ECONOMICS FOR DISASTER PREVENTION AND PREPAREDNESS

Climate Adaptation Costing in a Changing World

Valuing climate adaptation helps us orient our compass toward effective and resilient pathways

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ABBREVIATIONS

ACAG	Atmospheric Composition Analysis Group
AT	Apparent Temperature
BASE	Bottom-up climate Adaptation Strategies towards a sustainable Europe
BCA	Benefit-Cost Analysis
CATSIM	CATastrophe SIMulation
CCA	Climate Change Adaptation
CCC	Climate Change Committee
CCM	Climate Change Mitigation
CDRI	Coalition for Disaster Resilient Infrastructure
CER	Critical Entities Resilience Directive
CES	Constant Elasticity of Substitution
CGE	Computed General Equilibrium
COACCH	CO-designing the Assessment of Climate Change Costs
CPEIR	Climate Public Expenditure and Institutional Reviews
DAC	Development Assistance Committee
DG CLIMA	Directorate-General for Climate Action
DG ECFIN	Directorate-General for Economic and Financial Affairs
DG ECHO	Directorate-General for European Civil Protection and Humanitarian Aid Operations
DG RTD	Directorate-General for Research and Innovation
DRG	Disaster Resilience Goal
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
EC	European Commission
EDPP	Economics for Disaster Prevention and Preparedness
EEA	European Environment Agency
EFFIS	European Forest Fire Information System
EM-DAT	Emergency Events Database
ERR	Economic Rate of Return
EU	European Union
EUCP	European Climate Prediction Project
EUCRA	EU Climate Risk Assessment
EUROSTAT	European Statistical Office
EWS	Early Warning System
GDP	Gross Domestic Product
HRVAs	High-Vale Resources and Assets
I4CE	Institute for Climate Economics

IAM	Integrated Assessment Model
IAQ	Indoor Air Quality
IFF	Investment and Financial Flow
IFFAS	Integrated Forest Fire Analysis System
IFM	Integrated Fire Management
IIASA	International Institute for Applied Systems Analysis
ILO	International Labour Organization
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
KPI	Key Performance Indicator
LULUCF	Land Use, Land Use Change, and Forestry
MFMod	Macro-Fiscal Model
MFSA	Municipal Finance Self-Assessment
NAP3	Third National Adaptation Programme
NAP	National Adaptation Plan
NAS	National Adaptation Strategy
NBS	Nature-Based Solution
NHHAP	National Heat Health Action Plan
NPC	Net Present Cost
NPV	Net Present Value
NRA	National Risk Assessment
OECD	Organisation for Economic Co-operation and Development
PACINAS	Public Adaptation - Investigating the Austrian Adaptation Strategy
PESETA	Projection of Economic Impacts of Climate Change in Sectors of the European Union Based on Bottom-Up Analysis
PHIUS	Passive House Certification
PML	Probable Maximum (Asset) Loss
PNACC	National Climate Change Adaptation Plan (Plan National d'Adaptation au Changement Climatique)
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SDGs	Sustainable Development Goals
SET	Standard Effective Temperature
SPI	Standard Precipitation Index
SSP	Shared Socioeconomic Pathway
TRACE	Territorial Risk Assessment of Climate in Regions of Europe
UCPM	Union Civil Protection Mechanism
UCPMKN	Union Civil Protection Mechanism Knowledge Network

UHI	Urban Heat Island
UNFCCC	United Nations Framework Convention on Climate Change
UTCI	Universal Thermal Climate Index
WUI	Wildland-Urban Interface

Note: Throughout the report, currencies have been converted to euro values. If the original values were in other currencies, this is indicated in footnotes. The currency exchange rates used in this report come from the Eurostat database (Eurostat Database 2023). All dollar amounts are US dollars unless otherwise indicated.

