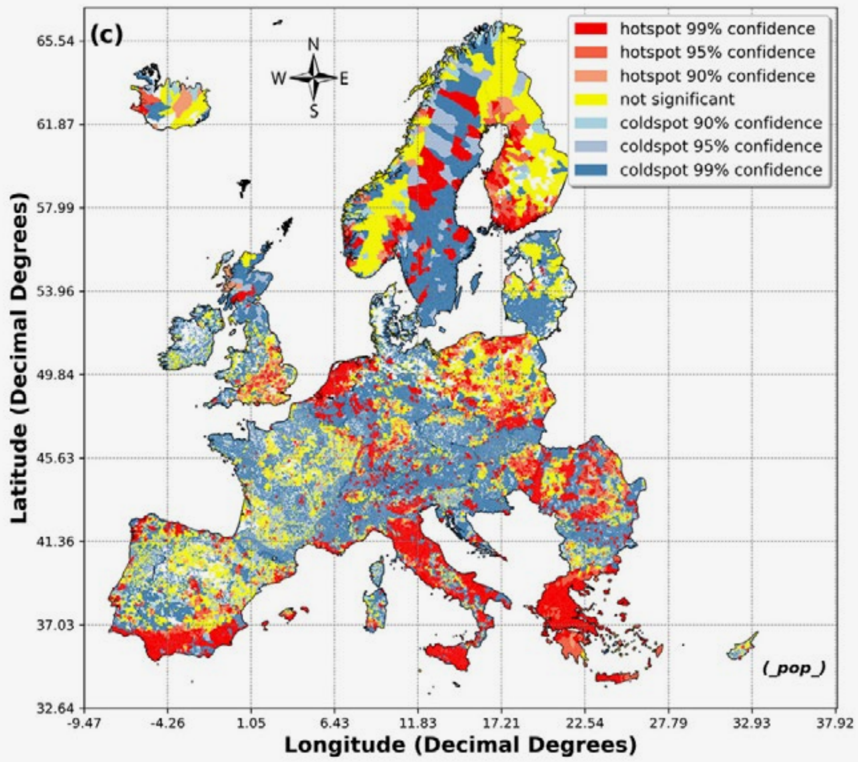
SUMMARY REPORT

1. Investing in preparedness in a rapidly evolving risk landscape

Germany faces an urgent need to strengthen its preparedness and response systems to protect people, infrastructure, and the economy from compounding shocks. The country is in the heart of Europe, the world's fastest-warming continent, where climate change is amplifying the frequency of extreme weather events, such as floods, heatwaves, and droughts.[19] As this report shows, the risks emanating from these natural hazards are often aggravated by a lack of risk-informed planning practices – for instance with accelerated construction in flood zones. Moreover, natural hazards are increasingly intersecting with other risks—from energy price shocks and supply chain disruptions to cyberattacks and geopolitical instability—creating a complex and rapidly evolving risk landscape (figure 2).

As risks in the country evolve, so too must the solutions, requiring continuous efforts to strengthen and maintain civil protection and emergency management capabilities. Yet public resources are limited and must be used strategically. Strengthening resilience is not only about spending more; it is also about investing smarter by deploying evidence-driven approaches to prioritize the most cost-effective solutions. This requires careful evaluation of where preparedness gaps are most critical, which interventions yield the highest social and economic returns, and how cross-sectoral coordination can maximize the impact of every euro invested.

Figure 2. European regions exposed to multihazards, identified absolute population exposure



Source: Antofie, T E, Luoni, S, Tilloy, A, Sibilia, A, Salari, S, Eklund, G, Rodomonti, D, Bountzouklis, C, and Corbane, C. 2025. Spatial Identification of Regions Exposed to Multi-hazards at the Pan-European Level. *Natural Hazards and Earth System Sciences* 25(1): 287–304.

Note: Hazard exposure considers river flooding, landslides, coastal inundation, earthquakes, subsidence, and wildfires.

The objective of this report is to inform these decisions by compiling the most recent evidence on Germany's evolving climate and disaster risks, and quantifying the economic benefits of targeted resilience investments. By linking scientific risk analysis with economic appraisal, the report aims to help policymakers identify and prioritize the most urgent and cost-effective opportunities to bolster the country's resilience, thereby improving preparedness not only for climate-related disasters, but for a wide range of future shocks. This summary report synthesizes the finding of several in-depth technical studies, including on evolving urban flood exposure trends, urban heat adaptation, wildfire resilience, and multi-hazard early warning systems. This report also provides the first systematic review of benefit-cost ratios of multi-hazard resilience measures in Germany, but emphasizes the need for further research on this topic.

This report provides a comprehensive overview of Germany's compound and natural hazard landscape and the economic rationale for investing in disaster risk reduction and preparedness. It starts with a discussion of compounding multi-hazard risks and cascading impacts under climate change, followed by three chapters that focus on three main climate risks in the country: floods, heatwaves, and wildfires. For each hazard, the report presents the current and future risks and impacts, outlines the policy frameworks in place and describes the potential gaps and opportunities, and presents benefit cost ratios (BCRs) from economic assessments of various adaptation measures, including from scientific literature and original analysis conducted for this report. The final section summarizes the priority actions needed to enhance multi-hazard resilience.

2. Compound risks: shocks never occur in isolation and can reinforce each other

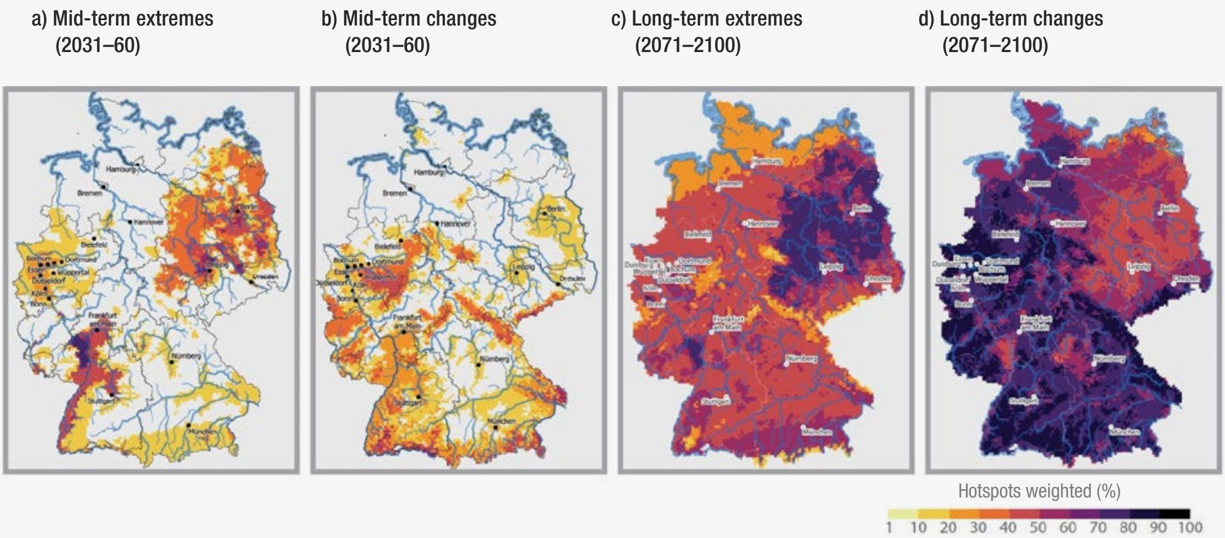
Exposure and Impacts: Germany is experiencing compounding multi-hazard impacts with cascading impacts

€80 billion
Economic losses from climate shocks (2018–22)

1.5–5 times
Expected increase in average annual costs of extreme events due to climate change by 2050

Germany faces rapidly evolving natural hazards, driven by climate change. Extreme climate events have already inflicted massive damage, with economic loss estimated to exceed €80 billion in 2018–22 alone, including the devastating 2021 Ahrtal flood (over €40 billion) and the drought and heat impacts from 2018–19 (over €35 billion).[20] Wildfires, once rare, are intensifying, and the 2,400 fires over 3,000 hectares the country experienced in 2022 were far above average.[21] The cumulative costs due to climate change for 2022–50 are projected at €280–900 billion, representing a 1.5- to 5-fold increase in the average annual costs of extreme events compared to the last two decades.[22] Extreme compounding heat and drought years could become almost 10 times more frequent in Germany over the next 50 years, with much higher temperatures and precipitation deficits.[23] Many regions in Germany, such as the Upper Rhine Valley, are exposed to multiple hazards, leading to compound and cascading risks and amplified disaster losses and impacts (figure 3), a general trend across Europe.[24]

Figure 3. Germany's mid- and long-term multihazard climate risk hotspots



Source: KWRA 2021

Note: The climate parameters considered were: high mean annual temperature; number of hot days; number of tropical nights; low annual precipitation; number of dry days; days with heavy rainfall. The significance of these climate parameters were examined for all climate impacts. Data basis: 85th percentile of the processed German Meteorological Service (DWD) reference ensemble v2018 (Brienen et al. 2020)[25] for the RCP8.5 scenario of the IPCC AR5 (IPCC 2013).[26] 100% means a threshold-breaking value for all climate parameters.

The cascading impacts of climate shocks can quickly overwhelm critical infrastructure and services, increasing the risk of simultaneous failures across sectors and severe consequences for people and the economy. Critical infrastructure, assets, and networks are highly exposed to compounding hazards with the potential for natural shock-induced technological (Natech) disasters. A World Bank analysis of natural hazard exposure in Europe shows that a substantial share of Germany's critical infrastructure assets is exposed to one or multiple hazards, including wildfires, landslides, and floods.[27] For road networks, while about 3 percent of Germany's road assets are exposed to flood hazards, this risk is compounded by other hazards including landslides and wildfires, with propagating disruptions to mobility and access. For several key economic sectors, these high levels of multihazard exposure are projected to translate into substantial impacts under climate change, particularly without decisive adaptation measures (table 2).[28] Germany has Europe's largest wildland-industrial interface area, indicating a potential for intensified impacts and damages when wildfires intersect with hazardous industry.[29] These escalating risks pose a significant security concern, showcasing vulnerabilities in critical lifeline networks, including water, power, transport, and telecommunications.

Disruptions in Germany's highly interconnected industrial hubs will reverberate along European value chains, with vast cross border implications. Climate change-driven low water levels on key inland waterways, such as the Rhine, severely disrupt water transport and have significant national economic impacts for industry or tourism, leading to an estimated 0.2–0.25 percent reduction in Germany's GDP during major drought events in 2018 and 2022.[30] Compound events in a constrained window can overwhelm infrastructure operation given potential conflicting demands—such as safety, services, environmental protection, or infrastructure maintenance— as observed during the COVID-19 pandemic, especially when concurrent across Europe or concentrated in subregions.[31] The economic fallout for the European Union (EU) from the cross border impacts of climate change on trade is estimated to be as high as €27.4 billion per year in a 3°C warming scenario.[32]

Table 2. Climate risks by impact types and sectors without and with adaptation measures

Action field	Climate risks without adaptation		Climate risks with adaptation		Climate risks with adaptation	
			With APAIII+ measures		With more far-reaching adaptation	
	Middle of the century		Middle of the century		Middle of the century	
	Weaker climate change	Strong climate change	Weaker climate change	Strong climate change	Weaker climate change	Strong climate change
Biodiversity	medium	medium-high	low-medium	medium-high	low	medium
Soil	low-medium	medium-high	low	medium	low	low-medium
Agriculture	medium	high	low-medium	high	low	medium
Forestry	medium	high	low-medium	high	low	medium-high
Fisheries	medium	high	low-medium	medium-high	low	medium-high
Coastal and marine protection	medium	high	low-medium	medium-high	low	medium
Water balance, water management	medium	high	low-medium	medium-high	low	medium
Construction	medium	medium-high	low-medium	medium	low	low-medium
Energy industry	low	low	low	low	low	low
Transport, transport infrastructure	low	medium	low	low-medium	low	low
Industry and commerce	low	medium	low	medium	low	low
Tourism	low	medium	low	medium	low	low-medium
Human health	medium		low	medium	low	medium

Source: UBA (2022) Link; KWRA (2021). Climate Impact and Risk Assessment (technical report in German, summary report in English)

Note: APAIII+ measures refer to measures included in the Federal Government's Adaptation Action Plan III and additional measures.

Compound climate hazards disproportionately affect vulnerable sectors and marginalized groups, exacerbating social inequality across Germany. Climate impacts interact with social risk drivers, making sectors such as human health (particularly in urban areas) and agriculture highly vulnerable to combined heat and flood hazards.[33] Socially vulnerable groups, such as low-income households and people with disabilities, often live in higher-risk areas with limited access to protective resources, increasing their exposure and reducing their preparedness.[34] They also tend to be employed in jobs with higher exposure, such as construction or agriculture, which are more exposed to heat risks. The intensification of climate disasters increases their losses and damages, amplifying existing social inequality. Cascading Natech events, such as toxic releases following a flood, also disproportionately harm these communities through long-term health burdens, loss of economic livelihoods, such as fishing and agriculture, and necessary evacuations.[35] Proactive investments are essential to address these intertwined social and economic justice issues.

Natural hazards need to be seen—and managed—as part of a wider risk landscape

Natural shocks rarely occur in isolation, as technological, public health, economic, and geopolitical factors amplify complex, compound, and cascading risks. The World Economic Forum's Global Risks Report 2025 assesses risks across five categories—economic, environmental, geopolitical, societal, and technological—emphasizing how shocks in one domain can cascade through systems (figure 4). It highlights a world marked by escalating conflict and geoeconomic fragmentation, which strain already fragile economies, while in the longer term, the risk landscape is dominated by climate and environmental factors. Evidence for Germany and Europe at large highlight that these are not isolated threats but interdependent, compound risks.[36] Rapid technological change, particularly artificial intelligence (AI), intersects with these dynamics, offering resilience tools but also creating new vulnerabilities. Given its high population density and industrialization, it is vital Germany identifies and manages these hazards as part of a single, interconnected risk landscape.[37]

The increasing frequency of compound natural hazards is creating escalating risks of catastrophic Natech accidents, particularly in highly industrialized nations like Germany, where such events can multiply losses. A Natech accident occurs when a natural hazard triggers a dangerous technological incident. Germany's unique vulnerability stems from its high population and industrial density—especially along its river basins and close to forests—combined with a high concentration of Seveso-registered sites, which are industrial facilities that handle or store large quantities of dangerous substances, such as chemicals, fuels, or explosives, covered by the EU Seveso Directive (2012/18) on the control of major-accident hazards involving dangerous substances.[38] Many wildfire-vulnerable assets in Germany are close to forests.[39] The 2019 Brandenburg wildfires threatened a biogas park, requiring 480 military helicopter missions for extensive emergency operations.[40] Flood events also exacerbate environmental pollution: during the 2021 Ahrtal flood, debris and flood waters were contaminated with significant amounts of diesel, oil, and sewage.[41] As climatic extremes coincide with industrial activity, the risk of cascading Natech disasters rises significantly, affecting military installations and operations, and adding a layer of concern for Europewide security and defense in the current geopolitical context.[42]

Figure 4. Global risks, ranked by severity over the short and long terms

	Short term (2 years)		Long term (10 years)
1st	Misinformation and disinformation (Technological)	1st	Extreme weather events (Environmental)
2nd	Extreme weather events (Environmental)	2nd	Biodiversity loss & ecosystem collapse (Environmental)
3rd	State-base armed conflict (Geopolitical)	3rd	Critical change to earth systems ((Environmental)
4th	Societal polarization (Societal)	4th	Natural resource shortages (Environmental)
5th	Cyber espionage and warfare (Technological)	5th	Misinformation and disinformation (Technological)
6th	Pollution (Environmental)	6th	Adverse outcomes of AI technologies (Technological)
7th	Inequality (Societal)	7th	Inequality (Societal)
8th	Involuntary migration or displacement (Societal)	8th	Societal polarization (Societal)
9th	Geoeconomic confrontation (Geopolitical)	9th	Cyber espionage and warfare (Technological)
10th	Erosion of human rights and/or civic freedoms (Societal)	10th	Pollution (Environmental)

Source: World Economic Forum 2025 Global Risks Report 2025

Cascading failures multiply losses across systems, encompassing direct property damage, supply chain disruption, digital failures, and immense long-term intangible costs like environmental contamination and public health crises. A flood affecting multiple chemical facilities, or droughts stressing energy systems, could multiply financial impacts through mass evacuations and toxic releases.[43] The 1986 Sandoz disaster, triggered by a fire, polluted the Rhine with chemical spills, killing aquatic life along 200 kilometers and impairing drinking water in four countries.[44] A significant portion of losses from past natural hazards are already attributed to industrial disruptions.[45] Studies confirm a clear global increase in recorded Natech events, with impacts particularly high in industrialized European countries.[46] Similarly, digital disruptions can paralyze critical infrastructure precisely when coordination is most vital. Germany's civil protection and emergency management increasingly rely on digital networks for communication, data, and logistics, making them vulnerable to cyberattacks, power outages, or damaged equipment. Strengthening digital operational resilience, as promoted under the EU's Digital Operational Resilience Act, is essential for effective disaster preparedness and response. Ensuring redundant communication, protected data systems, and coordinated cyber-incident response must become integral parts of civil protection.

Germany has developed a solid legal framework and cross-sectoral approach to DRM, characterized by shared federal and state responsibilities, but it faces challenges in the consistent integration of complex compound risks. The national system is anchored by the Federal Civil Protection and Disaster Assistance Act[47] and Federal Climate Adaptation Act,[48] which mandate nationwide risk analysis and the development and implementation of the German Climate Adaptation Strategy.[49] Prevention measures—including technical solutions, ecosystem-based approaches, and soft measures—are implemented cross-sectorally across areas such as environment, health, spatial planning, and transport.[50] Preparedness and response (training, emergency operations, awareness-raising, and EWS) are carried out at state level, supported by the Federal Government.[51] Germany also actively contributes to implementing EU-level frameworks, including the EU Civil Protection Mechanism for response coordination, the Seveso III Directive on Industrial Hazards, the Critical Entities Resilience Directive for Essential Services, and EU Directive 2024 on Disclosing Disaster-related Contingent Liabilities.[52] This structure, supported by the Federal Office of Civil Protection and Disaster Assistance (BBK), which plays a central coordination role, aims to enhance multihazard resilience and preparedness capacity.[53]

Despite robust policies, gaps remain in fully integrating compound risks into emergency response planning, including drills or resource pre-positioning required for strengthening civil protection for complex, cascading crises. While the Seveso III Directive covers external hazards, technical rules for guidance for chemical accident prevention lack specific wildfire requirements and the EU's 2025 Preparedness Strategy faces limitations in consistently integrating compound and Natech risks into national and site planning.[54] Existing risk assessments and land-use planning are not fully equipped to manage the intersection of wildfire and hazardous industry—a vulnerability highlighted by limited industry planning for climate-amplified risks.[55] After the biogas event in 2019, forest authorities started taking preventive forest management actions, such as safe access roads for emergency services, but there is scope for such actions to be scaled up. With an estimated 2,000 tons of unexploded ordnance unearthed in Germany each year, improvements in civil protection are also key to ensure safe access for emergency responders.[56]

Implementation of measures can also be hindered by coordination challenges stemming from Germany's multi-layered governance structure. Responsibilities for disaster risk management and climate adaptation are distributed across federal, state, and municipal levels. While this approach allows for tailored local action, it often leads to inconsistencies in the implementation of legal instruments and resilience strategies across regions. Differences in local priorities, resource availability, and administrative capacity can delay or fragment the rollout of critical measures. Additionally, effective coordination is further complicated by the need for cross-sectoral collaboration—spanning civil protection, infrastructure, health, environment, and private stakeholders—especially when addressing complex, compound, and cascading risks. Closing these coordination gaps is essential for scaling up cost-effective, integrated resilience investments and ensuring that national strategies translate into effective local action.

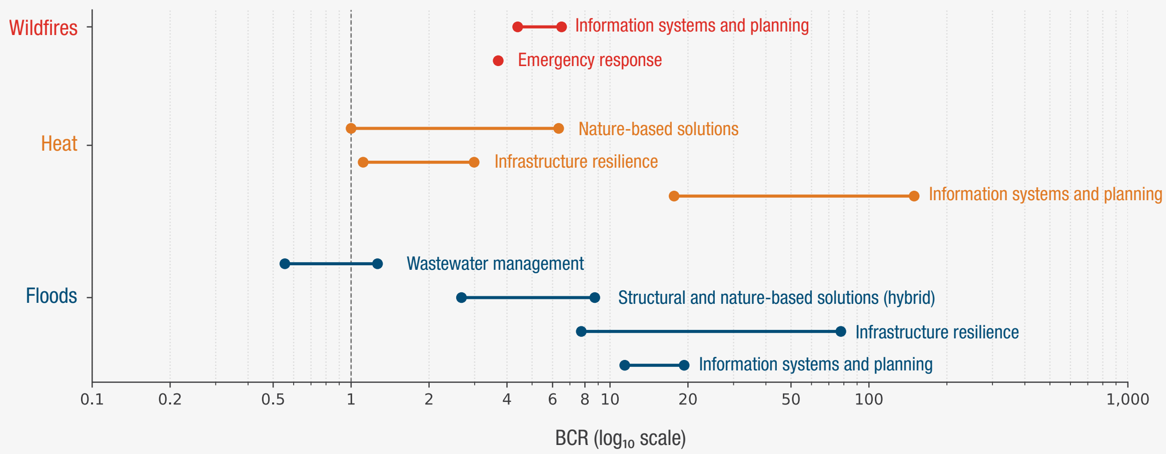
Strengthened civil protection is not just about disaster response; it is a cornerstone of national resilience in the face of overlapping risks. In Germany's dense, high-value industrial landscape, proactive resilience investments are indispensable for sustaining prosperity and security. A multistakeholder approach would help strengthen preparedness by revising regulations and integrating compound risks into land use planning, information, EWS, and trainings; industry implementing protective zones and shutdown protocols based on vulnerability assessments; and emergency services adapting strategies for large-scale hazards near hazardous sites.[57] Crucially, joint exercises should combine interacting hazards in one scenario to support cross-sectoral readiness and reduce the escalation of risks.[58]

Cascading and compound disasters cannot be assigned precise probabilities like for single-hazard shocks, and need to be planned for through "what-if" extreme scenarios and dedicated financing. Thus, compound shocks need to be integrated explicitly into planning, and decision-making mechanisms for civil protection and critical services across Germany. Another challenge is that compound cascading risks resulting from natural disasters are not explicitly covered in budgets. Despite spending an estimated €2.1–3.4 billion on climate adaptation in 2022, the integration of adaptation spending in the federal budget is limited and often non-explicit. Strengthening and clarifying these financial expenditures is vital to incentivize risk reduction and climate adaptation investments in the private sector and manage the escalating risks from compound, cascading, and extreme weather events.[59]

€2–6
Economic benefits of every €1 invested in resilience

Investing in multihazard and compound resilience is an economically rational and imperative choice, as the cost of inaction exceeds the investment required, while providing broad co-benefits. Prevention is proven to save lives, protect assets, and avoid further impacts (and costs), such as evacuations.[60] Quantitative evidence from Europe shows that investing in disaster risk reduction (DRR) yields median economic benefits of €2–10 per €1 invested, while investing in multihazard, compound resilience can yield €1–6 per €1 invested across diverse DRR measures.[61] Quantitative analysis also shows high economic returns for industrial asset resilience investments, with benefits estimated to exceed costs by a factor of 2.1 in Portugal.[62] Evidence in this report shows that, in Germany, a multi-hazard portfolio of investments would yield median benefits of about €2–6 in benefits per €1 invested, with the highest net-benefits from targeted protection measures to prevent large-scale impacts, such as securing oil reservoirs against floods (figure 5, box 1). Nonstructural measures—such as improved regulatory frameworks and EWS—are particularly cost-effective given relatively limited capital investments, but require multidisciplinary, crossinstitutional, and multistakeholder coordination. For Natech risks, early identification of escalation paths as part of "what-if" scenario planning can help avoid the exponential costs of business interruption and environmental contamination, ensuring resilience delivers returns in avoided losses, enhanced long-term social equity and ecological sustainability.[63]

Figure 5. Average benefit-cost ratios (BCR) of wildfire, flood, and heat adaptation measures in Germany



Source: World Bank team

Note: BCR ranges are aggregated and averaged from numerous case studies and analyses, including from scientific literature and original analysis conducted for this report. Where BCR exceeds 1, the benefit of an intervention exceeds the costs (e.g., an intervention with a BCR of 2 has benefits exceeding costs by a factor 2).

Box 1. Benefit cost ratios: Caveats and limitations

While the estimated BCRs present a strong economic case for investing in resilience measures, the analysis is inherently complex and subject to limitations that should be noted when interpreting results. Only a limited number of studies estimate BCRs for Germany (38 individual data points), which makes it difficult to generalize findings across intervention types and locations. BCRs for the same intervention type can differ significantly depending on local geographic conditions. There are particularly few studies estimating BCRs for wildfire interventions in Germany. Moreover, all BCR estimates tend to underestimate indirect benefits of measures, suffer from data scarcity, and rely on imperfect statistical methods and proxies, such as the value of statistical life (VSL). Furthermore, in several of the underlying studies climate projections are based on the IPCC 2007, which have since been updated by more accurate and up-to-date climate models. As a result, BCR ranges provided in this report should be interpreted as providing examples of the order of magnitude rather than precise and generalizable figures. While BCR ranges in this report make a strong case for preparedness investments in general, they cannot replace project specific investment appraisals.

3. Preparing for flood risks: the leading natural hazard is intensifying further

Exposure and impacts: Floods remain Germany's costliest extreme weather event

€71 billion total
€3.2 billion per year
Estimated damages from flash floods, river floods, and heavy rain between 2000 and 2021

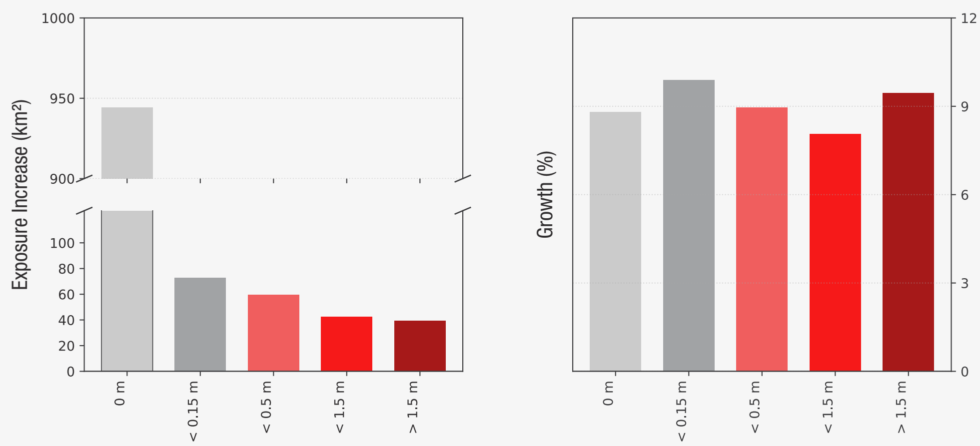
€40.5 billion
Total losses from 2021 summer flash floods

Over 210 km²
of settlement areas have been built in flood zones since 2016

Floods are Germany's costliest extreme weather events, imposing substantial impacts on lives, livelihoods, and the economy.[64] Over recent decades, the country has experienced numerous devastating floods, including coastal, fluvial, and pluvial events.[65] Between 2000 and 2021, damages from flash floods, fluvial floods, and heavy rain are estimated at €71 billion, averaging €3.2 billion annually.[66] The flash flood of summer 2021, an extreme event with a return period exceeding 1,000 years,[67] affected more than 65,000 people, damaged more than 9,000 buildings, and resulted in estimated total losses of €40.5 billion.[68] Flood risk is widespread and not limited to coastlines and major riversheds; it can severely damage critical infrastructure and disrupt essential infrastructure networks—particularly transport, power, telecommunication, logistics, and manufacturing—which in turn can severely hinder the delivery of essential services. Beyond direct financial and physical damage, floods also generate intangible losses with long-lasting effects, such as mental health impacts on flood-affected residents, social disruptions, and environmental damage.[69]

Communities across Germany continue to build in high-risk flood zones. Results from a new high-resolution analysis conducted for this report reveal that flood exposure grew significantly between 2016 and 2025 (figures 6 and 7), with overall flood exposure in settlement areas increasing by more than 214 square kilometers (km²). Over the past decade, 9 out of 16 federal states had the highest settlement growth rates in high-hazard flood zones, meaning that flood-exposed settlements grew significantly faster than in safe areas. Flood exposure is particularly high in river basins, along the North Sea coast, and in southern regions near the Alps and the Black Forest (Figure 7.a). For flood events with a 10 percent chance of occurring per decade (1-in-100 year return period), high-exposure areas are mostly clustered along the coast and major riversheds. As flooding intensity increases, exposure also increases along smaller riversheds and for pluvial flooding in central Germany, leaving only a few Gemeinden unexposed.

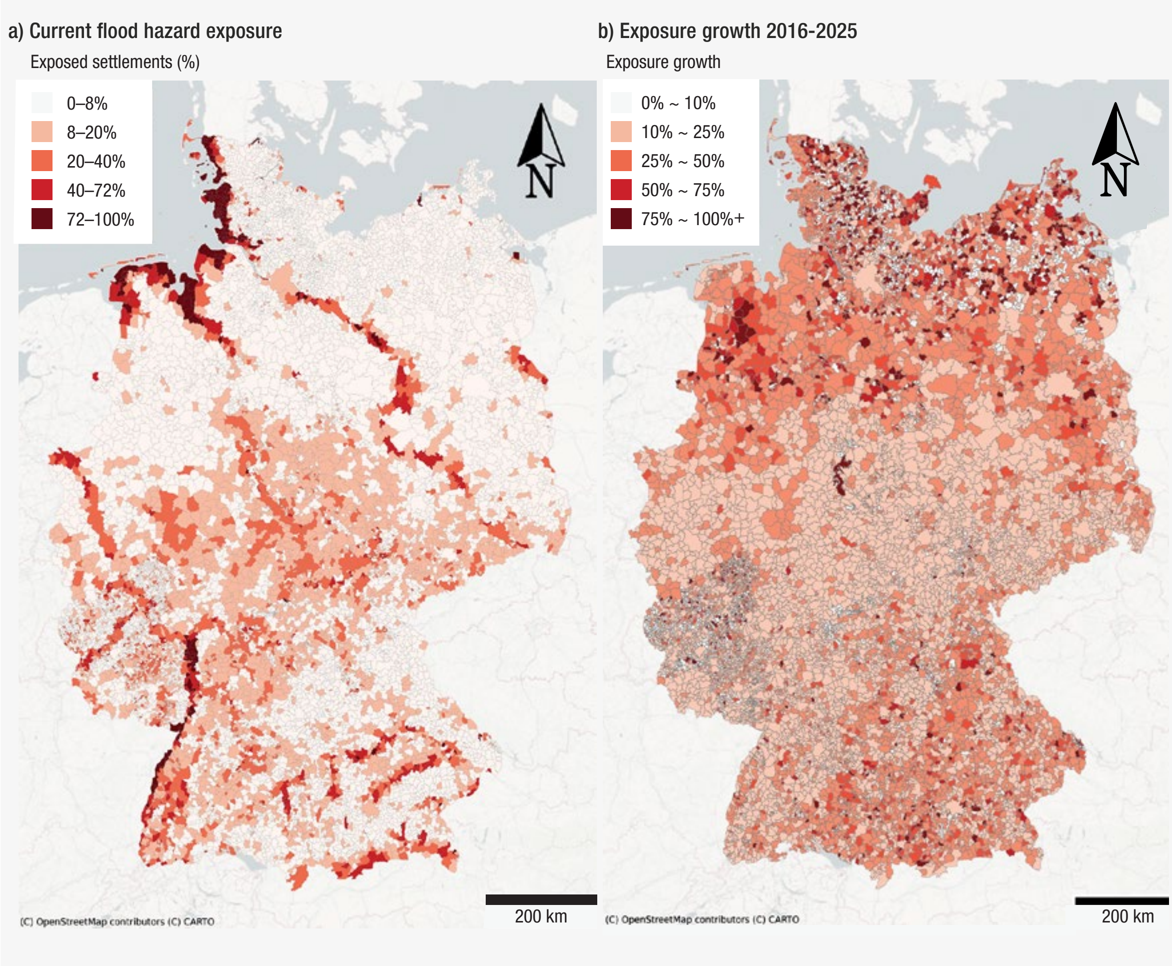
Figure 6. Total increase of exposed settlement area (km2) and their respective growth rates, 2016–25, in different flood depths for a 1-in-100-year flood



Source: World Bank team

Note: Considering pluvial, fluvial, and coastal floods with a 1-in-100-year return period.

Figure 7. Settlement flood hazard exposure and exposure growth from 2016-25 for a 1-in-100 year flood return period



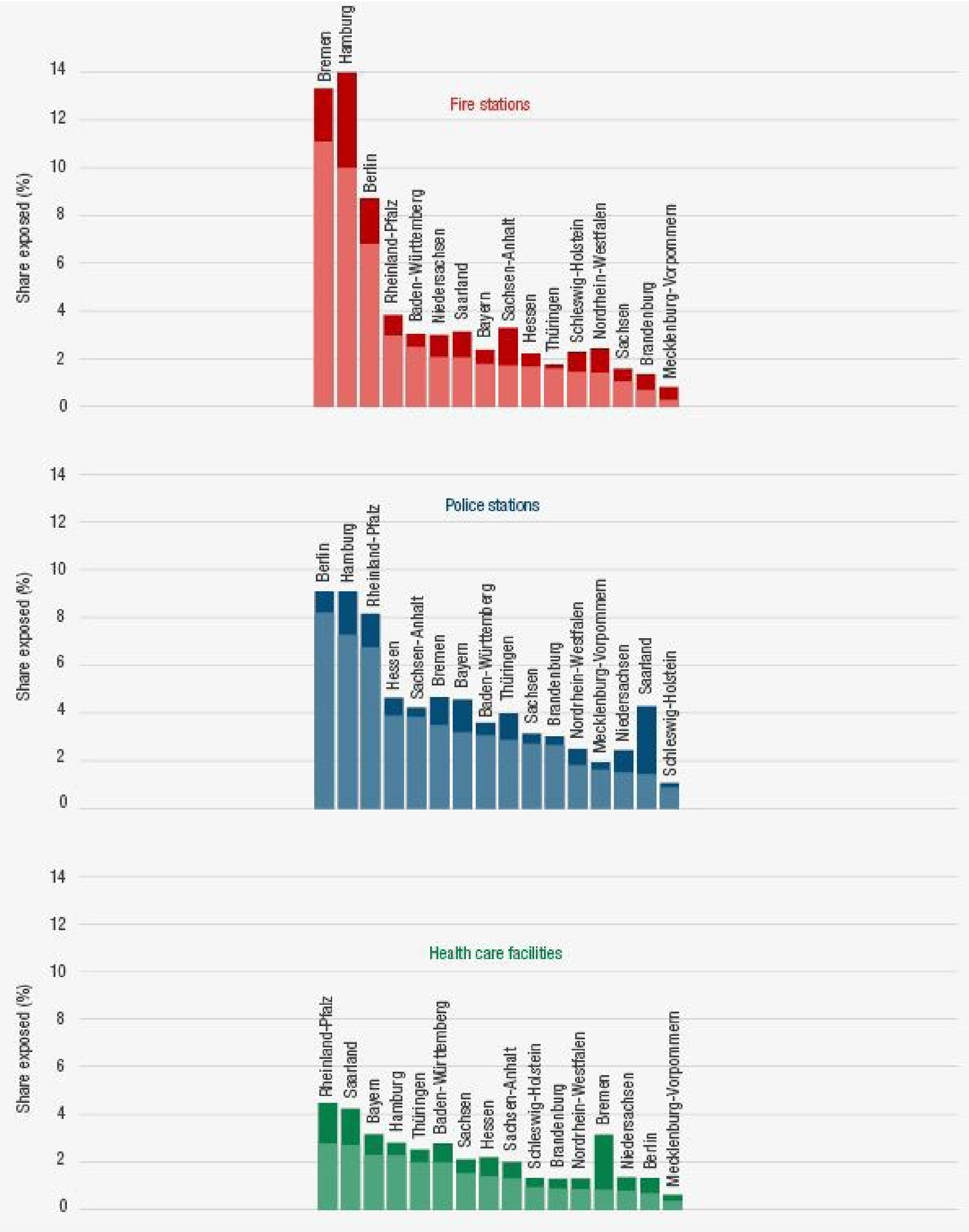
Source: World Bank team

Note: Exposure is defined using a 0.15-meter inundation depth threshold. Panel b) depicts settlement growth rates in flood zones.

Cascading effects: Floods threaten lives, the economy, critical infrastructure, and settlement areas

Critical infrastructure and essential service networks in Germany also face significant exposure to flood hazards, translating into elevated risks of physical damage and service disruption. Civil protection systems, which are crucial for effective disaster response, are also directly exposed to flood hazards and hence at risk of becoming inoperable. A national exposure analysis undertaken for this report indicates that 3.5 percent of police stations (256), 3.4 percent of education facilities (6,376), 2.6 percent of fire stations (1,503), and 2.2 percent of health care facilities (3,716), are located in flood-exposed areas for a 1-in-100-year event (figure 8).[70] Moreover, about 3 percent of roads in Germany are estimated to be located in flood zones, thus compromising effective response during flood disasters.[71] Thousands of emergency response-related assets (1,600) —including police stations, fire stations, education facilities, and health care facilities— and substantial sections of roads (12,100 km) and power lines (20,600 km) are also exposed to landslide hazards.[72]

Figure 8. Exposure of critical infrastructure assets to 1-in-10 and 1-in-100 floods



Source: World Bank team

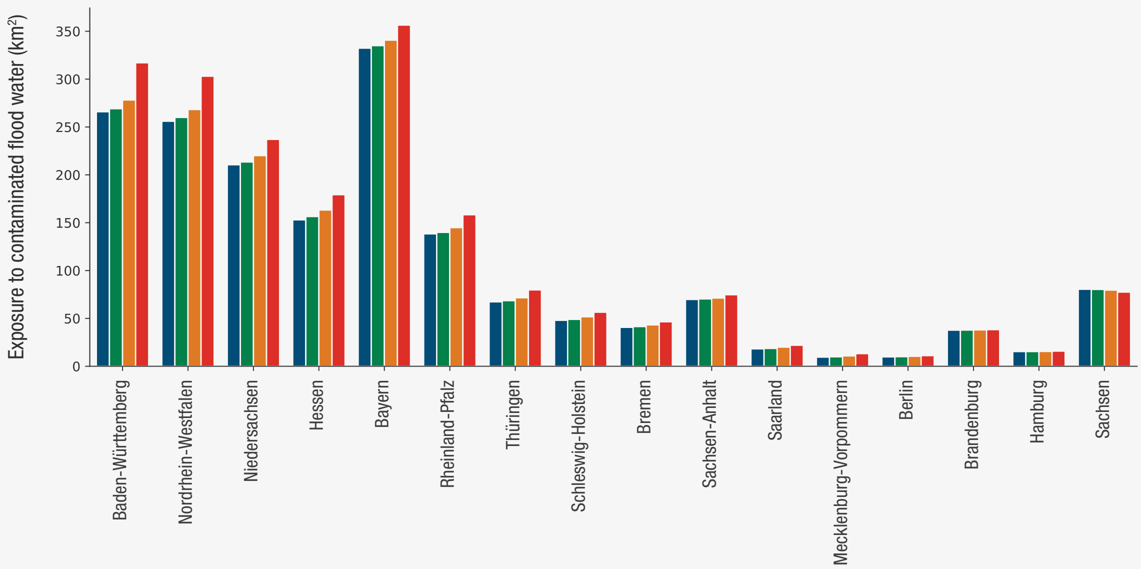
Recent events underscore the operational and economic implications of flood exposure for civil protection and critical infrastructure. The July 2021 floods demonstrated that localized extremes could trigger severe impacts across lifeline infrastructure, residential and commercial structures, and critical service provision. First responder capacity was impacted—for example, due to flood damage to fire stations—while damage to and destruction of education and health care facilities[73] disrupted service delivery in affected areas.[74] Transport networks were severely affected, with damage to roads and railways estimated at up to €2 billion,[75] roughly 100 bridges destroyed[76] in the Ahr valley, and more than 130 km of motorways closed, with repair costs estimated at €100 million.[77] At peak, around 200,000 people experienced power outages;[78] and, while most power infrastructure was restored within eight weeks, some areas required up to six months.[79] The 2021 floods rank among Europe's most destructive recent disasters for critical infrastructure.[80] Such disruptions, which are increasingly likely under climate change, highlight the need to complement national exposure screening with detailed localized risk assessments, enabling the prioritization of resilience investments.[81] Strengthening civil protection capabilities would help ensure preparedness in the most at risk communities.