GLOSSARY

Climate change adaptation: "The process of adjusting to live in a changing climate and making efforts to reduce the risk from the harmful impact of current or expected climate change and climate-induced hazards."[1] Adaptation options may be considered through "green" or "blue" (ecosystem-based) measures, "grey" (infrastructure-based) measures, and "soft" (policy, legal, social, and financial) measures.[2]

Climate change mitigation: "The effort to reduce climate change and decelerate global warming through the reduction of greenhouse gas emission into the atmosphere. Mitigation can be done by either reducing the sources of greenhouse gases or improving the carbon sinks on Earth, which store and absorb greenhouse gases."[3]

The cost of inaction to prevent losses and damage:[4] According to the EEA, "The total economic cost of climate change in the absence of planned—with or without mitigation measures.[5] Essentially, it is the 'damages that will result from allowing climate change to continue unabated.[6] The estimated losses from weather- and climate-related events can act as an initial proxy for the cost of not taking action to prevent losses and damage, both for the past[7] and modelled for the future (e.g. the Joint Research Centre's Peseta IV project[8])."

The cost of adaptation: The "costs of planning, preparing for, facilitating, and implementing adaptation measures to moderate harm or to exploit beneficial opportunities."[9]

The benefit of adaptation: The value of climate change damage and losses avoided by taking adaptation actions.[10] Co-benefits of adaptation, in terms of both climate extremes and slow-onset events can include "the positive effects on biodiversity, air quality, water management, greenhouse gas emission reductions, and health and well-being."[11]

The ancillary impacts of adaptation:[12] Impacts that may be "either positive (including co-benefits) or negative (maladaptation) and may or may not include cascading effects."

1 Intergovernmental Panel on Climate Change (IPCC). 2012. "Glossary of Terms." Link. Climate change adaptation is understood as an opportunity, bringing together opportunities to, *inter alia*, strengthen resilience.
2 European Environment Agency (EEA). Step 3. Identifying adaptation options. Link.
3 EEA. 2023d. *What Is the Difference between Adaptation and Mitigation?* Link.
4 EEA. 2023a. *Assessing the Costs and Benefits of Climate Change Adaptation*. Link.
5 Nicklin, H., et al. 2019. "Understanding the Costs of Inaction—An Assessment of Pluvial Flood Damages in Two European Cities." *Water* 11 (4): 801.
6 Ackerman, F., and Stanton, E. 2006. *Climate Change: The Costs of Inaction*. Link.
7 EEA. 2020b. *Urban Adaptation in Europe: How Cities and Towns Respond to Climate Change.* Link.
8 Feyen, L et al. 2020. *Climate Change Impacts and Adaptation in Europe: JRC PESETA IV Final Report.* Link.
9 Parry, M. L. et al. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Link.
10 Callaway, J. M. 2003. *OECD Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers – Adaptation Benefits and Costs - Measurement and Policy Issues.* Link.
11 Bapna, M., et al. 2019. *Adapt Now: A Global Call for Leadership on Climate Resilience, Global Commission on Adaptation*. Link.; World Bank (WB) and European Commission (EC). 2021. *Economics for Disaster Prevention and Preparedness: Investment in Disaster Risk Management in Europe Makes Economic Sense*. Link.
12 EEA 2023a.

Maladaptation:[13] When "an intervention intended to adapt a particular location or sector increases the likelihood of negative impacts on another location, sector or target group.[14] Maladaptation, for example, may reduce risks in one location but increase them elsewhere (e.g., downstream)."[15]

Iterative risk management (or adaptive management):[16] An established approach for improving future management strategies through monitoring, research, evaluation, and a learning process.[17]

Disaster risk management: Processes for designing, implementing, and evaluating strategies, policies, and measures to improve the understanding of disaster risk, foster management of risks and risk transfer, and promote continuous improvement in disaster preparedness, response, and recovery practices, with the explicit purpose of increasing human security, well-being, quality of life, and sustainable development.[18]

Disaster risk management investments: Investments in risk identification (risk assessments and so on), risk reduction (through prevention), early warning, emergency and response preparedness, public awareness, financial resilience (through the use of various instruments), and resilient recovery.