75 hospitals
At risk of flood-induced patient surges exceeding their capacity

Over 50% of Gemeinden
are projected to see an increase in flood exposure until 2050 under an optimistic climate change scenario (RCP2.6)

Indirect and cascading effects can also severely disrupt critical public services and emergency response capacity outside flood zones, underscoring the need to plan for cross-jurisdictional impacts. A recent national assessment links regional flood modeling with a gravity-based traffic model to evaluate health system vulnerabilities from flood-induced transport disruptions.[82] The analysis identifies hospitals across Germany that are at risk of emergency response delays and service disruption due to road closures and rerouting, and finds that access to critical health care can deteriorate both within flood-affected areas and at facilities located far from floodplains. Across Germany, 75 hospitals are at risk of patient surges exceeding their regular capacity, including 29 with increases greater than 50 percent and nine with increases exceeding 85 percent in service populations. Notably, one-third of these hospitals are located more than 10 km from the nearest inundation, indicating potential blind spots and under-preparedness among nonexposed facilities. These results highlight hidden risks and the transboundary dynamics of disaster resilience, warranting integrated, systemwide risk management and investment and business continuity planning of critical public service facilities.

Figure 9. Projected increase in flood exposure of settlements under the most pessimistic climate change scenario (SSP5-RCP8.5)



Source: World Bank team

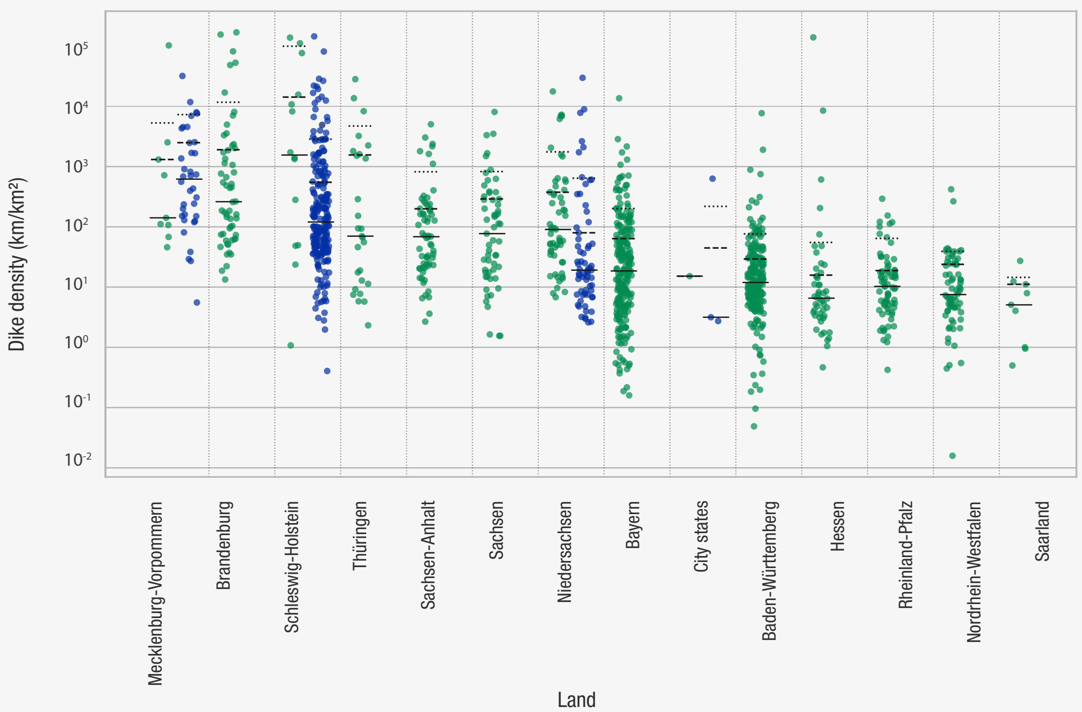
Note: Considering pluvial, fluvial, and coastal floods with a 1-in-100-year return period.

Across Germany, flood exposure of settlements is projected to rise, while the frequency of extreme flood events is also projected to increase under climate change.[83] While precise long-term projections remain complex, climate models indicate a clear trend of increased flood runoffs, higher peak flows, and shorter recurrence intervals of floods, particularly in rain-dominated regions like the low mountain ranges and eastern and southern Germany.[84] Over the next 50 years, settlement exposure to high-risk flooding is projected to increase linearly under the most optimistic climate scenario (RCP2.6) and exponentially under the most pessimistic climate scenario (RCP8.5).[85] Under RCP2.6, more than half of all Gemeinden are projected to see an increase in flood exposure until 2050, while under RCP 8.5, 10 percent of Gemeinden will see their settlement areas exposed to flood depths greater than 0.15 meters nearly triple between 2020 to 2080 (Figure 9). Pluvial flood damage is also expected to increase due to a projected increase in extreme precipitation and continued urbanization.[86] This will strain existing infrastructure, increasing the overloading of sewer networks and treatment plants, and therefore the risk of pollution.

<u>Costs and benefits</u>: An urgent need and opportunity to step up integrated flood risk management and prepare for residual risk

Upgrading flood protection infrastructure in Germany's most underprotected communities may take years, highlighting the urgent need for enhanced flood preparedness and civil protection measures. A new analysis conducted for this report highlights that the coverage of physical flood protections (dikes) varies significantly across flood-exposed Gemeinden. Many Gemeinden with significant flood exposure lag far behind their state's average structural flood protection level (figure 10), while others lack structural protection altogether. Dike protection levels vary significantly across states and hazards (riverine or coastal flooding). The analysis estimates that upgrading dikes systems in just 10 percent of the least-protected Gemeinden would require about 558 km of new dikes or equivalent flood protection infrastructure, at an estimated cost of €1.7–4.2 billion, and would potentially reduce expected flood exposure by 159 km^2.[87] With such measures requiring years for planning and construction, urgent action is needed in the meantime to enhance civil protection and disaster preparedness capabilities in the most at-risk areas.

Figure 10. Physical flood protection coverage, proxied by dike density (dike length relative to exposed area)



Source: World Bank team

Over the past decades, Germany has made significant progress by establishing robust legal frameworks for flood prevention and implementing risk reduction and resilience measures. The National Flood Protection Programme (NHWSP) represents a substantial joint federal-state investment of over €6.16 billion, focusing on large-scale, supra-regional prevention measures across major river basins.[88] The Federal Water Act mandates critical actions—such as creating comprehensive flood hazard and risk maps, designating floodplains, and preserving natural retention areas—and introduces new instruments, such as building regulations and categories for flood emergency areas.[89] Germany's commitment to forward-looking spatial planning was evidenced by the implementation of its first nationwide spatial plan for flood protection.[90] But implementing regulations consistently remains an issue, as new construction continues to take place in high-risk flood areas.[91] Local controversies surrounding flood risk reduction measures can delay critical defense schemes and hinder efforts to reduce flood losses.[92] A lack of incentives for risk reduction and prevention and cross-sectoral collaboration in land use and building regulation also hinder flood risk management strategies at different governance levels.[93]

Factor of €2-8 per €1 invested
Benefits of flood risk interventions exceed costs

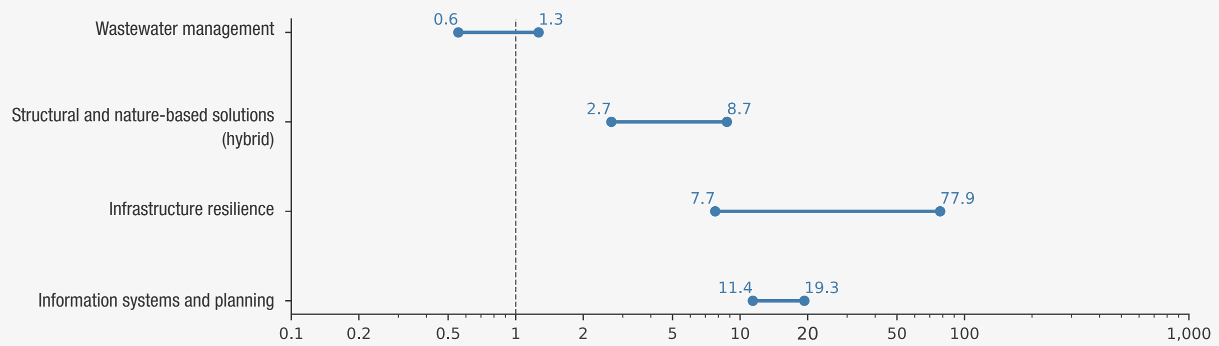
For most flood risk adaptation measures, median benefits are typically around €2-8 per €1 invested[94] and as high as €333 in certain cases. Based on a review conducted for this report, Figure 11 depicts the ranges of lower- and upper-bound estimates for 22 flood-specific benefit cost ratios (BCR) estimates for Germany found in the literature. The median BCRs values range from 2.2 to 7.6 across all interventions. High net benefits are found for soft measures, such as EWS and flood prevention spatial planning, nature-based solutions, and certain hard protection measures, such as dike-raising, securing oil tanks, and flood reservoirs.[95] Structural measures, such as new dike construction and infrastructure retrofitting, yield a wide range of BCR estimates, from around 1 up to 332.5. These measures usually require long implementation periods and high investment costs, with both the public and private sectors playing a crucial financing role. But obtaining precise cost-benefit estimates to guide investments remains a challenge as future flood damage remains highly uncertain, with past events showing no clear trend and future hotspots depending heavily on specific weather conditions.[96] Existing BCR estimates also vary widely in their methodological approach, with benefits often underestimated, as capturing indirect benefits is inherently difficult.

46%
Share of recipients who did not know how to act on warnings during the 2021 Ahrtal floods

€6–9
Avoided damages for every €1 invested in EWS

Flood EWS are one of the most cost-effective solutions, but only if paired with effective public awareness and information initiatives.[97] Effective EWS enable people to receive and act on warnings, including by evacuating from hazard zones, saving lives and reducing losses. A review of BCRs for flood EWS and behavioral initiatives in Germany show that every €1 invested yields median benefits worth €5.7-9.1 in avoided damage. But further efforts are needed to enhance the effectiveness of existing flood EWS and citizen preparedness.[98] Evidence from Germany indicates a persistent gap between advanced technical forecasts and their practical use, with emergency services often relying on ground truthing rather than anticipating and communicating uncertainties.[99] Surveys showed that during the 2021 Ahrtal floods, 46 percent of recipients did not know how to respond to the warnings received, in part due to a tendency to underestimate the actual severity of impending floods and a lack of situational knowledge regarding appropriate protective actions to take.[100] This underscores the need to enhance situational awareness by translating technical warnings into trusted, actionable decisions through emotionally resonant communication, trainings, information campaigns. These should address cultural factors, such as attachment to homes and belongings, and reach vulnerable population groups.

Figure 11. Average BCRs of selected flood adaptation measures in Germany



Source: World Bank team

Note: BCR ranges are aggregated and averaged from numerous case studies and analyses, including from scientific literature and original analysis conducted for this report.

At the same time, pressures on civil protection services need to be alleviated through continued strengthening of flood risk management systems nationwide. The full implementation of new legal instruments under the Water Act[101] remains uneven across federal states, reflecting differences in protection-level objectives and the need for instruments that are tailored to land use and ownership structures.[102] While structural protection measures are necessary to protect existing at-risk assets, risk-informed land use planning regulations are key to guiding new developments into safe areas. More rapidly implementable measures, such as effective EWS, are essential for protecting lives and livelihoods. The results presented in this section also emphasize the importance of integrating local profiles, land use practices, and behavioral considerations into broader mitigation strategies. Understanding the different hazard exposure profiles, geospatial vulnerabilities, and economic feasibility of interventions forms the foundation for informed, evidence-based, and effective flood risk management decisions.

4. Preparing for extreme heat: rising temperatures are an overlooked threat, especially in Germany's cities

Exposure and Impacts: Heat in Germany is a silent killer

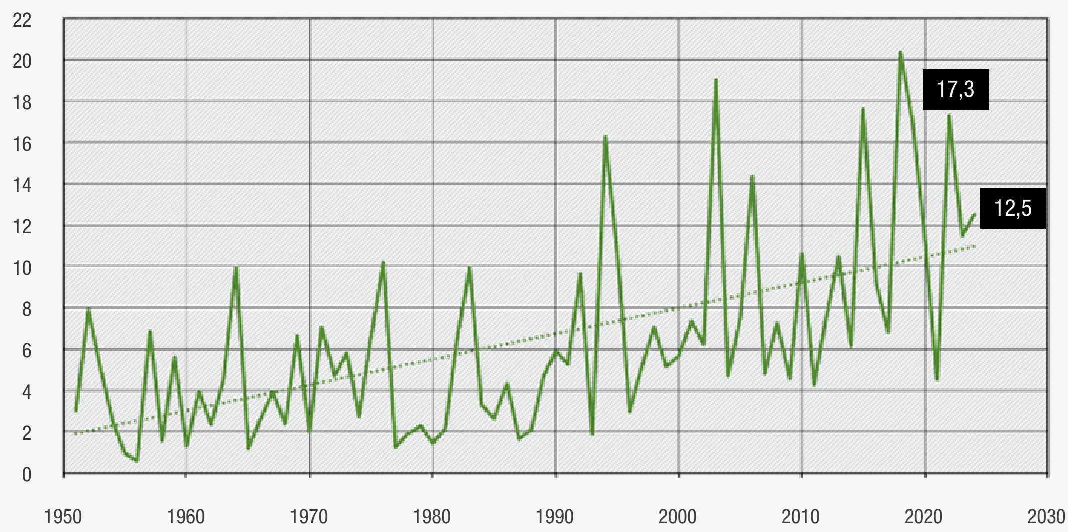
€34.9 billion
in losses caused by 2018-2019 heat and drought events

3-4x
Increase in number of nights with temperatures over 20°C by 2100 in 4 major German cities

48,000
heat-related deaths in Germany 2014 to 2023-related deaths in Germany

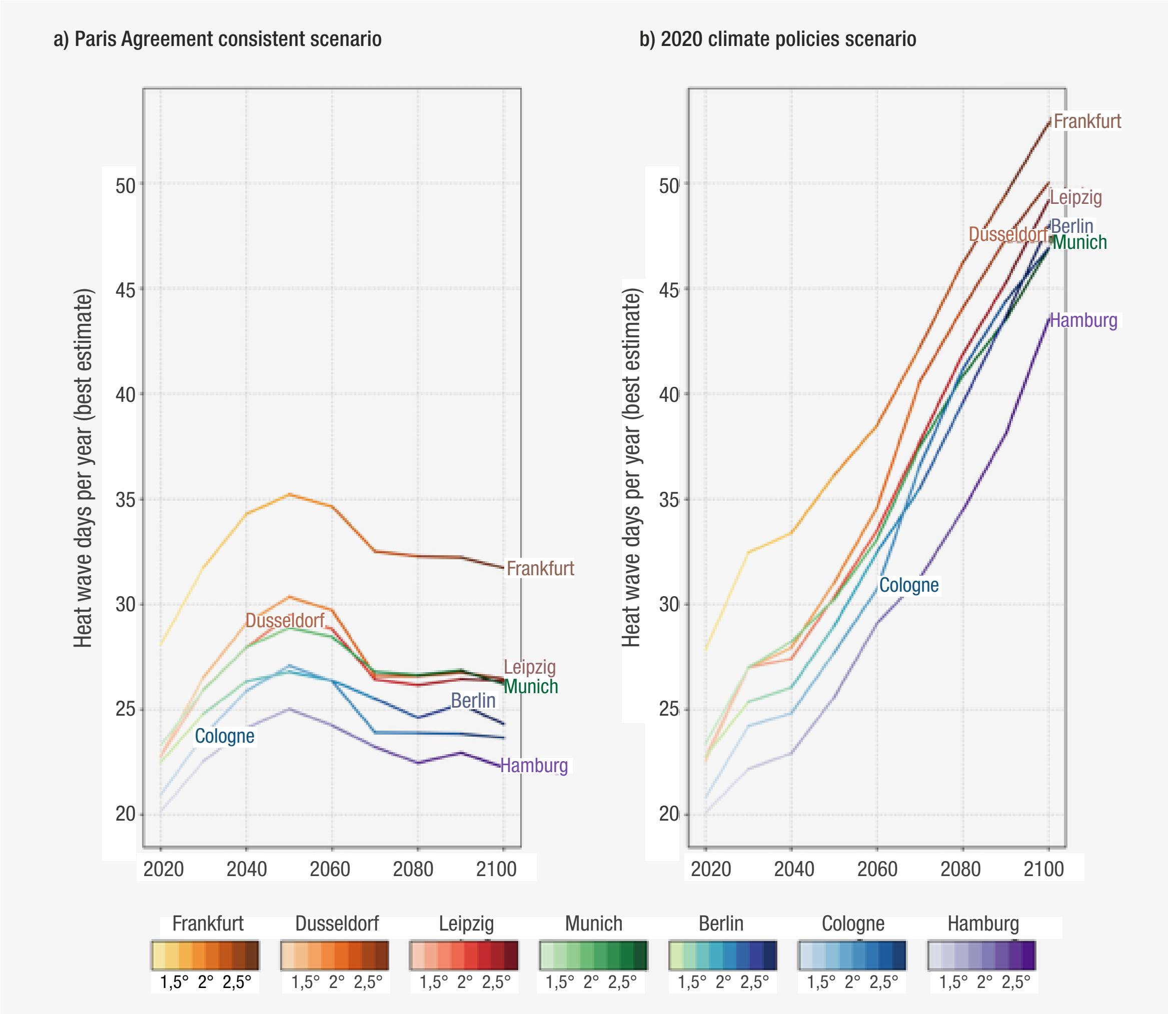
Germany's urban areas face significantly intensifying heat hazards due to climate change and the urban heat island (UHI) effect, leading to severe health and economic consequences. Unlike other European countries, Germany does not have a long tradition of mitigating and coping with intense heat stress. Yet, the drastic intensification of heat stress is evident, with the 2018 and 2019 extreme heat and drought events having caused €34.9 billion in losses and more than 15,000 deaths – about one-third of overall 48,000 heat-related deaths in 2014–23.[103] This report suggests that compared to the present day climate, an extremely hot year (a 1-in-20 year event) is projected to increase in intensity by 2°C by end of century under a scenario without additional climate action (the 2020 Climate Policies Scenario, or CPS).[104] The number of annual heatwave days is also expected to more than double by end of century compared to 2020 levels. In contrast, an ambitious climate change mitigation scenario (consistent with 1.5°C warming and the Paris Agreement), suggests a much smaller increase, underscoring the benefits of global mitigation efforts for German cities (figures 12 and 13).

Figure 12. Number of days with over 30°C in Germany and trend over time



Source: UBA 2025, with underlying data source Deutscher Wetterdienst (DWD), communication dated 20 November 2024

Figure 13. Cross-city comparison of projected heat wave days per year for two climate scenarios



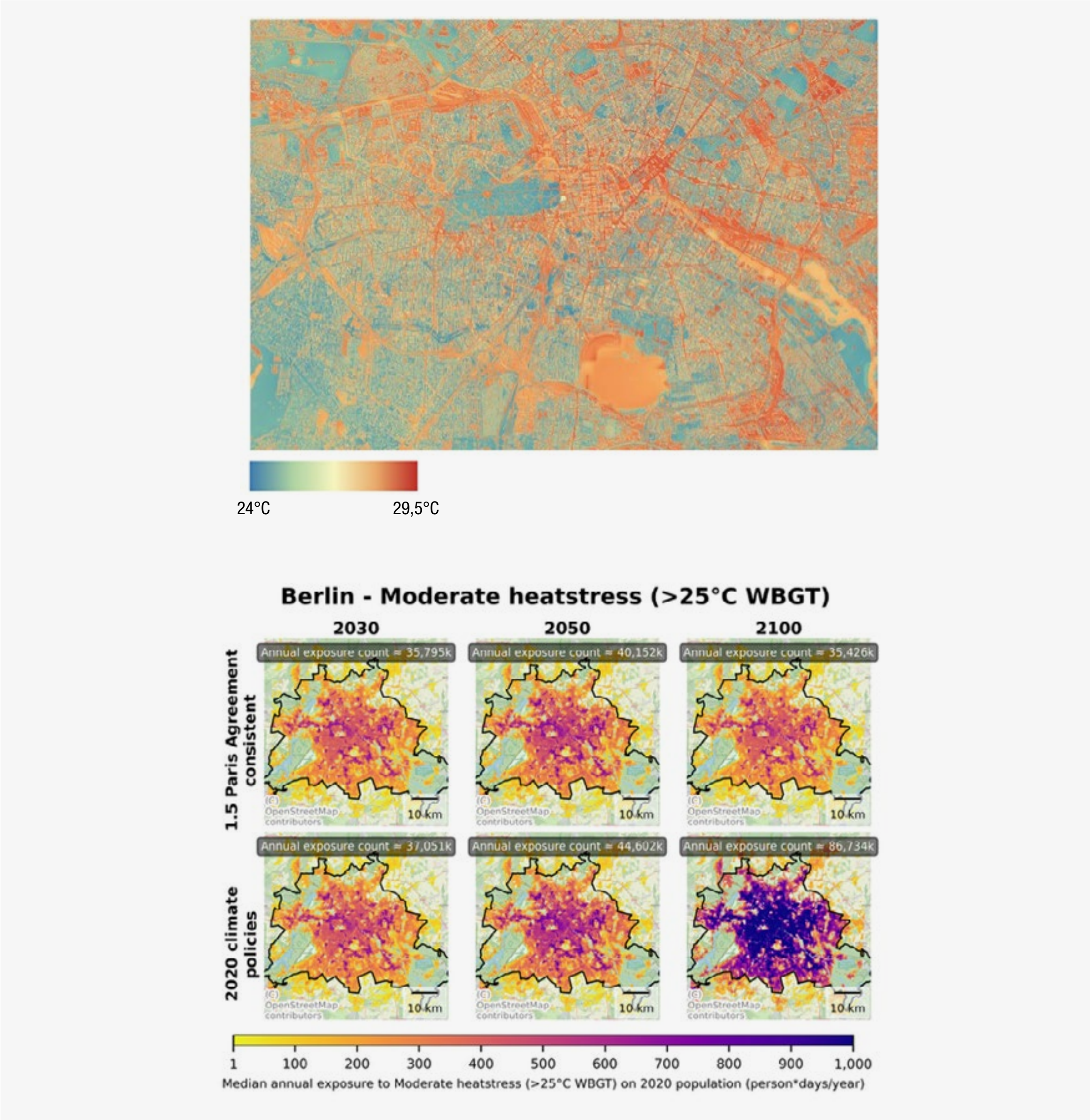
Source: Climate Analytics and World Bank 2025, based on PROVIDE Climate Risk Dashboard

Note: As best estimate for heat wave days we use the mean of all models available in the PROVIDE climate risk dashboard. Heat wave days are defined as the number of days among periods of at least three consecutive days in which the maximum and minimum temperature exceeds the 90th percentile value of a reference present period (2011-20).

Germany's major urban areas face escalating heat burdens, driven by increasing heatwave days and a surge in tropical nights. Frankfurt is currently projected to experience the most heatwave days among the seven cities studied, followed by Dusseldorf, Leipzig, Munich, Berlin, and Cologne, with Hamburg consistently showing the fewest. A critical concern is the surge in tropical nights (night-time temperatures above 20°C), which prevent nocturnal recovery and intensify the UHI effect; this phenomenon is projected to almost quadruple in Leipzig and triple in Berlin, Dusseldorf, and Munich by 2100 under the higher-emission scenario. Large metropolitan areas, such as Berlin and Munich, face high overall projected population exposure to heat stress across all heat stress levels and both climate scenarios, as measured by the wet bulb globe temperature (WBGT) which accounts for humidity, surface temperature, and radiation. Under the CPS, exposure counts are projected to increase drastically for all heat stress levels in all urban areas starting to accelerate mid-century until end of the century and in both city centers and suburban areas.

High-resolution urban modeling confirms that heat intensity varies significantly within cities, driven by localized land use and urban design elements. Modeling for Berlin shows that heat hotspots are concentrated in areas with a low presence of trees and a high percentage of sealed surfaces, such as grassy green areas, streets, or parking lots (figure 14), emphasizing that targeted green and blue infrastructure interventions at street and neighborhood levels are vital to mitigate the UHI effect. Conversely, historical building blocks can experience lower heat levels because high building density is balanced by a greater number of large trees and shading provided by the buildings themselves.

Figure 14. Berlin: Spatial differences in peak temperature (in °C WBGT) and heat exposure projections



Source: Climate Analytics and World Bank 2025, based on PROVIDE Climate Risk Dashboard

2.5-9 factor increase
Projected increase of heat-related deaths by 2100

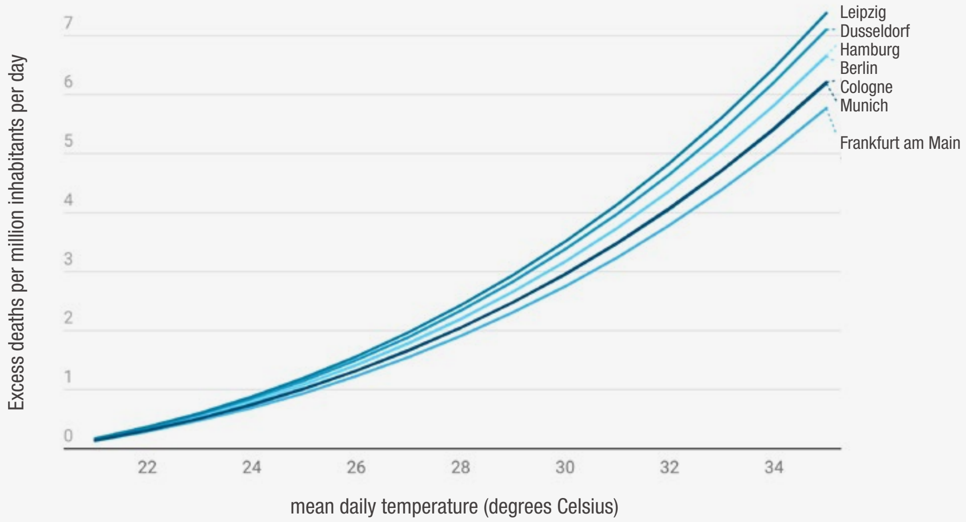
1,080
Additional heat-related deaths per year in seven major German cities by 2100

€350 million GDP impact
Cumulative from heat-related productivity losses 2022-2050

Cascading effects: Health and productivity losses due to heat are escalating

Increased heat exposure will lead to a drastic rise in heat-induced mortality and morbidity and decrease in labor productivity that is largely avoidable through ambitious climate action. High resolution modelling and projections at national level suggest that annual heat-related excess mortality in Germany could further increase by a factor of 2.5 to 9 without adaptation by 2100.[105] Already beforehand, annual government heat-related healthcare expenditures are estimated to increase between €44 and €99 million by 2030 and between €210 and €470 million by 2050.[106] Extreme heat also leads to decreased labor productivity and increased days off work, resulting in a projected cumulative GDP impact of around €350 million up to 2050.[107] Projections show that Berlin would experience the highest number of additional daily deaths, reaching up to an additional 24 deaths per day with a mean daily temperature of 35°C among the seven cities (figure 15). Together, the seven cities (representing 12 percent of Germany's population) are projected to experience about 1,080 heat-related deaths annually by the end of the century under the CPS. But achieving the Paris-Agreement 1.5°C limit could avoid over 450 of these deaths each year, demonstrating the high value of prevention.

Figure 15. Heat vulnerability in German cities: additional heat-related deaths per million inhabitants for each day over 20°C



Source: Climate Analytics and World Bank 2025, based on PROVIDE Climate Risk Dashboard

Note: In number of excess deaths per million inhabitants per day (vertical axis) and mean daily temperature in degrees Celsius (horizontal axis).

Up to €3.4 billion
Economic benefit of climate mitigation aligned with 1.5° in terms of reduced heat mortality

6.9 million hours
Reduction in heat-related work hour losses by 2100 through climate mitigation, equivalent to **€358 million** avoided GDP losses across seven cities

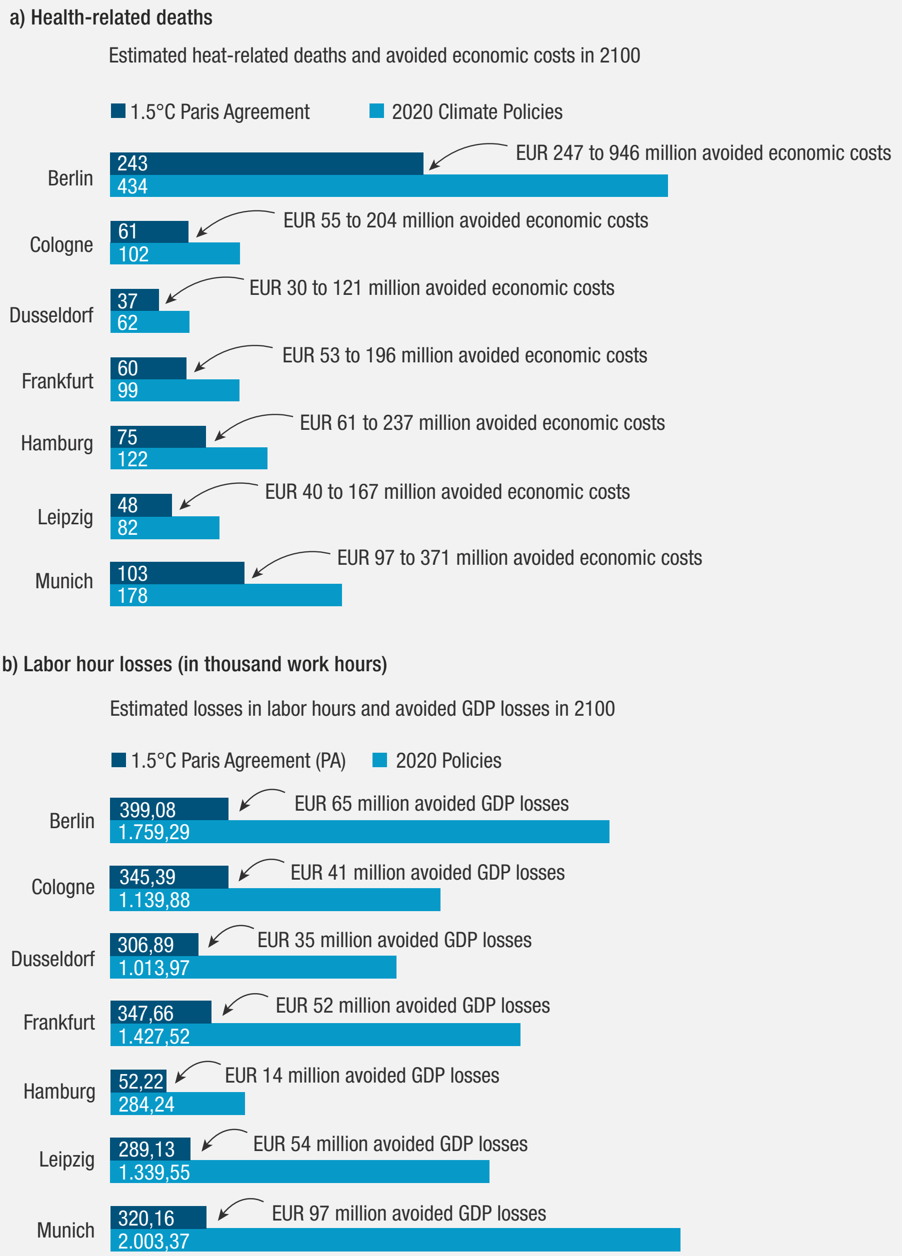
2,200
Number of avoided heat-related emergency admissions if heat risks are addressed through climate mitigation

11 percent
Increase in heat-related mortality by 2050 in a business-as-usual scenario

Mitigating heat risks through effective climate action yields substantial economic benefits by avoiding mortality, morbidity, and productivity losses. The total economic benefit of reducing mortality is estimated to range from €594 million to €3.4 billion by 2100 if the 1.5°C limit is achieved compared to CPS (figure 16). More ambitious global mitigation could also lead to yearly medical cost savings of over €210,000 in the seven cities by 2100, equivalent to avoiding over 2,200 heat-related emergency admissions, highlighting the strain on health care systems under CPS. Heat-related productivity losses, measured by lost working hours, are projected to increase substantially across all seven urban areas, posing a significant threat to the economy, while achieving the 1.5°C goal is estimated to reduce heat-related losses in work hours by 6.9 million hours. This equates to avoided GDP losses of €358 million for the seven cities combined in 2100, directly linking climate resilience to economic productivity.

Even with ambitious global climate action, German cities would need to urgently prepare for substantial heat-related socioeconomic impacts by mid-century and earlier, given the inertia in both the economic and climate systems. Under the CPS, the seven cities would encounter substantial increases in mortality (11 percent), morbidity (14 percent), and productivity losses (36 percent) by 2050 compared to 2030. Under the optimistic Paris Agreement-compatible scenario, German cities would still be expected to experience an 8 percent increase in excess mortality and life years lost, 10 percent increase in emergency admissions, and a 36 percent increase in lost work hours by 2050, compared to 2030. Regardless of which future climate scenario is considered, impacts due to locked-in warming will be substantial up to mid century, particularly on mortality, morbidity and labor productivity, thus supporting the urgent case for adaptation at national and local levels.

Figure 16. Estimated number of heat-related deaths and labor hour losses, with avoided economic costs, in 2100 under two scenarios



Source: Climate Analytics and World Bank 2025, based on PROVIDE Climate Risk Dashboard and EUROSTAT

Note: avoided economic costs are calculated using the Value of Lost Life (VOLY) for lower estimates and the Value of Statistical Life (VSL) for upper estimates.

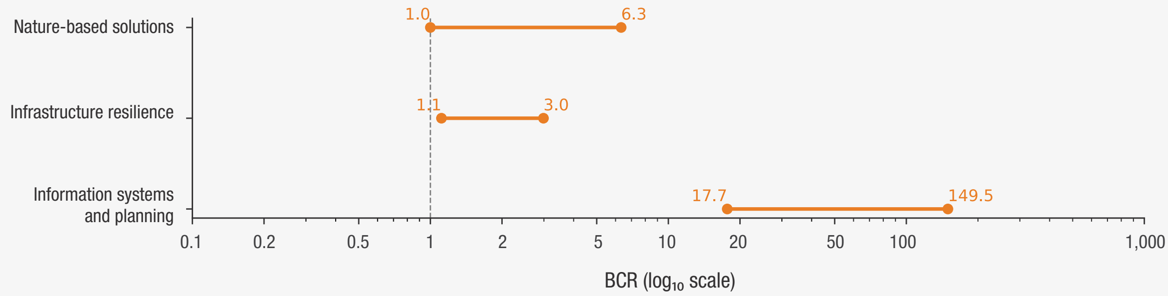
Germany has established a core heat preparedness framework, comprising a national warning system and local action plans, but its coverage remains limited, and implementation requires greater resources and integration. Central to the effort is the national HHWS, developed by the German Meteorological Service (DWD) in 2003, which disseminates timely warnings.[108] This is complemented by HHAPs (with guidelines published at national level and actual responsibilities held by municipalities),[109] which over 20 cities, including Cologne, Berlin, and Leipzig, have published (and more cities are developing) to manage acute heat extremes and focus on vulnerable groups.[110] However, across Germany's roughly 11,000 Gemeinden, HHAP coverage is limited. While local governments in Berlin, Stuttgart, Potsdam, Rostock, and other cities are increasingly implementing urban greening and soft measures, such as heat-adapted planning, trainings or information campaigns, challenges persist.[111] Scaling these efforts is hampered by a lack of resources; the absence of a legal obligation for Gemeinden to create such plans; and difficulties in coordinating actions, assessing effectiveness and reaching the most vulnerable.[112]

Costs and benefits: Heat adaptation measures save lives and yield economic dividends

€1-4
Benefits generated for each €1 invested in heat adaptation

Economic assessments confirm that heat adaptation measures in Germany are highly cost-effective, with benefits generally exceeding costs. Heat adaptation measures assessed in this report yield median benefits of €1–4 for every €1 invested, and up to €500 in certain cases (figure 17). This positive return on investment is often driven by the high BCRs of soft measures and combining green and gray infrastructure measures, which generate significant health, social, and environmental co-benefits. While some hard measures, such as building retrofitting, may have BCRs below 1 due to high investment costs and indirect benefits that are hard to monetize, most adaptation measures show a strong economic rationale, which confirms the need for targeting and prioritizing infrastructure interventions to reduce productivity impacts of heat. Building ventilation and air conditioning are generally most cost-effective and urgent where they mitigate risks to vulnerable populations, such as nursing homes, though no specific BCR estimates are available for Germany. Soft measures, such as improved planning or HHWS, generally show very high BCRs. In general, given the range of returns, adaptation packages that include soft and hard measures are likely to yield higher BCRs than individual infrastructure measures.

Figure 17. Average BCRs of selected heat adaptation measures in Germany



Source: World Bank team

Note: BCR ranges are aggregated and averaged from numerous case studies and analyses, including scientific literature and original analysis conducted for this report.

Up to €500
Benefits per €1 invested in HHWS

Factor of 2–199
Benefits of a nationwide voluntary heat alert register for vulnerable groups exceed costs

Given their low implementation cost and significant life-saving impact, soft adaptation measures are identified as high-yield, no-regret options. The HHWS[113] can yield extremely high economic returns—€80–500 for every €1 invested—primarily by substantially reducing heat-induced mortality and hospitalization. Implementing HHAPs[114] and related soft measures in the health sector also show strong positive effects on real GDP due to both reduced heat-triggered impacts and stimulated economic activity. A nationwide voluntary register for tailored heat alerts (elderly people with pre-existing conditions) is projected to have benefits (avoided morbidity and mortality) that exceed implementation costs by factors of 2 under the most conservative assumptions, and up to around 199 under the most advantageous conditions. A nationwide digital map of cooling spaces, combined with awareness campaigns and water provision, also shows benefits in terms of avoided health costs that outweigh costs by factors of about 3–41. Such information-based interventions could be combined to direct alerted vulnerable people to safe refuge at minimal additional cost, strongly supporting national expansion. The overall portfolio of heat information systems and planning assessed in this report yields median benefits of €3-41 per €1 invested.

Urban heat interventions are essential for safeguarding public health and economic productivity in Germany. Projected increases in heat extremes—even under 1.5°C—necessitate proactive, targeted adaptation measures. Detailed hazard and exposure mapping, particularly using WBGT, provides a robust foundation for identifying vulnerable areas and informing policy decisions. Based on this, policy makers can develop and implement comprehensive city-level HHAPs, leveraging high-resolution urban modeling for street- and building-level heat reduction and tailoring adaptation measures to vulnerable groups considering population projections. Among others, the city of Karlsruhe, which integrated local UHI data and protective factors to refine warning capacity and provide tailored recommendations to vulnerable people, serves as a model.[115] Ultimately, fully integrating heat adaptation into urban planning, health policies, labor protection, and civil protection strategies across all levels of government is crucial for building climate-resilient cities that can protect their populations and economies in a hotter climate, as indicated by initial evidence on these measures' full range of benefits.

5. Preparing for wildfires: once limited in reach, their impacts are spreading

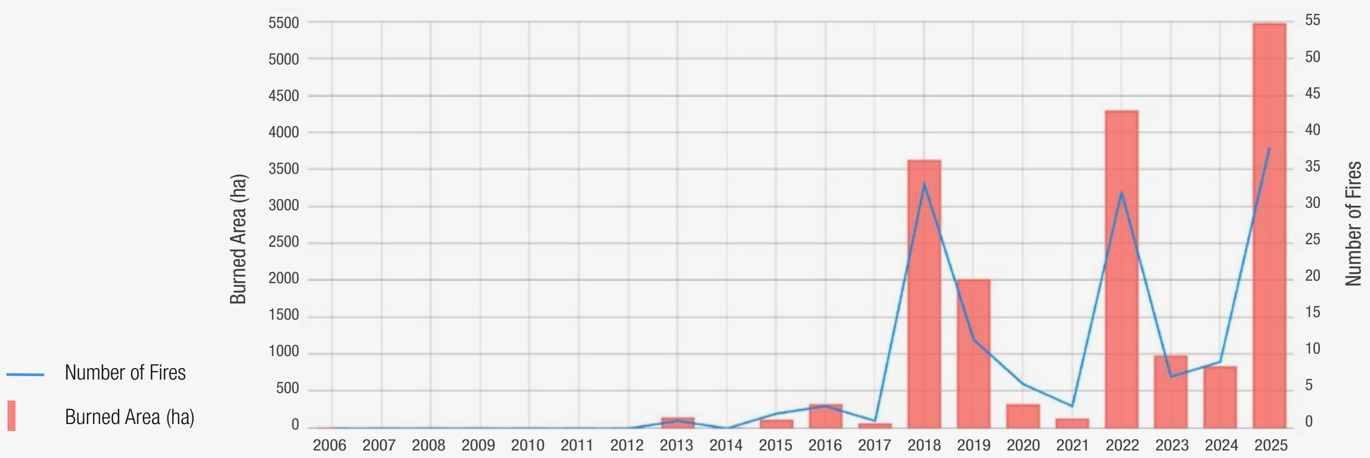
Exposure and impacts: Spreading like wildfire

4,000+ hectares
€5.13 million
Direct damage from wildfires during the 2022 fire season

5,475 hectares
Area burned by wildfires in 2025 (as of November)

Germany is facing rapidly intensifying wildfire risk, with recent seasons demonstrating losses significantly above the long-term average, underscoring the urgent need for proactive interventions. In recent decades, wildfires have become a growing threat, with the 2022 fire season burning over 4,000 hectares and causing €5.13 million in direct damages, dramatically exceeding the 1991–2021 long-term average of €1.87 million (figures 18 and 19).[116] The trend continues to worsen: as of November 2025, over 5,400 hectares had burned in 2025, marking the highest annual area in history and nearly half of the total 12,000 hectares total area burned over 2001–2020.[117] This surge is directly linked to prolonged periods of heat and drought, which have increased wildfire risk, particularly between March and October.[118] Given these emerging risks linked to climate change impacts in Europe, proactive investments in prevention and forest resilience are crucial to prevent potentially catastrophic losses.[119]

Figure 18. Number of fires and burnt area (2006-25)



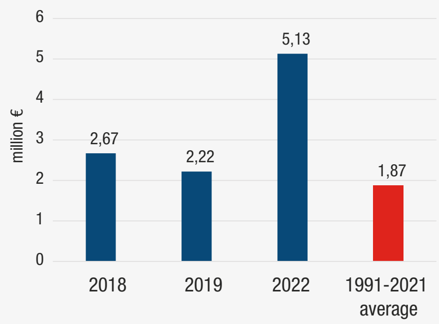
Source: European Forest Fire Information System (EFFIS) 2025 EFFIS Annual Statistics for Germany

Note: Up to 2024, the chart shows full year statistics. 2025 is updated up to November. Fires mapped in EFFIS of approximately 30 hectares or larger.