Disaster risk reduction: Denotes both a policy goal or objective and the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing exposure, hazard, or vulnerability; and improving resilience. Disaster risk reduction comprises both disaster prevention and disaster preparedness.[19]

Disaster prevention: Activities and measures that prevent or reduce the harmful impacts of actual or potential disasters on humans, assets, and society.[20]

Disaster preparedness: Precautionary activities and actions that enhance the capacity to reduce the harmful impacts of and losses from potential, imminent, or current disasters.[21]

Tipping point: A level of change in system properties beyond which a system reorganizes, often in a nonlinear manner, and does not return to the initial state even if the drivers of the change are abated. For the climate system, the term refers to a critical threshold at which global or regional climate changes from one stable state to another. Tipping points also may refer to impact; the term can imply that an impact tipping point is (about to be) reached in a natural or human system.[22]

Climate variability: Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).[23]

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13 EEA 2023a.
14 Noble, I. R., et al. 2014. "Adaptation Needs and Options." In Climate Change 2014: Impacts, Adaptation and Vulnerability, edited by C. B. Field et al., 833–868. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the 5th Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.
15 IPCC. 2022b. *IPCC Sixth Assessment Report – Technical Summary, Intergovernmental Panel on Climate Change*. Link.
16 Watkiss, P. et al. 2014a. D1.2 Design of Policy-Led Analytical Framework. Link.
17 Reeder, T., and N. Ranger. 2011. *How Do You Adapt in an Uncertain World? Lessons from the Thames Estuary 2100 Project.* Link.
18 WB and EC. 2021a. See also UCPM Knowledge Network. Disaster Prevention and Management. Link.
19 IPCC. 2012b. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Link.
20 See UCPM Knowledge Network. Link. UN Office for Disaster Risk Reduction (UNDRR). Terminology – Prevention. Link. Given ongoing discussions at EU level related to the Nature Restoration Law, nature is also considered within this definition.
21 WB and EC 2021; UCPM Knowledge Network. Lin.; UNDRR. Terminology – Preparedness. Link.
22 IPCC. Glossary. Link.
23 IPCC. Glossary. Link.

White, green blue measures: Solutions usually used to mitigate urban heat island effects within cities.[24]

- *White measures* aim to counteract some of the absorption of solar radiation and heat storage of paved surfaces and built-up areas. White solutions are generally "cool materials" that are generally lighter or reflect more solar radiation than traditional darker materials.

- *Green measures* aim to provide cooling through the effect of shading as well as evapotranspiration. Green solutions include green roofs, vertical gardens, parks or urban forests.

- *Blue measures* aim to provide cooling by evaporation, heat absorption, and heat transport. Blue measures are generally water bodies such as ponds, lakes, or rivers. They also encompass water spray from fountains, which can locally have high cooling effects because of the large contact surface between the water and air.

Incremental adaptation: adaptation that maintains the essence and integrity of a system or process at a given scale.[25]

Transformational adaptation: adaptation that changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts.[26] Linked to transformational adaptation is transformative change, which is systemwide. It goes beyond technological change through the consideration of social and economic factors that, with technology, can bring about rapid change at scale.[27]

24 WB. 2020a. Analysis of Heat Waves and Urban Heat Island Effects in Central European Cities and Implications for Urban Planning. WB, Washington, DC. Link.
25 Mach, K. J. et al. 2014. "Annex II: Glossary." Link.
26 Mach, K. J. et al. 2014. Link.
27 Möller, V., R. et al. 2022. "Annex II: Glossary." Link.

Statement from the European Commission

The impacts of climate change can seem unavoidable, overwhelming, immediate, distant, and sometimes all these things together. The fact is that the world is rapidly heating up and Europe is warming around twice as fast as the global average. We have seen historical temperature records being exceeded month after month. 2023 was the warmest calendar year ever registered. These are not the type of records that we aspire to see broken.

Preparing for climatic conditions that we have never experienced is a challenge on many levels. Climate risks will impact all aspects of our lives. There are measurable costs, such as those that take stock of the assets that have been destroyed, and there are the costs too difficult to quantify: how could we measure or monetise the grief for destroyed livelihoods, species going extinct, or put a price on losing your family's home after a major disaster?