The wildfire threat is geographically concentrated, and impacts are projected to extend further due to a combination of climate change and forest shifts. Brandenburg is the most severely affected state, with impacts extending far beyond direct damage to include the climate and forestry sectors. Large parts of northeastern and northwestern Germany, and the Upper Rhine Plain, also frequently experience wildfires, but Brandenburg consistently bears the brunt, accounting for 51 percent of the total burned area between 2001 and 2020.[120] This regional disparity is driven by a high proportion of fire-susceptible pure coniferous forests, sandy soils, and ammunition contamination in former military training areas, which complicate firefighting efforts.[121]

Climate change is projected to significantly exacerbate Germany's wildfire risk, necessitating urgent, long-term adaptation and risk reduction measures. The anticipated increase in prolonged droughts and heatwaves will create drier vegetative fuels and overall weather conditions that are highly conducive to wildfire ignition and spread, potentially expanding fire-prone regions into new temperate zones.[122] Future climate projections indicate a substantial increase in some regions in both the frequency and intensity of wildfires, particularly in the northeast and under higher warming scenarios.[123] The German Environmental Agency, Umweltbundesamt, has classified the pessimistic climate risk for forest fires at the end of the century as "high", and adaptation as urgent, given the long lead times.[124] This underscores the immediate need for action, including shifting from vulnerable monocultures to diverse, climate-resilient mixed deciduous forests to enhance overall resilience.[125]

Figure 19. Direct damage from wildfires (2018–21)



Source: World Bank team, based on EFFIS annual fire reports

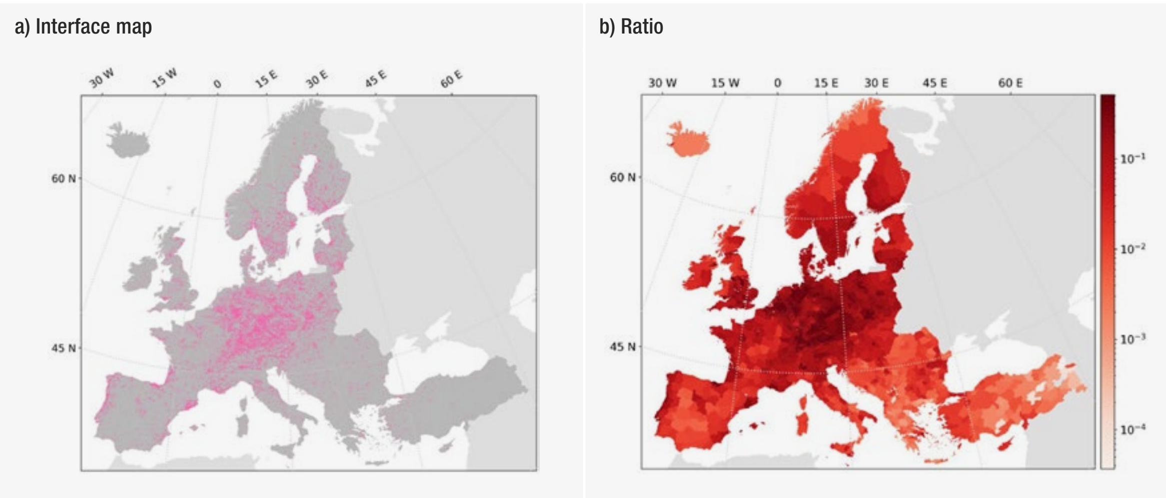
Cascading effects: Wildfires affect critical services, industrial facilities, human health, and ecosystems

High exposure of communities, particularly in periurban areas, to wildfire hazard due to proximity to forested areas is a warning sign when considered in the context of climate trends and forest health. Germany has a high wildland-urban interface area, where forests border settled areas, making communities and infrastructure susceptible to fire due to proximity to high fuel loads and frequent human-induced ignitions.[126] Communities are also vulnerable to wildfire risk: exposure is particularly high near urban centers and in areas with high shares of socially vulnerable people—including young people (under 18) women, and older adults (over 65).[127] Wildfires also release substantial fine dust and air pollutants, with the 2022 fires emitting almost 0.28 million tons of carbon dioxide equivalents, severely compromising the German forest's function as a carbon sink and harming both human health and the environment.[128]

€30–€40 million
Estimated losses to the forestry sector due to wildfires in the 2022 season

Sectoral impacts from wildfires are substantial and projected to worsen. Beyond immediate damage, wildfires cause high losses to the forestry sector, particularly coniferous forests, with the 2022 season resulting in an estimated €30–40 million loss in terms of impacts on forest products.[129] Critical infrastructure is also significantly exposed: over 18,000 km of roads and over 39,000 km power lines are in zones with high wildfire hazard.[130] Emergency response facilities are also at risk, with thousands of fire stations, police stations, health and education facilities located in potential high-hazard areas. And when fires occur in former military training areas, it poses unique challenges for firefighting due to the presence of unexploded ordnance. At 9 percent of its total land area, Germany has Europe's largest wildland-industrial interface area (figure 20). This indicates an urgent need for more refined sector and asset-specific wildfire risk assessments to inform prevention and preparedness investments as well as business contingency planning.[131]

Figure 20. Wildland-industrial interface map and ratio of wildland-industrial interface area over total fuel area map



Source: Planas, E, Paugam, R, Àgueda, A, Vacca, P and Pastor, E. 2023 Fires at the Wildland-industrial Interface. Is There an Emerging Problem? *Fire Safety Journal* 141: 10 3906.

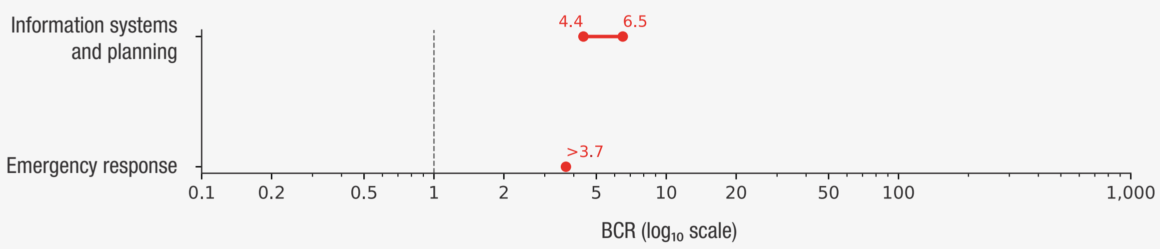
Germany is actively strengthening its wildfire risk management framework through proactive, climate-smart forest management and advanced technology, though it faces resource and scaling challenges, particularly on private lands. Policy is guided by the Federal Forest and Civil Protection Acts, supported by the Forest Climate Fund and EU funds.[132] Prevention efforts emphasize strategic fuel reduction and shifting from vulnerable monocultures to climate-resilient mixed forests.[133] For preparedness, key tools include the DWD's daily fire danger forecasts and Brandenburg's FireWatch camera monitoring system.[134] While local firefighting forces are highly effective (99 percent fires contained under one hectare and within two hours), efforts are focusing on enhancing capabilities for large-scale vegetation fires, including specialized training and equipment, strengthening interagency cooperation, and dedicated aerial firefighting resources.[135] Challenges persist in ensuring consistent implementation of prevention across fragmented private forest ownership, raising public preparedness, evaluating the effectiveness of measures, and securing funding for forest conversion.[136] Examples such as the 2022 Germany-Czechia fire also highlight the need for unified approaches to transboundary fire management.[137]

Costs and benefits: Emerging evidence makes a strong case for investments in wildfire prevention and response

Investing in dedicated wildfire resilience interventions is highly cost-effective and crucial for mitigating substantial economic damage. While there are practically no studies on BCRs of wildfire resilience investments for Germany, findings for other countries confirm that the potential benefits of avoided losses far outweigh the costs. The total potential damage caused by wildfires, particularly when affecting critical infrastructure and industrial sites, justifies proactive investment to reduce future losses. National-level adaptation in forestry in Germany shows potential to reduce up to €40 billion real GDP losses due to climate change.[138] Quantitative evidence from Europe shows that, depending on investments, BCRs range from 1.6–39.3 for varied interventions across Greece, Portugal, Austria, and Sweden in: prevention (fuel management, fire breaks, and water supply; critical infrastructure protection), preparedness (monitoring and early detection; public awareness campaigns), response (fire suppression), and climate adaptation (decision support tool for forestry adaptation).[139] These types of investment are also qualitatively outlined to be beneficial in Germany and are being developed or already implemented in certain states.[140]

New quantitative evidence for Germany also shows that investing in soft measures and forest resilience can yield substantial net benefits. Case studies conducted for this report highlight that investments in wildfire preparedness are highly cost-effective (figure 21). Measures to strengthen early detection and response capabilities are key to contributing to a more resilient landscape in the face of climate risks.

Figure 21. Average BCRs of selected wildfire adaptation measures in Germany



Source: World Bank team

Note: BCR ranges are aggregated and averaged from original analysis conducted for this report.

€4–€7
Return for every €1 invested, as wildfire risk increases under medium and high future climate scenarios

Early detection investments are highly cost-effective, with returns set to increase significantly under future climate change scenarios. Brandenburg's automated FireWatch system, which detects roughly 60 percent of all daylight forest fires, has proven operational reliability, is low cost, and is integrated into state-level response.[141] It currently yields an estimated €3 return for every €1 invested, a figure projected to grow to €4.4–6.5 under medium and high future climate scenarios as wildfire risk increases; this is aligned with BCRs found across Europe for wildfire alert and preparedness factors, which range from 1.6 to 39.3.[142] This information system is estimated to help avoid over €1.2 million in direct losses annually under current conditions, (€2.5 million under a future climate change high warming scenario), confirming a strong value for investment even without considering co-benefits from avoided emissions and health and ecosystem services.[143] To sustain and build on these benefits, opportunities exist to modernize and expand the system, which could reduce damage by an additional 10–15 percent.[144]

Rapid suppression is essential for effective wildfire emergency response, with early aerial intervention offering significant benefits. An illustrative case study on rapid aerial suppression (within 15–30 minutes) versus delayed action shows it can prevent €16,500–27,400 per incident in combined damage and response costs, significantly reducing fire spread and translating to a high BCR of 3.7.[145] This supports evidence that aerial firefighting, though costly and complex, is most beneficial in the initial response phase.[146] Opportunities exist to maximize suppression effectiveness by streamlining authorization, improving equipment, and integrating FireWatch data to directly support aerial dispatch decisions,[147] or using unmanned aerial vehicles and infrared technology for a potential 31 percent suppression cost savings.[148] But challenges remain, as highlighted in Brandenburg's Directorate-General for European Civil Protection and Humanitarian Aid Operations wildfire peer review, including the need to improve the system's capacity to use aerial resources, reduce mobilization time, clarify cost and reimbursement processes, and managing factors such as strong winds, thick smoke, or safety limitations in munition-contaminated areas.[149]

€16,500–27,400
Estimated reduction in damage and response costs for each fire incident when effectiveness of aerial suppression is increased (deployed within 15–30 minutes)

Investing in complementary measures significantly enhances the benefits of wildfire preparedness investments, including action-oriented information campaigns and a crucial shift to climate-smart forest management. Since most wildfires are caused by humans, public education offers substantial benefits by reducing ignition sources.[150] Climate-smart forest management is a cornerstone of long-term prevention and resilience: though initial conversion costs are high, active strategies are considered economically sustainable over the long term (including higher yields), avoiding the nonreversible ecosystem and productivity impacts of passive maladaptive approaches.[151] National-level adaptation in forestry shows potential to reduce up to €40 billion real GDP losses due to climate change.[152] Beyond direct timber yields, these measures offer co-benefits, such as enhancing disaster resilience and supporting the bioeconomy through new biomaterials.[153] Crucially, as German forests have become a net source of carbon dioxide since 2018, due to tree death triggered by droughts and pests, climate-smart management is key to restoring its function as a carbon sink and ecosystem benefits, which can help fund resilience and wildfire management investments.[154]

Wildfire risk management requires a sustained, multilevel investment strategy that prioritizes cost-effective interventions and long-term forest adaptation to prevent escalating climate risks. Given the significant losses avoided on health and economy and the projected exacerbation of risk, proactive investments are needed. Analysis confirms the high value of interventions such as the FireWatch early detection system. Capitalizing on these proven high returns would require investments in modernizing EWS, streamlining deployment protocols, ensuring consistent implementation of climate-smart forest management, and reducing the vulnerability of settlements and critical infrastructures exposed to high risk.

Conclusion and recommendations

Proactive investment in multihazard resilience is an economic imperative for Germany, as avoiding escalating climate impacts offers high returns on investment when carefully evaluated. With future cumulative climate costs projected to reach up to €900 billion by 2050, resilience and prevention measures are an economically rational choice. Resilience investments consistently demonstrate high BCRs, generally yielding a median return of around €2-6 in benefits for Germany for every €1 invested.[155] Specific, hazard-focused findings from the analysis underscore the urgency and value of targeted investments that are economically compelling for safeguarding its population, critical infrastructure, and economy.

Action is needed to enhance civil protection capacities, while mandating the integration of complex, compound, and Natech risks across planning levels. This strategy provides the most robust path for safeguarding people, maintaining economic productivity, and securing the country's economic future against the increasing likelihood of major cascading disasters. Table 3 summarizes recommended priority actions derived from this report and highlights the key role of enhanced civil protection capacities. They include: i) strengthening resilience against compound, cascading, multi-hazard risks through enhancing risk-informed planning, information and early warning systems effectiveness; ii) preventing further increases in flood exposure and impacts through enhanced flood protection measures, supporting flood resilient settlement development and enhancing preparedness to floods; iii) ensuring protection against extreme heat through implementing local prevention and preparedness measures and national level measures to tackle productivity and health impacts; and iv) support wildfire resilience by managing exposure of settlements, industrial facilities, and infrastructure, enhancing ecosystem resilience, and strengthening preparedness and effective response.

Low-regret, soft measures provide the highest and most immediate economic returns, justifying their rapid nationwide implementation to address compound risks. EWS, improved planning, and awareness campaigns are crucial for saving lives and protecting assets across all hazards, forming the cornerstone of effective preparedness. For extreme heat, improving the effectiveness of the national HHWS and its outreach to vulnerable populations has potential for very high returns of up to around €199 for every €1 invested. This is driven by substantially lower mortality and hospitalization costs. Other targeted heat measures—such as a public digital map of cooling spaces combined with awareness—show strong economic net benefits, with BCRs of around €3–41 per €1 invested. For floods, soft EWS measures are highly efficient, returning up to €44.5 for every €1 invested, contributing significantly to the overall median range of BCRs of 2.3-7.6 for all flood adaptation measures.

Technological investments in rapid response and early detection for wildfires offer high, quantifiable returns that are set to increase as climate risk escalates. Brandenburg's automated FireWatch early detection system yields high net benefits (€3 for €1 invested), avoiding over €1.2 million in direct annual losses, and is projected to rise to €4.4–6.5 per €1 invested under future warming scenarios. Rapid aerial suppression also offers a high return (€3.7 per €1 invested), preventing €16,500–27,400 in combined damage and response costs per fire incident through timely intervention.

Long-term structural and ecosystem investments are essential for deep resilience, supported by economic evidence showing a wide range of positive returns. While nonstructural measures show high economic returns, more complex structural flood measures (dikes, infrastructure, wastewater) also yield positive BCRs, typically yielding €1.7–6.8 per €1 invested. Achieving long-term resilience requires financing for integrating gray and green measures, such as urban greening for heat mitigation, creating natural flood plains and polders, and the essential shift to climate-smart forest conversion for long-term wildfire prevention and restoring the forest's function as a vital carbon sink.

Table 3. Recommendations and priority policy actions for Germany to move forward

Actors and sectors	Recommendations and priority policy actions
Strengthen resilience against compound, cascading multi-hazard risks	
Key actors: Federal, state and municipal authorities, companies Key sectors: DRM, civil protection, building and infrastructure	**Enhance multi hazard-risk informed planning:** • Improve vulnerability analytics of critical assets, networks, and settlements and evidence on BCRs of multi-hazard investments • Enhance cross-sectoral and institutional planning for complex emergencies (incl. private sector contingency planning and financing) with "what-if" scenarios • Strengthen resilience of critical infrastructure and building stock
Key actors: Federal, state and municipal authorities, meteorological services, households, companies Key sectors: DRM, civil protection	**Strengthen multi-hazard information and early warning systems:** • Enhance effectiveness of multi-hazard EWS • Support situational awareness and community preparedness (drills, tailored action-oriented communication and warnings, information campaigns)
Prevent increase of flood exposure and impacts	
Key actors: Federal, state and municipal authorities Key sectors: Building and infrastructure, transportation, water, environment	**Enhance comprehensive flood protection measures:** • Identify underprotected areas, enhance protection and strengthen resilience of vulnerable infrastructure and civil protection services • Combine green and grey infrastructure to increase co-benefits • Strengthen evidence for current BCRs for flood hazard interventions
Key actors: Federal, state and municipal authorities Key sectors: Building and infrastructure, spatial planning	**Support flood resilient settlement development:** • Enhance enforcement of flood risk informed land use and spatial planning • Enforce flood risk informed building regulations and incentivize insurance uptake
Key actors: Federal, state and municipal authorities, households, companies Key sectors: DRM, civil protection	**Enhance public preparedness to floods:** • Promote contingency planning of civil protection and critical infrastructure systems • Enhance FEWS effectiveness through action-oriented awareness campaigns
Ensure awareness and preparedness against extreme heat	
Key actors: Municipal authorities, households, companies Key sectors: Building and infrastructure, urban planning, health, civil protection	**Enhance local heat prevention and preparedness:** • Implement urban scale heat reduction measures, including seasonal response planning (cooling spaces, water provision, healthcare capacity) • Support implementation of Heat Health Action Plans by enhancing capacity, coordination, and knowledge exchanges • Retrofit buildings and tackle indoor heat in high risk locations
Key actors: Federal state and municipal authorities, healthcare providers, companies Key sectors: Civil protection, health, building and infrastructure	**Implement measures to tackle heat-related productivity and health impacts:** • Implement measures to address heat-related productivity impacts (e.g. heat protection equipment, labor protection regulations) • Enhance the effectiveness of HEWS (incl. nationwide voluntary heat alert register) and implement sectoral contingency planning (health sector)
Support wildfire resilience of forests, people and assets	
Key actors: Federal state and municipal authorities, companies, forest and landowners, households Key sectors: DRM, civil protection, building and infrastructure	**Manage wildfire exposure of settlements and infrastructure:** • Improve wildfire vulnerability analytics of settlements and critical or industrial infrastructure assets • Promote individual preparedness and contingency planning of communities and industrial sector actors
Key actors: Federal state and municipal authorities, forest and landowners Key sectors: Environment, forestry	**Enhance wildfire resilience of forests and ecosystems:** • Implement forest resilience and wildfire prevention measures in exposed areas (fuel reduction and breaks, forest management, drought resilience, access for emergency services)
Key actors: Federal state and municipal authorities, local and voluntary fire brigades Key sectors: DRM, civil protection	**Strengthen wildfire preparedness and effective response:** • Scenario planning and trainings for wildfires and natural-technological hazards, including managing hazardous chemical materials and unexploded ordnance • Enhance effectiveness of emergency and information services (incl. rapid detection and aerial response, water prepositioning) • Implement public awareness campaigns and tailored action-oriented trainings

Source: World Bank team

Endnotes

1 Umweltbundesamt 2024a Neue Deutsche Anpassungsstrategie soll Klimaresilienz stärken; Trenczek, J, Lühr, O, Eiserbeck, L and Sandhövel, M 2022a Übersicht vergangener Extremwetterschäden in Deutschland: Methodik und Erstellung einer Schadensüber sicht; Trenczek, J, Lühr, O, Eiserbeck, L, Sandhövel, M and Ibens, D 2022b Schäden der Dürre- und Hitzeextreme 2018 und 2019 Eine ex-post-Analyse; Wang, J, Nikolaou, N, an der Haiden, M and Irrgang, C 2024 High-resolution Modeling and Projection of Heat-related Mortality in Germany under Climate Change *Communications Medicine* 4: 206.

2 Flaute, M, Reuschel, S and Stöver, B 2022 Volkswirtschaftliche Folgekosten durch Klimawandel: Szenarioanalyse bis 2050 GWS; Trenczek et al. 2022a.

3 Euronews October 19, 2025 German Federal Office of Civil Protection Publishes Guide Removing War as an "Unlikely" Possibility.

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5 The World Bank and Overseas Development Institute (ODI) Triple Dividend of Resilience framework identifies and quantifies three types of benefits (dividends) in any resilience investment. The triple dividend includes saved lives and avoided losses (dividend 1), induced economic and development benefits (dividend 2), and environmental and social co-benefits (dividend 3). For details, see World Bank. 2021. Economics for Disaster Prevention and Preparedness - Investment in Disaster Risk Management in Europe Makes Economic Sense. and Tanner et al. 2015. The Triple Dividend of Resilience.

6 World Bank and European Commission 2021 Economics for Disaster Prevention and Preparedness: Investment in Disaster Risk Management in Europe Makes Economic Sense.

7 The background analysis for this report is based on a review of 200+ studies, of which 22 had quantitative estimates and six had BCR estimates (20 investments for flood risk reduction, 12 for heat risk reduction, 0 for wildfire risk reduction) specifically for Germany. Additional BCRs were calculated under this project (two investments each for flood risk, heat and wildfire risk reduction). Across all interventions and hazards, the median BCR range is €1.95-6.25 for lower-bound and upper-bound estimates, respectively. The median BCRs for respective hazards ranges from €1 (minimum of lower bound estimates medians for heat) to €7.6 (maximum of upper-bound estimates medians for floods). The average (mean) across all investments and hazards is €5.8-38.8 and the majority of BCR values (both lower and upper bound estimates) indicate benefits of at least €2 per €1 invested. Due to the existence of a few high BCR values and many lower to mid values, the distribution of the BCRs presents a positive skewness of 4.4-3.6 (for lower and upper bound values) when all values are included, indicating a distribution with an asymmetric tail significantly skewed to the right. Thus, this report focuses mostly on median estimates, as they are less sensitive to extreme values.

8 Background analysis on emergency response related asset exposure to multiple hazards undertaken for World Bank 2024 *From Data to Decisions: Tools for Making Smart Investments in Prevention and Preparedness in Europe*. This regional exposure assessment estimates how many emergency response and critical infrastructure assets are exposed to natural hazards across the EU. The spatial exposure assessment is conducted with asset and hazard data from the open sources. The results provide initial insights on CI exposures in Germany and could be further improved by more precise, Germany-specific exposure assessments.

9 Seveso sites are industrial sites that regulated under Seveso III Directive (2012/18/EU) because of the presence of dangerous substances in sufficient quantities. See European Union. 2012. Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC.

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11 Trenczek et al. 2022a. The estimated €40.5 billion total loss includes: 1) a direct losses (€33.1 billion) published by the Federal Ministry of the Interior (BMI) and Federal Ministry of Finance (BMF) in March 2022; 2) operational costs (€0.3 billion) to apply for the Solidarity Fund; and 3) indirect damage (€7.1 billion) due to losses in industrial production resulted from the extreme weather event, etc. (see Trenczek et al. 2022c; Thieken et al. 2023).

12 Rentschler et al. 2023. Extreme flood risk is defined as exposure to more than 1.5-meters inundation depth for a 1-in-100-year flood event.

13 See technical report for more details.

14 48,000 heat-related deaths 2014–23; includes an overall direct economic loss of €20.7 billion in the forestry, industry and commerce, and agriculture sectors (Trenczek et al. 2022b); 8,300, 6,900, and 9,100 heat-related mortality was estimated for 2018, 2019, and 2022, respectively, as a result of unprecedented heatwaves (Wang et al. 2024; Huber, V, Breitner-Busch, S, He, C, Matthies-Wiesler, F, Peters, A and Schneider, A. 2024. Heat-Related Mortality in the Extreme Summer of 2022—an Analysis Based on Daily Data Deutsches Arzteblatt International 121(3): 79–85. Robert Koch Institut. 2025. Aktuelle Daten und Informationen zu Infektionskrankheiten und Public Health: Epidemiologisches Bulletin Trenczek et al. 2022a; Trenczek et al. 2022b).

15 Climate Analytics and World Bank background analysis for this report.

16 *In history* meaning on record in EFFIS large-scale fire mapping; hectares burned as of November 2025; reflected in the Fire Weather Index anomalies (EFFIS. 2025. EFFIS Estimates for European Union: Annual Statistics for Germany; data up to November, 2025).

17 See endnote number 8**.**

18 See technical report for more details.

19 EEA 2024 European Climate Risk Assessment European Environment Agency.

20 BMWK and BMUV 2023 Bezifferung von Klimafolgekosten in Deutschland; Flaute, Reuschel and Stöver 2022; BMWK 2022 Hitze, Dürre, Starkregen: Über 80 Milliarden Euro Schäden durch Extremwetter in Deutschland. Trenczek, J., Oliver Lühr P., Eiserbeck, L., Sandhövel, M., Ibens, D. 2022b. Schäden der Dürre- und Hitzeextreme 2018 und 2019 - Eine ex-post-Analyse.

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22 Annual costs are around €6,9 billion per year 2000-2021 (€145 billion overall cumulative costs due to climate change 2000-2021). Institut für ökologische Wirtschaftsforschung (IÖW). 2023. Kosten durch Klimawandelfolgen in Deutschland. Link.; Annual costs are around €10-32 billion per year projected 2022-2050 (€280-900 billion overall cumulative costs due to climate change 2022-2050). Flaute, Reuschel and Stöver 2022; Trenczek et al. 2022a.

23 Xoplaki, E, Ellsäßer, F, Grieger, J, Nissen, K M, Pinto, J G, Augenstein, M, Chen, T-C, Feldmann, H, Friederichs, P, Gliksman, D, Goulier, L, Haustein, K, Heinke, J, Jach, L, Knutzen, F, Kollet, S, Luterbacher, J, Luther, N, Mohr, S, Mudersbach, C, Müller, C, Rousi, E, Simon, F, Suarez-Gutierrez, L, Szemkus, S, Vallejo-Bernal, S M, Vlachopoulos, O and Wolf, F 2025 Compound Events in Germany in 2018: Drivers and Case Studies *Natural Hazards Earth System Sciences* 25(2): 541–564; Sutanto, S J, Duku, C, Gülveren, M, Dankers, R and Paparrizos, S 2025 Future Intensification of Compound and Cascading Drought and Heatwave Risks in Europe EGUsphere [preprint]. Drought impacts on the economic sector are projected to increase from a median of 3 to 4 months under both SSP1-2.6 and SSP 5-8.5 and up to 6 months (75th percentile) under SSP5-8.5; impacts on the ecosystem sector are anticipated to increase from 3 to 4 months under SSP5-8.5 (Sutanto et al. 2025).

24 Umweltbundesamt 2021b Klimawirkungs- und Risikoanalyse (KwRa) 2021 für Deutschland; EEA 2024; Zscheischler, J, Westra, S, van den Hurk, B J J M, Seneviratne, S I, Ward, P J, Pitman, A, AghaKouchak, A, Bresch, D N, Leonard, M, Wahl, T and Zhang, X 2018 Future Climate Risk from Compound Events *Nature Climate Change* 8(6): 469—477; van den Hurk, B J J M, White, C J, Ramos, A M, Ward, P J, Martius, O, Olbert, I, Roscoe, K, Goulart, H M D and Zscheischler, J 2023 Consideration of Compound Drivers and Impacts in the Disaster Risk Reduction Cycle *iScience* 26(3): 106030; CNN 2025 Wildfire Threat - Fire in Southern France Threatens Marseille; GDV 2019 *Naturgefahrenreport 2019: Die Schaden-Chronik Der Deutschen Versicherer* Gesamtverband der Deutschen Versicherungswirtschaft; Ellsäßer, F, Xoplaki, E, and the The climXtreme research network on climate change and extreme events 2022 Compound Events in Germany: Drivers and Case Studies EGU22-11534.

25 Brienen, S.; Walter, A.; Brendel, C.; Fleischer, C.; Ganske, A.; Haller, M.; Helms, M. 2020. Klimawandelbedingte Änderungen in Atmosphäre und Hydrosphäre: Schlussbericht des Schwerpunktthemas Szenarienbildung (SP 101) im Themenfeld 1 des BMVI-Expertennetzwerks. Bundesministerium für Verkehr und digitale Infrastruktur (BMVI), Berlin. doi:10.5675/ExpNBS2020.2020.02.

26 Intergovernmental Panel on Climate Change (IPCC) 2013 Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

27 See background analysis on emergency response related asset exposure to multiple hazards undertaken for World Bank 2024 based on a total number of assets of 40,938 from open source data sources. This regional exposure assessment estimates how many emergency response and critical infrastructure assets are exposed to natural hazards across the EU. The spatial exposure assessment is conducted with asset and hazard data from the open sources. The results provide initial insights on CI exposures in Germany and could be further improved by more precise, Germany-specific exposure assessments.

28 Umweltbundesamt 2024a; BMUKN December 11, 2024 Bundeskabinett beschließt Anpassungsstrategie an den Klimawandel; Bundesregierung December 11, 2024 Klimaanpassungsstrategie 2024; Umweltbundesamt 2021b; EEA 2024.

29 Planas et al. 2023.

30 In 2018, a 132-day shutdown of goods transport on the Rhine due to low water levels had significant economic impacts, with steel giant ThyssenKrupp producing 200,000 fewer tonnes of steel due to rising fuel prices, and Germany's GDP reduced by an estimated 0.2% (Kaufmann, D January 8, 2019 Low Rhine Poses Threat to Businesses *DW*). During the summer drought of 2022, barges on the Rhine were reduced to load only 30–40% of their capacity to avoid running aground. Between June and August, freight charges for a liquid tanker barge rose from around €20 to about €110 per tonne, leading to an estimated impact on GDP at 0.25% or more (EEA 2024; Wagner, R and Sterling, T August 10, 2022 Low Rhine Water Levels Threaten Germany's Economic Growth *Reuters*.

31 van den Hurk et al. 2023; Corbane, C, Eklund, G, Gyenes, Z, Lentini, A, San-Miguel, J, Durrant, T, Boca, R, Maianti, P, Libertà, G, Oom, D, Branco, A, De Rigo, D, Suarez Moreno, M, Ferrari, D, Roglia, E, Scionti N, Broglia, M, Hrast Essenfelder, A, Toreti, A, Salamon, P, D'angelo, C, Dworak, T, Berglund M, Santini, M, Proietti, C, Tsionis, G, Wood, M, Guagnini, E, Pla Freixa, P, Magrotti, G, De La Rosa Blul, J C, Guglielmelli, A, Krausmann, E, Menoni, S, Faiella, A, Gazzola, V, Boni, M P, Ruiz Moreno, A, Colpo, P, Spagnolo, L, Rembold, F, Baruth, B, Van Wijk, L, Koutelos, K, Valsamos, G, Jungwirth, R, Robuchon, M, Dubois, G, Di Girolamo, F, Schvitz, G, Galariotis, I, Linge, J, Kotseva, B, Krzysztofowicz, M, Jensen, K, Muench, S, Roeslin, S, Bountzouklis, C, Sibilia, A, Rodomonti, D and Salari, S 2024 Cross-Border and Emerging Risks in Europe: Overview of State of Science, Knowledge and Capacity. Publications Office of the European Union.

32 EEA 2024.

33 EEA 2024; Umweltbundesamt 2021b; BMUV 2023 Federal Climate Adaptation Act.

34 Federal Ministry for Economic Cooperation and Development (BMZ) 2022c Disaster Risk Management Understanding Risks, Preventing Disasters, Strengthening Resilience.

35 Corbane et al. 2024.

36 van den Hurk et al. 2023. Low-income and vulnerable groups are more likely to live in high-risk areas and struggle to recover (Schneider et al. 2022; Zhang et al. 2024; Schneider et al. 2023; Scherber 2014; Fekete and Nehren 2023; Thieken et al. 2016).

37 Corbane et al. 2024.

38 Corbane et al. 2024.

39 Kern and Krausmann 2020; Umweltbundesamt. 2019. Biogasanlagen [cited in Kern and Krausmann 2020].

40 Maerkische Allgemeine. 2019. Waldbrand bei Jüterbog gelöscht [cited in Kern and Krausmann 2020].

41 Kuhn 2021.

42 These include direct impacts on installations and public services used by the military, and increased demand for military support for natural disaster response, instability, conflict escalation, etc. (Tavares Da Costa, R and Krausmann, E 2021 Impacts of Natural Hazards and Climate Change on EU Security and Defence Publications Office of the European Union).

43 14 megatrends to be considered for Natech and crossborder risks in complex and dynamic ways, also interacting in parts with climate change (Corbane et al. 2024).

44 Corbane et al. 2024.

45 Evidence based on analysis of a selection of Natech accidents suggests that such events have severe monetary impacts compared to purely technical accidents, although reporting is toward severe accidents, and Natech accidents are likely underreported. Further research based on improved reported datasets (events and impacts) would have to be undertaken to understand these aspects better (Corbane et al. 2024).

46 Ricci, F, Casson Moreno, V and Cozzani, V 2021 A Comprehensive Analysis of the Occurrence of Natech Events in the Process Industry *Process Safety and Environmental Protection* 147: 703–713; Corbane et al. 2024; Krausmann, E, Cruz, A and Salzano, E 2017 Natech Risk Assessment and Management: Reducing the Risk of Natural-Hazard Impact on Hazardous Installations. Elsevier.

47 Bundesamt für Justiz 2020 Gesetz über den Zivilschutz und die Katastrophenhilfe des Bundes.

48 BMUV 2023.

49 Sectoral laws and regulations have been established to address specific hazard risks, while states often enact their own laws on emergency and disaster response and climate adaptation, subject to local context.

50 BMZ 2025 Preventing Disasters – Enabling Sustainable Development; European Commission 2021 Germany. For critical infrastructure and networks, insights from the KLIWAS studies with detailed vulnerability assessments of transport networks were used to inform sectoral investment strategies, adjustment of tailored regulations, management, and coordination as well as more overarching strategies, such as the German National Adaptation Strategy over the past 10 years (KLIWAS. 2015. KLIWAS — Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt — Entwicklung von Anpassungsoptionen).

51 The DWD is responsible for weather forecasting and issuing official warnings of extreme weather phenomena that pose potential danger to the public, while flood and seismological monitoring and early warnings are provided at state level in cooperation with federal authorities. During a disaster or emergency event, response operations are carried out by different civil protection actors—fire services, Federal Agency for Technical Relief (THW), local disaster management authorities, and participating relief organizations—and supported by the Federation when asked for assistance (European Commission 2021). To enhance public preparedness, information and awareness-raising campaigns have been established at local levels, supporting local groups and organizations working in the field of community-based disaster risk management (BMZ 2025).

52 Federal Ministry for the Environment Nature Conservation, Building and Nuclear Safety, Germany 2012 TRAS 310 Technical Rule on Installation Safety 310: Precautions and Measures against the Hazard Sources Precipitation and Floods. Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, Germany 2015 TRAS 320 Precautions and Measures against the Hazard Sources Wind, Snow Loads and Ice loads.

53 BBK Federal Office for Civil Protection.

54 European Commission EU Preparedness Union Strategy; Necci, A and Krausmann, E 2022 Natech Risk Management: Guidance for Operators of Hazardous Industrial Sites and for National Authorities; Girgin, S, Necci, A and Krausmann, E 2019 Dealing with Cascading Multi-hazard Risks in National Risk Assessment: The Case of Natech Accidents *International Journal of Disaster Risk Reduction* 35: 101072; Krausmann, Cruz and Salzano 2017; Poljansek, K, Casajus Valles, A, Marín Ferrer, M, Artes-Vivancos, T, Boca, R, Bonadonna, C, Branco, A, Campanharo, W, De Jager, A, de Rigo, D, Dottori, F, Durrant Houston, T, Estreguil, C, Ferrari, D, Frischknecht, C, Galbusera, L, García Puerta, B, Giannopoulos, G, Girgin, S, Gowland, R, Grecchi, R, Hernandez Ceballos, M A, Iurlaro, G, Kambourakis, G, Karlos, V, Krausmann, E, Larcher, M, Lequarre, A S, Libertà, G, Loughlin, S C, Maianti, P, Mangione, D, Marques, A, Menoni, S, Montero Prieto, M, Naumann, G, Necci, A, Oom, D, Pfieffer, H, Robuchon, M, Salamon, P, Sangiorgi, M, San-Miguel-Ayanz, J, Sousa, M L, Theocharidou, M, Theodoridis, G, Trueba Alonso, C, Tsionis, G, Vogt, J V, and Wood, M 2021. Recommendations for National Risk Assessment for Disaster Risk Management in EU – Where Science and Policy Meet – Version 1 European Commission; Corbane et al. 2024. RAPID-N web-based decision-support system for rapid Natech risk analysis is available online free of charge—see, e.g., OECD/EU. 2024. Managing Risks from Natural Hazards to Hazardous Installations (Natech): A Guide for Senior Leaders in Industry and Public Authorities, OECD Series on Chemical Accidents.

55 Some industrial actors, particularly in the Rhine corridor, have gone beyond legal requirements by planning for climate-amplified flood risks to avoid costly shutdowns but these remain isolated cases rather than systematic practice (ChemCologne 2014 Compact Trockene Anlagen auch bei starkem Hochwasser *ChemCologna Compact* 1/2014: 12).

56 Higginbotham, A January 2016 There Are Still Thousands of Tons of Unexploded Bombs in Germany, Left Over From World War II *Smithsonian Magazine*.

57 Tzioutzios, D, Suarez-Paba, M, Luo, X and Cruz, A 2024 Natech Risk Communication *Oxford Research Encyclopedia of Natural Hazard Science*; van den Hurk et al. 2023; Hu, X, Wang, Y, Mao, Y and Tong, R 2025 Coping with Gray Swans: Scenario-task-driven Adaptive Governance for Natech Risks *International Journal of Disaster Risk Reduction* 128: 105744.

58 Corbane et al. 2024.

59 Hölscher, L, Schulze, P, Kohli, A and Peter, M 2025 *Ausgaben des Bundes für die Anpassung an den Klimawandel* Umweltbundesamt. A total of €612.6 million was paid to Germany through the EU Solidarity Fund after the 2021 floods (European Parliament, 2022 Seven Countries to Receive Nearly €720 million in EU Aid After Natural Disasters in 2021 Press release, November 17.

60 Corbane et al. 2024.

61 For diverse investments in preparedness for health systems and fast oil spill clean-ups, nuclear hazard impact prevention such as uranium leakage, nuclear power plant contingency mechanisms and security, chemical risk prevention and remediation through hazardous waste clean-ups, multihazard EWS, emergency equipment, and awareness raising campaigns (World Bank and European Commission 2021).

62 World Bank and European Commission 2021.

63 Natech accidents are, by definition, *compounding and cascading*, making it difficult to model all the potential outcomes. Costs can be direct (e.g., property damage), indirect (e.g., supply chain disruption), and intangible (e.g., loss of life, environmental degradation). Assigning a monetary value to these is methodologically complex and often contentious. Comprehensive, publicly available data on all technological incidents, their natural triggers, and the full extent of their costs is often limited due to proprietary information, security concerns, and the difficulty of tracking all long-term effects. Despite this, studies have shown an increase in the number of recorded Natech events in the last 70 years and particularly since the early 1990s—mostly triggered by storms, lighting, and extreme temperatures, followed by hydrological

and seismic disasters—and a greater impact in countries with high distribution of industrial activities in Europe, including Germany, Italy, and France (Brignone, M, Santamato, F, Ravina, M, Busini, V and Panepinto, D 2025 NaTech Database and Methodologies for its Risk Assessment: A Review *Natural Hazards* 121: 19565–19590; Ricci et al. 2021). A few databases on technological incidents have been established at EU level, such as the eNatech database (which provides publicly available information on Natech accidents including about the initiating cause (type of natural hazard), date, time, and sites of events, information about the industrial facility, the sequence of events leading to the critical event (fire, explosion, or toxic substances release), contributing factors, hazardous substances involved, environmental conditions, emergency response activities, and consequences for human health, the environment, the economy, and communities) and the eMARS (Major Accident Reporting System), first established by the EU's Seveso Directive 82/501/EEC in 1982.