In this climate change reality, we need to take a systemic approach. The good news is that this also offers an opportunity to do things better: be more resilient, agile, coherent and harness better the potential for creating economic value.

To be able to deliver we need to know how much climate risk management is going to cost and what economic benefits could be leveraged. This report contributes to answer some of these questions. It sheds light on the complexity of the task at hand. We need to be resilient in so many different areas, that is one of the reasons why our knowledge on adaptation costs has been so fragmented. The report and its case studies offer a good basis to advance in our understanding.

Which of the possible future climate scenarios will materialise depends on how fast global emissions will be cut to net zero. In between, many outcomes are possible, and we will need to ensure the capacity to adjust course if needed. This is another reason why this report is so valuable: it highlights the importance of flexible adaptation pathways and ways to develop them. In the European Commission we consider this essential for making forward progress and we stand ready to significantly step up our efforts in this respect.

Building climate resilience is our responsibility and an opportunity to ensure our future competitiveness. The cost may be substantial, but I see them as investment in a safer future for the current and next generations. The costs of inaction are substantially higher than the investment needed. Our society needs safe living conditions and housing, food security, more resilient infrastructure, and ecosystems that continue to support us. Greater climate resilience will also spur lower economic losses from climate related events, and more sustainable public finances.

I am very pleased that the World Bank partnered with the European Commission on this important endeavour – its expertise and experience are invaluable. I am truly impressed with the comprehensiveness and depth of the analysis.

Building climate resilience, in tandem with tackling emissions, is a historical challenge and a necessity. It can only be achieved by working together.

Wopke Hoekstra

Commissioner for Climate Action
European Commission

Statement from the World Bank

We live in a time when crises have become normal. In Europe, the scale of loss and destruction from disaster events is staggering. Recent years recorded multiple concurrent major disasters—including floods, wildfires, heatwaves, and droughts. In 2023 alone, the hottest year on record, economic losses from disasters amounted to €77 billion across Europe.[28]

Europe is warming faster than any other continent in the world. Recent events indicate a disturbing trend—- ongoing global warming driving increasingly intense climate extremes. Projections suggest that economic losses from climate-related events in the EU could soar to €175 billion per year in a 3°C warming scenario.[29]

Globally—and in Europe—disasters have far-reaching effects, with the vulnerable suffering the most.[30] Disasters not only have a direct impact on physical assets and infrastructure, but also increase poverty and exacerbate inequality over the long term. When mechanisms to prevent, prepare, respond, and recover from disasters are missing or inadequate, these events can erode decades of development and deeply affect society's welfare.

Preparing for this new era of climate challenges is critical for safeguarding the well-being of Europe's communities and economies. Many countries in the region have set ambitious goals, which require substantial investment to mitigate and adapt to the projected changes, such as the increased frequency and intensity of extreme weather events. While much needs to be done, financial resources are scarce, with many urgent and often competing priorities.

To respond to these challenges, focused and smart investments are needed in climate adaptation and disaster prevention and preparedness, accompanied by strengthening and adapting infrastructure, institutions, societies, and finance at different levels of government.

Focused – because while Europe has been taking steps to invest in disaster and climate resilience, critical sectors, including those providing civil protection and emergency response, remain highly exposed. If infrastructure fails—because a fire station is destroyed in an earthquake, critical evacuation routes are flooded, or hospitals are evacuated because of wildfires—people, homes and businesses cannot be saved, magnifying the impacts of an event. If public financing is severely affected—or even depleted—due to the impact of major catastrophic events, the government cannot provide timely emergency, recovery and reconstruction support to its populations and the economy.

Smart – because while preventive investments make clear economic sense,[31] more can be achieved using data and information to scale up prevention, preparedness and adaptation efforts in a cost-effective, and targeted manner. In an environment of constrained resources, the region will not be able to successfully manage current and future risks unless investments to prevent and prepare for disasters are prioritized. At the same time, disaster prevention and climate adaptation efforts are closely interlinked and should be integrated to maximize the benefits of socioeconomic development and fiscal sustainability.