64 BMWK 2023 Was uns die Folgen des Klimawandels kosten – Merkblatt #05. Schäden von Flutereignissen in Deutschland.

65 Surminski, S, Roezer, V and Golnaraghi, M 2020 *Flood Risk Management in Germany - Building Flood Resilience in a Changing Climate* The Geneva Association.

66 Trenczek et al. 2022a.

67 Schäfer, A, Mühr, B, Daniell, J, Ehret, U, Ehmele, F, Küpfer, K, Brand, J, Wisotzky, C, Skapski, J, Rentz, L, Mohr, S and Kunz, M 2021 Hochwasser Mitteleuropa, Juli 2021 (Deutschland): 21. Juli 2021—Bericht Nr. 1 „Nordrhein-Westfalen & Rheinland-Pfalz" CEDIM Forensic Disaster Analysis Group; Thieken et al. 2023.

68 This includes 1) direct losses (€33.1 billion), published by the BMI and BMF in March 2022; 2) operational costs (€0.3 billion) to apply for the Solidarity Fund; and 3) indirect damage (€7.1 billion) for losses in industrial production resulting from the flood (Trenczek et al. 2022c; Thieken et al. 2023).

69 Thieken et al. 2016.

70 Background analysis on emergency response-related asset exposure to multiple hazards undertaken for World Bank 2024.

71 Koks et al. 2019.

72 See endnote number 8.

73 Rheinlandpfalz Die Landesregierung 2021.

74 Koks, E E, van Ginkel, K C H, van Marle, M J E and Lemnitzer, A 2022 Brief Communication: Critical Infrastructure Impacts of the 2021 Mid-July Western European Flood Event *Natural Hazards Earth System Sciences* 22: 3831–3838; von Hauser, C September 16, 2021 Wie geht es weiter auf den gesperrten Autobahnen A1, A61 und A553? *Rheinische Post*. Roads, railways, wastewater, health care, and education were expected to have particularly long reconstruction timelines.

75 Koks et al. 2022.

76 RND July 23, 2021 Milliarden-Schäden nach Flut: Bahn braucht Monate, um zerstörte Strecken wiederherzustellen *RedaktionsNetzwerk Deutschland*; DKKV 2022 DKKV Anfrage: Informationen zur Flutkatastrophe im Ahrtal Deutsches Komitee Katastrophenvorsorge e.V.

77 Hauser 2021.

78 Koks et al. 2022.

79 Koks et al. 2022.

80 EEA 2024.

81 Hallegatte, S Rentschler, J and Rozenberg, J 2019 *Lifelines: The Resilient Infrastructure Opportunity* World Bank; Maiwald, H, Schwarz, J, Kaufmann, C, Langhammer, T, Golz, S and Wehner, T 2022 Innovative Vulnerability and Risk Assessment of Urban Areas Against Flood Events: Prognosis of Structural Damage with a New Approach Considering Flow Velocity Water 14(18): 2793; Fekete, A 2020 *Critical* Infrastructure Cascading Effects. Disaster Resilience Assessment for Floods Affecting City of Cologne and Rhein-Erft-Kreis *Journal of Flood Risk Management* 13(2): e312600; Schneider, M, Priesmeier, P, Fekete, A, Lichte, D and Fiedrich, F 2024 Cascading Effects of Critical Infrastructures in a Flood Scenario: A Case Study in the City of Cologne *Proceedings of the International ISCRAM Conference*; Fehling, D, Arns, A and Vafeidis, A 2022 Current and Future Exposure of Critical Infrastructure to Coastal Flooding in Rostock, Germany EGU22-5054.

82 Wassmer, J, Bryant, S, Schimansky, P, Keegan, L T, Pregnolato, M, Kurths, J, Marwan, N and Merz, B 2025 Unveiling Hidden Risks in Health Care from Flood-induced Transportation Disruption in Germany *Communications Earth & Environment* 6: 676.

83 Umweltbundesamt 2021b; Umweltbundesamt 2021a Climate Impact and Risk Assessment 2021 for Germany (Summary); DWD 2022 Nationaler Klimareport.

84 Umweltbundesamt 2021a.

85 Background analysis for this report.

86 Rözer, V, Müller, M, Bubeck, P, Kienzler, S, Thieken, A, Pech, I, Schröter, K, Buchholz, O and Kreibich, H 2016 Coping with Pluvial Floods by Private Households. Water 8(7): 304.

87 Background analysis for this report.

88 The NHWSP comprises around 110 flood protection measures and 242 submeasures. LAWA 2023 10 Jahre Nationales Hochwasser schutzprogramm (NHWSP); DKKV 2015 Das Hochwasser im Juni 2013: Bewährungsprobe für das Hochwasserrisikomanagement in Deutschland. DKKV-Schriftenreihe Nr. 53; Schuh, C and Hatz, M 2018 The German National Flood Protection Programme: Evaluating the Impact of Supraregional Flood Protection Measures on Extreme Floods Using Hydrodynamic Modelling *River Flow 2018 - Ninth International Conference on Fluvial Hydraulics 40*; Umweltbundesamt 2022a More Space for Rivers.

89 Government of Germany. 2009. Gesetz zur Ordnung des Wasserhaushalts (Wasserhaushaltsgesetz - WHG); Gocht, C 2024 Institutional Approaches to Flood Risk Management in Vietnam and Germany - A Comparison *EGU General Assembly Conference Abstracts*; Umweltbundesamt 2022b Identifying and Managing Flood Risks; Höllermann, B, Evers, M and Johann, G 2022 The Safety Paradox in Flood Protection: The Importance of Communicating and Contextualizing Uncertainties EGU22-9160; Umweltbundesamt 2021a.

90 Umweltbundesamt. 2022a.

91 Background analysis for this report.

92 Otto, A, Hornberg, A and Thieken, A 2016 Local Controversies of Flood Risk Reduction Measures in Germany. An Explorative Overview and Recent Insights *Journal of Flood Risk Management* 11(S1): S382–S394.

93 Surminski, Roezer and Golnaraghi 2020.

94 Around €2-5 when excluding extreme values above €10.

95 For infrastructure resilience, estimates are highest for securing oil tanks, as this measure has potential to avoid extreme damages and costs from oil spillages and associated pollution clean-up costs (BCR of 32.3–332.5). The average BCR of protection measures, excluding oil-specific measures, is 1.6–14.2. The lowest BCRs (0.01–0.24) are found for building extreme weather-resilient power line networks.

96 Flaute, Reuschel and Stöver 2022; Voß, M, Kahlenborn, W, Porst, L, Dorsch, L, Nilson, E, Rudolph, E and Lohrengel, A F 2021 Klimawirkungs- und Risikoanalyse 2021 für Deutschland – Teilbericht 4: Risiken und Anpassung im Cluster Infrastruktur *Climate Change* 23.

97 Tröltzsch, J, Görlach, B, Lückge, H, Peter, M and Sartorius, C 2012 Kosten und Nutzen von Anpassungsmaßnahmen an den Klimawandel - Analyse von 28 Anpassungsmaßnahmen in Deutschland.

98 Thieken et al. 2023.

99 Kox, T, Lüder, C and Gerhold, L 2018 Anticipation and Response: Emergency Services in Severe Weather Situations in Germany *International Journal of Disaster Risk Science* 9: 116–128.

100 Murdock, H, Heidenreich, A, Bubeck, P and Thieken, A H 2023 Analysing Emergency Response with an Online Survey of Local Residents following the July 2021 Flood Event in Western Germany EGU-8809.; Kreibich, H., Hudson, P. and Merz, B., 2021. Knowing what to do substantially improves the effectiveness of flood early warning. *Bulletin of the American Meteorological Society*, 102(7), pp.E1450-E1463.

101 Government of Germany 2009.

102 Albrecht, J and Hartmann, T 2021 Land for Flood Risk Management—Instruments and Strategies of Land Management for Polders and Dike Relocations in Germany *Environmental Science & Policy* 118: 36–44.

103 Includes an overall direct economic loss of €20.7 billion in the forestry, industry and commerce, and agriculture sectors (Trenczek et al. 2022b); 8,300, 6,900, and 9,100 heat-related mortality were estimated for 2018, 2019, and 2022, respectively as a result of unprecedented heatwaves (Wang et al. 2024; Huber et al. 2024; Trenczek et al. 2022a; Trenczek et al. 2022b).

104 Climate Analytics and World Bank background analysis for this report. The reference period is 2011–20 for the current climate; the study largely builds on existing studies and data from the Horizon Europe PROVIDE project, with simplified methodologies used to link existing research to health and labor productivity impacts. Based on the PROVIDE Climate Risk Dashboard as a primary source for urban heat stress data and projections, two defined climate scenarios are used in this analysis: 1) A Paris Agreement-compatible scenario (SSP1-1.9), where a broader shift toward sustainable development is combined with stricter climate policies and global warming peaks at 1.6°C in 2060 and declines to 1.3°C by 2100; and 2) the 2020 CPS (SSP2-4.5), where no further climate action is taken beyond climate policies that were in place in 2020, and global warming reaches 2.9°C by 2100 and continues increasing into the next century.

105 Wang et al. 2024. High-resolution modeling and projection of heat-related mortality in Germany under climate change. Communications Medicine 4:206.

106 Markus et al. 2022. Volkswirtschaftliche Folgekosten durch Klimawandel: Szenarioanalyse bis 2050. Studie im Rahmen des Projektes Kosten durch Klimawandelfolgen in Deutschland. GWS Research Report No. 2022/02.

107 Markus et al. 2022.

108 Warnings are disseminated to the public, health care providers, and federal state ministries based on weather and perceived temperature forecasts (Mücke, H and Litvinovitch, J M 2020 Heat Extremes, Public Health Impacts, and Adaptation Policy in Germany. Int J Environ Res Public Health. 2020 Oct 27;17(21):7862. Matzarakis, A 2022 Heat Health Warning System in Germany - New Developments and Lessons Learned *EMS Annual Meeting Abstracts* 19: EMS2022-37).

109 In Germany, while the aim is to reduce heat stress and impacts on the national level, HHAPs largely remain a responsibility of municipalities. The Climate Adaptation Law ('Klimaanpassungsgesetz') adopted in 2024 emphasizes the need to address extreme heat in strategies and action plans at the municipal level. Nevertheless, guidelines and recommendations for HHAPs have been published at the national level in the past decades. For instance, guided by recommendations from the World Health Organization and the National Adaptation Strategy on Climate Change, the Ministry of Environment adopted and published recommendations for the development of a national HHAP in 2017. In 2023, Germany's Federal Ministry of Health published a national 'Heat protection plan for Health' to strengthen and advance activities of the federal government, federal states, local authorities, civil society, and the general public. In addition, the Federal Ministry of Health published template heat protection plans for organised sports, pharmacies and outpatient psychological practices in 2025.

110 HHAPs represent an integrated approach combining short-, medium-, and long-term health protection measures, with public health services playing a crucial, though regionally varied, role in their implementation (Geffert, K, Rehfuess, E and Rechel, B 2022 The Role of Public Health Services in Implementing Heat Health Action Plans in Germany European Journal of Public Health 32(3): ckac130.070; Ochsmann, M 2025 Hitzeaktionspläne in der kommunalen Praxis). The Leipzig HHAP, adopted in 2025 to fill the gap of coordinating actions and ensure adequate crisis management during extreme heat events, focuses on managing acute heat extremes, risk communication, and awareness-raising, with particular concerns for protecting three vulnerable groups: infants and young children, elderly, and homeless people (City of Leipzig. 2024. Leipzigs Hitzeaktionsplan für die Jahre 2024 bis 2026).

111 Examples include heat stress reduction through urban planning in Stuttgart and Berlin's city climate development StEP Klima-plan (Mahlkow, N and Donner, J 2016 From Planning to Implementation? The Role of Climate Change Adaptation Plans to Tackle Heat Stress: A Case Study of Berlin, Germany *Journal of Planning Education and Research* 37(4)). Remscheid, Potsdam, and Rostock are also emerging as climate pioneers in their regions, demonstrating effective local transformation pathways (Haupt, W, Kern, K and Irmisch, J L 2022 From Climate Policy Pioneers to Climate Policy Leaders? The Examples of the Eastern German Cities of Potsdam and Rostock *Urban Research & Practice* 17(1): 29–50; Haupt, W and Kern, K 2022 Explaining Climate Policy Pathways of Unlikely City Pioneers: The Case of the German City of Remscheid *Urban Climate* 45: 101220; Zanocco, C and Sousa-Silva, R 2023 Extreme Heat Experience Influences Public Support for Local Climate Adaptation Policies in Germany *Urban Climate* 52: 101759; Huber, B and Dunst, L 2021 *Climate Change Adaptation in Urban Land Use Planning. On the Integration Status of Climate Adaptation-relevant Measures in Land-use Plans and Local Development Plans of Medium-sized Cities in Germany*; Herrmann, A, Haefeli, W E, Lindemann, U, Rapp, K, Roigk, P and Becker, C 2019 Epidemiology and Prevention of Heat-related Adverse Health Effects on Elderly People *Zeitschrift für Gerontologie und Geriatrie* 52(5): 487–502; Otto, A and Thieken, A H 2024 How Do Childcare Centers Cope With Heat? – Findings of a Mixed-method Approach from Three German Cities *Climate Risk Management* 44: 100597; Heidenreich, A, Deppermann, L H, Thieken, A H and Otto, A 2024 Maßnahmen zur Hitze- und Starkregenvorsorge in Kitas und Pflegeeinrichtungen: Eine Evaluation von Risikowahrnehmung, Kommunikation und Informationsmaterialien *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* 67:730–739).

112 Hannemann, L, Janson, D, Grewe, H A, Blättner, B and Mücke , H-G 2023 Heat in German Cities: A Study on Existing and Planned Measures to Protect Human Health *Journal of Public Health* 32: 1733–1742; Blättner, B, Janson, D, Roth, A, Grewe, H A and Mücke, H-G 2020 Health Protection Against Heat Extremes in Germany: What Has Been Done in Federal States and Municipalities? *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* 63(8): 1013–1019.

113 Developed by the DWD in 2003, the HHWS serves as a central component of Germany's heat preparedness framework, providing timely heat warnings based on weather forecasts and perceived temperature models, and incorporating thresholds for strong and extreme heat stress. Its primary objective is to reduce heat-related mortality by disseminating information and warnings to the general public, health care providers, and federal state ministries. Beyond the national system, cities like Karlsruhe have further refined their warning capabilities by integrating local UHI data and protective factors to provide tailored recommendations for vulnerable populations (Mücke and Litvinovitch 2020; Matzarakis 2022; Gangwisch, M and Matzarakis, A 2024 Composition of Factors for Local Heat Adaptation Measures at the Local Level in Cities of the Mid-latitude – An Approach for the South-west of Germany *Environment International* 187: 108718.).

114 By the end of 2024, more than 20 German cities and districts had published HHAPs, and more than 20 Gemeinden were developing one. Examples include HHAPs in Mannheim, Cologne (for the elderly), and Berlin (with specific plans for various health sector target groups). But given that Germany has a total of around 11,000 Gemeinden, the overall number of HHAPs remains relatively limited, though some cities are actively pursuing heat preparedness measures even without a formal HHAP. HHAPs represent an integrated approach combining short, medium, and long-term health protection measures, with public health services playing a crucial, though regionally varied, role in their implementation. The quality of HHAPs implementation is hampered by barriers such as lacking resources and competing priorities and lack of information on effectiveness of strategies and measures (Ochsmann, M 2025 Hitzeaktionspläne in der kommunalen Praxis; Deutsches Institut für Urbanistik (Difu). 2025. Hitzeaktionspläne in der kommunalen Praxis; Winklmayr, C, Matthies-Wiesler, F, Muthers, S, Buchien, S, Kuch, B, an der Heiden, M and Mücke, H-G 2023 Heat in Germany: Health Risks and Preventive Measures *Journal of Health Monitoring* 8(4): 3–32; StadtMannheimer 2021 Mannheimer Hitzeaktionsplan: Anpassung an den Klimawandel in Mannheim; Stadt Köln 2022 Hitzeaktionsplan für Menschen im Alter German Climate Change and Health Alliance 2022 Musterhitzeschutzpläne; Geffert, Rehfuess and Rechel 2022; Hannemann et al. 2023; Blättner et al. 2020.

115 Gangwisch and Matzarakis 2024.

116 San-Miguel-Ayanz et al. 2023; Thies, B 2025 Machine Learning Wildfire Susceptibility Mapping for Germany Natural Hazards 121: 12517–12530; EFFIS. 2025; San-Miguel-Ayanz, J, Durrant, T, Boca, R, Libertà, G, Branco, A, De Rigo, D, Ferrari, D, Maianti, P, Artés Vivancos, T, Oom, D, Pfeiffer, H, Nuijten, D and Leray, T 2019 Forest Fires in Europe, Middle East and North Africa 2018; San-Miguel-Ayanz, J, Durrant, T, Boca, R, Libertà, G, Branco, A, De Rigo, D, Ferrari, D, Maianti, P, Artés Vivancos, T, Oom, D, Pfeiffer, H and Grecchi, R 2020 Forest Fires in Europe, Middle East and North Africa 2019.

117 Reflected in the Fire Weather Index anomalies (EFFIS 2025, data up to November 2025).

118 Gnilke, A and Sanders T 2021 Forest Fire History in Germany (2001–2020) Thünen-Institut of Forest Ecosystems; DWD 2025 German Climate Atlas; Thies 2025.

119 Costa, H, de Rigo, D, Libertà, G, Houston Durrant, T and San-Miguel-Ayanz, J 2020 European Wildfire Danger and Vulnerability in a Changing Climate: Towards Integrating Risk Dimensions Publications Office of the European Union; Gudmundsson, L, Rego, F C, Rocha, M and Seneviratne, S I 2014 Predicting Above Normal Wildfire Activity in Southern Europe as a Function of Meteorological Drought *Environmental Research Letters* 9(8):084008.

120 Umweltbundesamt 2024b. Waldbrände; Gnilke and Sanders 2021.

121 Umweltbundesamt 2024b; Gnilke and Sanders 2021.

122 Heisig, J, Olsonm, E and Pebesma, E 2022 Mapping Wildfire Fuels, Behavior, and Hazard in a Managed Temperate Forest Using Airborne LiDAR and Sentinel-1 & -2 EGU General Assembly 2022; Feyen, L, Ciscar, J C, Obarreta, D, Soria, A et al. 2020 Climate Change Impacts and Adaptation in Europe. JRC PESETA IV Final Report Publications Office of the European Union; Gerberding, K and Schirpke, U 2025 Mapping the Probability of Forest Fire Hazard Across the European Alps Under Climate Change Scenarios *Journal of Environmental Management* 377: 124600; Costa, H., de Rigo, D., Libertà, G., Houston Durrant, T., San-Miguel-Ayanz, J., European wildfire danger and vulnerability in a changing climate: towards integrating risk dimensions, EUR 30116 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN: 978-92-76-16898-0, doi:10.2760/46951, JRC119980 Content.

123 Frequency used here for intensity. Costa et al. 2020, with projections at regional level and subject to refinements under current the European Commission's JRC PESETA V; Horn, K H, Vulova, S, Li, H and Kleinschmit, B 2025 Modelling Current and Future Forest Fire Susceptibility in North-eastern Germany *Natural Hazards Earth System Sciences* 25: 383–401.

124 Kahlenborn, W, Porst, L, Voß, M, Fritsch, U, Renner, K, Zebisch, M, Wolf, M, Schönthaler, K and Schauser, I 2021 *Climate Impact and Risk Assessment 2021 for Germany* (English Summary) Umweltbundesamt.

125 Kahlenborn et al. 2021.

126 Forests border the majority of German cities and most settled areas to within a 50-meter buffer zone, making the country prone to fire risks due to its proximity to potential fuel loads (Fekete and Nehren 2023; Costa et al. 2020).

127 Fekete and Nehren 2023.

128 Umweltbundesamt 2024b.

129 AGDW 2025 Krise im Wald; DStGB 2022 Feuerwehr-Zwischenbilanz: Rekord-Waldbrandjahr 2022; Gnilke and Sanders 2021; DVF August 26, 2022 Rekord-Waldbrandsommer 2022: Fast 4300 Hektar Wald verbrannt – Waldeigentümer und Feuerwehren fordern finanzielle Unterstützung für Präventionsmaßnahmen Deutscher Feuerwehr Verband; DPT April 23, 2023 Bessere Waldbrandbekämpfung gefordert Deutscher Präventionstag; Eriksen, C., Hauri, A., Aebi, S., and Kamberaj J. 2023. Adapting to Climate Change: Lessons for Swiss Civil Protection.

130 See endnote number 8.

131 Planas et al. 2023.

132 Resilience projects are supported by the Forest Climate Fund for Resilience, EU funds, such as the European Agricultural Fund for Rural Development (EAFRD), and through regional cooperation. Germany's approach is guided by overarching strategies, including the German Strategy for Adaptation to Climate Change (DAS), Climate Action Plan 2050, Forest Strategies 2020 and 2050, National Biodiversity Strategy, and National Bioeconomy Strategy and supported by the Civil Protection Act, as well as various national laws on forests, natural conservation, and environment and ecosystem protection, including the Federal Forest Act, the Nature Conservation Act Nature conservation, the Forest Damage Compensation, the Federal Climate Change Mitigation and the Fuel Emissions Trading Acts (Scientific Advisory Board on Forest Policy (WBW) 2022 Adaptation of Forests and Forestry to Climate Change; BBK 2022 Deutsche Strategie zur Stärkung der Resilienz gegenüber Katastrophen; Spielmann, M, Bücking, W, Quadt, V and Krumm, F 2013 Integration of Nature Protection in Forest Policy in Baden-Württemberg (Germany). INTEGRATE Country Report EFICENT-OEF). As Germany's main legislation governing forest fire management, the Federal Forest Act sets out the rules and guidelines for managing and protecting forests, while the Civil Protection Act

regulates civil protection and rescue activities, including forest fire management and suppression operations. Under the national legislation framework, implementing wildfire prevention and suppression measures, and coordinating emergency responses and firefighting operations, is overseen by the Federal Ministry of Food and Agriculture (BMEL) and are the duties of state forestry administrations and civil protection ministries (Eftychidis et al. 2023. FirEUrisk - Developing a Holistic, Risk-wise Strategy for European Wildfire Management). These efforts are integrated across various levels of government (the Gemeinden, the 16 federal states, and the federation), blending strategic documents, legal instruments, and practical measures (WBW 2022; BBK 2022; Spielmann et al. 2013). The Forest Climate Fund (Waldklimafonds) is a key financial mechanism supporting projects to increase forest ecosystem resilience and design preventive measures against large-scale wildfires (BBK 2022). The BMEL also fosters crossborder and regional cooperation in forest fire prevention, notably with the Global Fire Monitoring Center in Freiburg, and leads on panEuropean initiatives such as the Forest Risk Knowledge Mechanism to inform policy decisions and support coordination to increase forest resilience against risks (BBK 2022). The EU has launched projects like DRYADS and TREEADS to develop holistic fire management systems by integrating innovative solutions such as satellite data (Copernicus), AI-driven simulations, and machine learning for fire prediction, drones for real-time monitoring, virtual reality for training, and ecofriendly extinguishing materials (Feuerwehr-Magazin April 4, 2022 Projekt DRYADS 23 Millionen Euro für die Waldbrandprävention).

133 These include fuel management and breaks (especially on rescue routes), fire drills, water extraction points or water wells, forest fire protection through fuel management (clearing flammable material from "wound strips" and creating protective strips, fire barriers, or fuel breaks), and network path maintenance. Some experts also recommend other methods, such as targeted controlled grazing, to reduce ground vegetation. Various wildfire risk prevention options that emphasize proactive forest management and adaptation strategies have also been promoted, including shifting from conifer-dominated monocultures to diverse, climate-resilient mixed deciduous forests to reduce flammability and strengthen resilience. For the prioritization of prevention measures in areas where people or critical infrastructure are at high fire risk, key actions include establishing priority zones for silvicultural prevention by combining forest stock and exposure data, active management of easily flammable deadwood, and developing dynamic vulnerability maps incorporating forest structure parameters (BBK 2022; Süddeutsche Zeitung June 4, 2023 Waldbrandprävention und Feuer-Bekämpfung kosten Millionen; Müller, M M, Vilà-Vilardell, L and Vacik, H 2020 Waldbrände in den Alpen – Stand des Wissens, zukünftige Herausforderungen und Optionen für ein integriertes Waldbrandmanagement EUSALP; Brand Herde Waldweide: Konzept Brandherde – integrative Waldbrandvorsorge; BBK 2022; BMLEH 2024 Ergebnisse der Waldzustandserhebung 2024; WBW 2022; BMUV 2024 Draft Federal Action Plan on NBS for Climate and Biodiversity; Land Brandenburg 2024 Pyrophob: Strategien zur Entwicklung von widerstandsfähigen Wäldern auf Waldbrandflächen; Hartebrodt, C, Hengst, Y, Gehrke, A, Jentner, E and Held, A 2023 Management von Totholz in der Waldbrandprävention; Hartebrodt, C, Hengst, Y, Maitry, F and Held, A 2024 Neue Informationsquellen für das Waldbrandmanagemen; ErWIN Project 2024 Erweiterung des ökologischen, waldbaulichen und technischen Wissens zu WaldbrändeN (ErWiN)).

134 DWD Overview - Weather and Climate; IQ – FireWatch.

135 In Germany, Gemeinden are generally responsible for emergency response, including firefighting operations (ETH Zürich 2023 Adapting to Climate Change: Lessons for Swiss Civil Protection). Public education and information campaigns have also been promoted to raise awareness and promote prevention and preparedness, undertaken notably through the BBK's Federal Academy for Civil Protection and Civil Defense (Nordakademie June 4, 2024 Digitale Waldbrandprävention mit Erfolg; Hepper, J 2023 Forschung zum präventiven Waldbrandschutz *Brennpunkt Wald*; BBK Bundesakademie für Bevölkerungsschutz und zivile Verteidigung; Müller, M 2022 Gutachterliche Stellungnahme auf der Grundlage der Beauftragung vom 30.09.2022 gemäß der Vorhabensbeschreibung vom 23.09.2022 auf der Grundlage des Kabinettsbeschlusses vom 23.08.2022 mit dem Kernthema der Analyse des Einflusses von Totholz auf das Brandgeschehen im Nationalpark Sächsische Schweiz; Mendes C, Negro D, Piñeiro A, Rodríguez C, Casartelli, V, Marengo, A, Melinato, S, My-siak, J, Mohammadi S, Salpina, D, Brăilescu, C, Sørensen, J and Griem, G 2025 UCPM Wildfire Peer Review Report: Land Brandenburg 2025 CMCC). Germany has requested assistance from the Union Civil Protection Mechanism in the form of aerial firefighting capacities during the 2022 fire season, as well as using rapid mapping provided by the Copernicus Emergency Management Service; Dammers, T. 2022. Katastrophenhilfe – nicht gefragt, Tagesschau; Seidler, C. 2022. Braucht Deutschland diese Maschine?, Der Spiegel. Germany does not have any publicly owned firefighting aircraft but use military or the federal police helicopters on a needs basis, and discussions are ongoing around acquiring dedicated aircraft for firefighting purposes (FVA EFI 2021 Waldbrandbekämpfung aus der Luft -eine Fachempfehlung für Entscheidungsträger; DPT 2023). To further enhance the effectiveness of firefighting in Germany and cooperation and communication between stakeholders at multiple levels (e.g. municipal fire departments, forest administrations, forest companies, and volunteer firefighters), operational tactical maps are also being developed, which contain information about forest roads, permissible weight for emergency vehicles, location of water extraction points, and escape routes (BMI June 2, 2022 Bund und Länder geben Startschuss für das Gemeinsame Kompetenzzentrum Bevölkerungsschutz; BBK Das Gemeinsame Kompetenzzentrum Bevölkerungsschutz; Weidinger, J, Schlauderer, S and Overhage, S 2024 Determinants for the Acceptance of Emergency Response Information Systems: Ethnographical Insights into the Digitalization of a Voluntary Fire Department; Center of Fire Statistics 2023 World Fire Statistics No 28; Müller, Vilà-Vilardell and Vacik 2020; Hartebrodt et al. 2024). Efforts need to be made to enhance firefighting capacity and effectiveness, including through investments in more specialized equipment for accessing and suppressing wildfires, improved training for firefighters in nonurban fire environments, and establishing better data and information systems on wildfire risk, forest cover, and at-risk communities and infrastructure (DPT 2023; Hepper 2023; Hartebrodt et al. 2024; Expertenkommission 2023 Bericht der Expertenkommission Waldbrände Sommer 2022 in Sachsen).

136 The new Federal Forest Act is still in draft form and under discussion, and while its final scope remains uncertain, it may include provisions to strengthen support for preventive wildfire measures for forest owners (BMEL 2024 Viertes Gesetz zur Änderung des Bundeswaldgesetzes; BBK 2022; Süddeutsche Zeitung 2023; Müller, Vilà-Vilardell and Vacik 2020; FNR 2024 Wie entstehen feuerabweisende Wälder? Fachagentur Nachwachsende Rohstoffe e V).

137 GFDRR and World Bank. 2025. Management of Wildfire Risk in the European Union.

138 GWS. 2022. Volkswirtschaftliche Folgekosten durch Klimawandel: Szenarioanalyse bis 2050 Studie im Rahmen des Projektes Kosten durch Klimawandelfolgen in Deutschland.

139 BCRs from European countries: Cross-border support and coordination mechanisms for wildfires (Portugal and Spain): 1.6, Firefighter training and capacity building (Sweden): 2.1, Improvements to industries in WUI (Portugal): 2.1, Improvements to houses in WUI (Portugal): 3.1, Decision support tools for adaptation and sustainable forest management (Austria): 5.8, Alerting and evacuation planning (Portugal): 11, Fuel management (Portugal): 11.9, Alerting and evacuation planning (Greece): 39.3. For details, see World Bank and European Commission 2021 and World Bank. 2024. From Data to Decisions: Tools for Making Smart Investments in Prevention and Preparedness in Europe. Washington, D.C.: World Bank Group.

140 These include fuel management, fire breaks, and water supply—e.g. narrow 10–30-meter zones and active management of easily flammable deadwood, particularly where settlements or critical infrastructure are at risk (Hartebrodt et al. 2023; Hartebrodt et al. 2024), clearing flammable material from "wound strips" in Mecklenburg-Vorpommern (Süddeutsche Zeitung 2023), and establishing water wells, as discussed by Berlin Parliament (Abgeordnetenhaus Berlin. 2023. Waldbrandprävention in Berlin - Drucksache 19 / 15 316 Schriftliche Anfrage des Abgeordneten Karsten Woldeit (AfD)—and critical infrastructure protection, including building codes related to fire safety established and implemented as prescriptive rules, regulated in the "Musterbauordnung"-short MBO model building code (Maiworm, B, Hammann, C and Schleich, M 2023 Prescriptive Building Regulations, Safety Objectives, and Residual Risk in Germany *Fire Technology* 59: 3203–3230). Qualitative evidence suggests that the current building code regulations are sufficient to prevent fire from spreading (Maiworm, B, Göldner, M, Mannl, K and Hammann, C 2024 Evaluating 900 Potentially Harming Fires in Germany: Is the Prescriptive Building Code Effective? German Fire Departments Assessed Fire Safety Measures in Buildings Through On-Site Inspections *Fire Technology* 60: 2041–2065). Germany's infrastructure has generally been quite well protected against various hazards in the past (Eismann, C 2014 Trends in Critical Infrastructure Protection in Germany *TRANSACTIONS* of the VŠB – *Technical University of Ostrava Safety Engineering Series* 9(2); BMI Protecting Critical Infrastructure).

141 IQ FIreWatch March 2, 2023 IQ Firewatch – 20 Years of Protecting People, Nature, and Property; Müller M.M., Vilà-Vilardell L., Vacik H. 2020 Forest fires in the Alps – State of knowledge, future challenges and options for an integrated fire management. EUSALP Action Group 8. Monitoring and early detection investments can be done with reasonable unit costs – e.g., in Mecklenburg-Vorpommern, monitoring particularly endangered forest areas (332,000 hectares) has cost an average of €0.5 million annually over the past five years, working out at €1.5 per hectare, per year.

142 BCR values have been rounded up. Actual values are 3.02 for current conditions and 4.42–6.54 for future climate scenarios. The calculation uses conservative values, such as a 30% damage reduction (based on UNDRR report values for benefits of such types of information and EWS) and approximately €5,400 per hectare in loss values (based 2023 German and Brandenburg-specific fire loss data). Given lack of data and information for Germany on avoided losses or value of reduction of damages through EWS, the analysis had to make several assumptions and transfer values from other countries.; The BCRs from other countries include Cross-border support and coordination mechanisms for forest fire risks and weather forecasts (Portugal and Spain): 1.6, Decision support tools for adaptation and sustainable forest management (Austria): 5.8, Alerting and evacuation planning (Portugal): 11.9, Alerting and evacuation planning (Greece): 39.3. For details, see World Bank and European Commission 2021.

143 With confirmed detection ranges of 20 kilometers, FireWatch alerts firefighting services within minutes of ignition (IQ FireWatch Why IQ FireWatch). The BCA did not consider avoided carbon emission costs, but estimated total cost of emissions at €11.8 million under current climate and €17.1 and 27.8 million, respectively, under medium (2040–55) and high (2056–75) climate scenarios.

144 This includes: modernizing FireWatch (integrating advanced tools such as AI-supported smoke detection, real-time thermal satellite feeds and drone-based surveillance, or mobile sensor systems to enhance detection capabilities and response speed); expanding detection coverage to wildland-urban interface areas and regions with critical infrastructure; and developing a hybrid early warning strategy that blends current ground-based systems with predictive fire behavior modeling (e.g., Australia's Phoenix RapidFire). With such improvements, Brandenburg could avoid another €0.6–1.6million in losses each year, particularly in climate-stressed fire seasons, enhancing the state's capabilities and aligning with emerging best practices across the EU Civil Protection Mechanism and broader risk-informed public investment frameworks. Additional improvements needed would be in terms of night detection, coverage of former munitions and mountainous areas, and including nonforest vegetation fires.

145 Comparing early (within 15–30 minutes) to delayed (within 90–120 minutes) intervention after ignition or ground-based detection, the study finds that aerial firefighting assets, such as helicopters and fixed-wing aircraft, are effective suppression tools despite their resource-intensive characteristics, with effectiveness critically dependent on the timing of intervention. Concerns have been raised regarding delayed mobilization of aircraft for fire suppression, often due to multitiered approval chains (Gemeinde-district-state-federal). By the time the aircraft arrive, sometimes hours after initial detection, fires have often surpassed their early controllable phase, significantly reducing suppression effectiveness and leading to avoidable losses. The methodology uses published wildfire growth models, expert benchmarks, and real suppression costs to estimate fire growth and associated damages, which vary significantly with response timing.

146 FVA EFI 2021.

147 Mendes et al. 2025. These results align with studies from Portugal, Australia, and Spain (AerialFire. 2025. Case Study: The Fire Boss Advantage in Portugal and Galicia, Spain). This would involve establishing readiness protocols for rapid aerial deployment, especially during extreme fire danger days; preauthorizing aerial contracts or dispatch triggers to reduce administrative delays; and ensuring early detection is paired with early suppression for enhanced effectiveness. It is also important to validate this study's model using local data (e.g., LSTE or EU RescEU logs) for deployment times and avoided losses from Brandenburg's historical fires, and undertake future research to explore the long-term, broader economic, social, and environmental benefits of such interventions. Data sharing can allow for validation of this model over Brandenburg's historical fires. Assumptions and transferred values from the literature indicate that this is a pilot study that would need to be improved with further research and local validation. The literature also shows that using innovative information technologies—such as unmanned aerial vehicles, intelligent protective clothing, digital plans and maps, and integrated on-site emergency response systems—could improve the effectiveness of emergency response, though perceived compatibility and complexity of emerging technologies might also be substantial acceptance barriers (Weidinger, J, Schlauderer, S and Overhage, S 2018 Is the Frontier Shifting into the Right Direction? A Qualitative Analysis of Acceptance Factors for Novel Firefighter Information Technologies *Information Systems Frontiers* 20: 669–692; Schlauderer, S, Overhage, S and Weidinger, J 2016 New Vistas for Firefighter Information Systems? Towards a Systematic Evaluation of Emerging Technologies from a Task-Technology Fit Perspective *49th Hawaii International Conference on System Sciences*: 178–187.

148 Christensen, B R 2015 Use of UAV or Remotely Piloted Aircraft and Forward-looking Infrared in Forest, Rural and Wildland Fire Management: Evaluation Using Simple Economic Analysis *New Zealand Journal of Forestry Science* 45: 16.

149 Mendes et al. 2025; Christensen 2015.

150 Nordakademie 2024; Hepper 2023; BBK Bundesakademie für Bevölkerungsschutz und zivile Verteidigung; Knuth D, Schulz S, Kietzmann D, Stumpf K, Schmidt S 2017 Better Safe Than Sorry - Emergency Knowledge and Preparedness in the German Population *Fire Safety Journal* 93: 98–101; Stumpf, K, Knuth, D, Kietzmann, D and Schmidt, S 2017 Adoption of Fire Prevention Measures – Predictors in a Representative German Sample Safety Science 94: 94–102. A review of best practices on wildfire risk awareness and communication drawn from Europe and beyond (including Germany) shows a wide cost range, from €150,000 to €10 million (Plana, E, Serra, M, Nebot, S, Smeenk, A, Macri, P, Vendrell, J, Pronto, L, Canaleta, G, Gomes, J and Alfonso, L 2024 Wildfire Risk Awareness and Communication: Analysis of Good Practices Union Civil Protection Knowledge Network). The effectiveness of such campaigns can be measured through surveys (Climate-Adapt 2023 Awareness Raising Campaigns for Stakeholders' Behavioural Change.

151 Griess, V C, Acevedo, R, Härtl, F, Staupendahl, K and Knoke, T 2012 Does Mixing Tree Species Enhance Stand Resistance Against Natural Hazards? A Case Study For Spruce Forest Ecology and Management 267: 284–296. For example, implementing climate-adapted forest conversion could require annual investments of €540–640 million per year over the next 50 years, averaging €485 million over a 200-year simulation period (Rosenkranz, L, von Arnim, G, Englert, H, Husmann, K, Regelmann, C, Roering, H-W, Rosenberger, R, Seintsch, B, Dieter, M and Möhring, B 2023 Alternative Forest Management Strategies to Adapt to Climate Change: An Economic Evaluation for Germany). Other studies estimate that, depending on the stock, necessary forest conversion would cost €5,000–15,000 per hectare (DVF 2022; Waldanpassung 2021 Zukunftsaufgabe Waldanpassung). Active strategies are considered economically sustainable over the long term given higher projected yields and returns, becoming economically advantageous after approximately 90 years, considering a 1.5% interest rate (Rosenkranz et al. 2023).

152 GWS. 2022.

153 Hanewinkel, M, Augustynczik, A L D and Yousefpour, R 2022 Climate-Smart Forestry Case Study: Germany, in *Forest Bioeconomy and Climate Change*, edited by L Hetemäki, J Kangas and H Peltola. *Managing Forest Ecosystems* 42.

154 Hanewinkel, Augustynczik and Yousefpour 2022; European Space Agency 2025 A Troubling Shift in Europe's Forest Carbon Balance; Thünen Institute. 2025. This is why Wheat is not a Carbon Sink. Revenue generated from the voluntary carbon market is extremely variable (Machnik, D, Schambil, K, Tänzler, D, Götz, M and Meierhofer, F 2022 Infopapier zur Marktanalyse Freiwillige Kompensation 2021; Umweltbundesamt 2025 Freiwillige Kompensationszahlungen als Klimabeitrag nutzen). This is important because implementing biodiversity strategies, such as the EU Biodiversity Strategy 2030, involves setting aside protected forest areas and could lead to a decrease in timber harvest (estimated 13–44% over 200 years) and a reduction in silvicultural contribution margins (Regelmann, Rozenkrantz, L, Seintsch, B and Dieter, M 2023 Economic Evaluation of Different Implementation Variants and Categories of the EU Biodiversity Strategy 2030 Using Forestry in Germany as a Case Study). Some measures might have very high abatement costs per tonne of carbon dioxide due to environmental considerations and there are trade-offs between climate adaptation and mitigation objectives in terms of management practices (Bösch M, Elsässer P, Rock J, Rüter S, Weimar H, Dieter M. 2017 "Costs and Carbon Sequestration Potential of Alternative Forest Management Measures in Germany Forest Policy Economy 78: 88–97; Bösch M, Elsasser P, Rock J, Weimar H and Dieter M 2019 Extent and Costs of Forest-based Climate Change Mitigation in Germany: Accounting for Substitution Carbon Management 10(2): 127–134; Hanewinkel, Augustynczik and Yousefpour 2022).

155 See endnote number 7.

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