28 Munich Re. 2023. Record thunderstorm losses and deadly earthquakes: The Natural Disasters of 2023. Link.
29 EC (European Commission). 2020. *PESETA IV*. Link.
30 World Bank. 2022d. Overlooked: *Examining the Impact of Disasters and Climate Shocks on Poverty in the Europe and Central Asia Region.* Link.
31 World Bank and European Commission. 2021. Economics for Disaster Prevention and Preparedness: Investment in Disaster Risk Management in Europe Makes Economic Sense. Link.

At the World Bank Group, we are modernizing our mission and instruments to ensure better support to countries globally and in Europe. In the region, the World Bank Group has been strengthening partnerships, providing financing and sharing knowledge to help communities manage the risks of disasters and climate change. Among these efforts, we support countries to modernize their policy and strategic frameworks, and prioritize, design and finance investments that strengthen disaster and climate resilience, including in critical infrastructure and emergency response services.

This series of analytical reports, produced as part of a partnership with the European Commission, attests to our commitment.

Building on results generated in 2021,[32] this set of reports provides new evidence, tools, and examples for countries in Europe to strengthen their disaster and climate resilience in a focused and smart manner. By highlighting aspects such as prioritized decision-making, understanding the costs of climate change, and risk-informed budgeting, these reports can be instrumental in developing and implementing nuanced policies and strategic investments that are attuned to the diverse hazards facing Europe. By embracing such new tools and approaches, we can ensure that communities are more resilient in the face of ever-evolving climate impacts and help secure a sustainable future for generations to come.

Antonella Bassani

Vice President, Europe and Central Asia
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32 World Bank and European Commission. 2021. Economics for Disaster Prevention and Preparedness. Link.

Executive Summary

The impacts of climatic shocks are already being felt across Europe and are bound to intensify in line with further climate change. Even rapid and far-reaching progress on decarbonization cannot avoid the extent of climate change that is already locked in due to past emissions. These trends call for urgent climate adaptation investment strategies that can prepare countries for a wide range of climate hazards and their complex impacts across communities and economic sectors. However, formulating concrete investment strategies can be challenging as adaptation needs are vast and difficult to estimate. To overcome this challenge, this report reviews evidence-based prioritization and costing approaches and illustrates their application in a series of case studies. These approaches can support policy makers in identifying bankable and effective adaptation investments, raising and allocating adequate financing, and thus ultimately facilitating more effective climate change adaptation across Europe.

Why Europe needs to adapt to and mitigate climate change at the same time

Europe urgently needs to scale up investments in climate adaptation. The continent is warming faster than any other global region,[33] with economic losses mounting precipitously. From 1980 to 2022, weather and climate-related events across the European Union caused total losses of about €650 billion, or around €15.5 billion per year.[34] Under climate change, annual economic losses are projected to rise significantly from these levels; for example, under a high emission scenario, EU GDP could be 7 percent lower than in the baseline by a conservative estimate.[35] Across all scenarios, losses could reach 2.2 percent of GDP by 2070, and one-quarter of EU regions could experience GDP losses greater than 5 percent, noting that these estimates do not take tipping points into account.[36] Europe will have to deal with more frequent and intense climate events[37] that stretch preparedness and response capacity and will need to promote structural changes to deal with systemic impacts on all economic sectors.[38] Evidence suggests the continent is unprepared for the larger disasters already being experienced, as illustrated by the losses from floods in 2021 (more than €40 billion in Germany),[39] drought in 2022, and increasingly disruptive seasonal heatwaves and wildfire seasons.

Immediate action is required, both for climate mitigation and climate adaptation, starting now and building into the future. Climate change adaptation

33 World Meteorological Organization (WMO) and Copernicus. 2022. State of the climate in Europe report. Link.; Pörtner, H.-O. et al. 2022. *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Link.; European Environment Agency. 2024. Europe is not prepared for rapidly growing climate risks. Link.
34 EEA 2023e.
35 GDP reduction by end of century; "Over the period 2031-2050, the cumulative additional GDP cost of a pathway leading to worse global warming could amount to EUR 2.4 trillion in the EU, compared to the costs under a pathway compatible with the 1.5°C objective of the Paris Agreement." EC. 2024. Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society. Link.
36 Bosello et al. 2020. D2.7. Macroeconomic, spatially-resolved impact assessment. Deliverable of the H2020 COACCH project. Link.
37 Kovats, R. S., et al. 2014. "Europe." Link.
38 European Environment Agency. 2024. Europe is not prepared for rapidly growing climate risks. Link.
39 Prognos. 2022. Extreme weather damages in Germany since 2018. Link.

(CCA) is essential not only to bolster climate resilience and curtail losses but to reap additional socio-economic and environmental benefits. It is complementary to climate change mitigation (CCM), as the next twenty years of climate change are already locked in, and early action is needed to prepare for the possible larger changes that will follow. The potential for adaptation is limited, however. Soft limits apply where current approaches may be insufficient and scaling up is needed to overcome constraints, while hard limits require very different and more transformational adaptation. Adaptive capacity may, indeed, decrease or be insufficient to cope with the scale of change needed, depending on interactions between socioeconomic and climate scenarios and on residual impacts that could be substantial, particularly affecting vulnerable people and communities. Even under a best-case 1.5°C degree warming scenario, certain global, climate, and socioeconomic tipping points[40] may already have been reached. With warming between 2° and 4°C, ten of sixteen climate tipping points (five global and five regional)[41] could be reached; these include a significant ice loss in the Barents Sea and an ice-free Arctic, which would have a direct impact on Europe.[42]

The commitment of the EU and its Member States to CCM and CCA is enshrined in and empowered by an underpinning framework. At EU level, this commitment is anchored in several different legislative frameworks, strategies, and action plans, particularly the European Climate Law, the Green Deal, including the EU Adaptation Strategy, as well as the Nature Restoration Law presently under discussion.[43] The EU is committed to disaster resilience through initiatives that include, notably, the EU-wide Disaster Resilience Goals (DRGs), which set four key priority areas for the European Commission (EC) and the Member States. At the national level, EU Member States have also committed to accelerating efforts toward disaster prevention and preparedness and CCA through disaster risk management (DRM) and CCA plans, as well as legislation in line with EU and international standards and agreements. Opportunities exist to translate this commitment into effective and feasible forward-looking actions, such as increasing the funding available to tailor and integrate CCM and CCA interventions.

Acting on both climate mitigation and adaptation is economically beneficial and has broader social and environmental benefits. Together these actions can reduce direct losses resulting from disaster and climate impacts while enhancing growth and providing trade and job opportunities, productivity gains, emission reductions and air quality improvements, ecological value, and biodiversity. Studies show that adaptation can, for example, be extremely cost effective in reducing economic losses from climate change–related coastal and river floods.[44] A recent report from the World Bank and the EC reviewing more than seventy investments across Europe has also shown that investments with a portfolio of measures addressing disaster risks can deliver high benefit-cost ratios and a triple dividend, with numerous co-benefits.[45]

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40 IPCC. WGII AR6 full report. Link; GSI. 2023. Global tipping points report. Link.

41 “Regional” is meant to cover the Europe region as aligned with climate models; “cross-country” is used, where suitable, to clarify.

42 McKay et al. 2022. Global warming exceeding 1.5°C could trigger multiple climate tipping points. Link.

43 EC. 2023. Nature Restoration Law. Link. According to the EC, investment into nature restoration adds €8 to €38 in economic value for every €1 spent, thanks to the ecosystem services that support food security, ecosystem and climate resilience and mitigation, and human health.

44 Lincke et al. 2018. D2.3. Impacts on infrastructure, built environment, and transport Deliverable of the H2020 COACCH project. Linkä; Lincke and Hinkel. 2018. Economically robust protection against 21st century sea-level rise. Global Environmental Change 51, 67-73. Link.

45 The triple dividend of resilience investments includes saved lives and avoided losses (dividend 1), induced economic and development benefits (dividend 2), and environmental and social benefits (dividend 3). Benefit-cost ratios typically ranged between 2 to 10. World Bank. 2021a.; Tanner et al. 2015. The Triple Dividend of Resilience. Link.

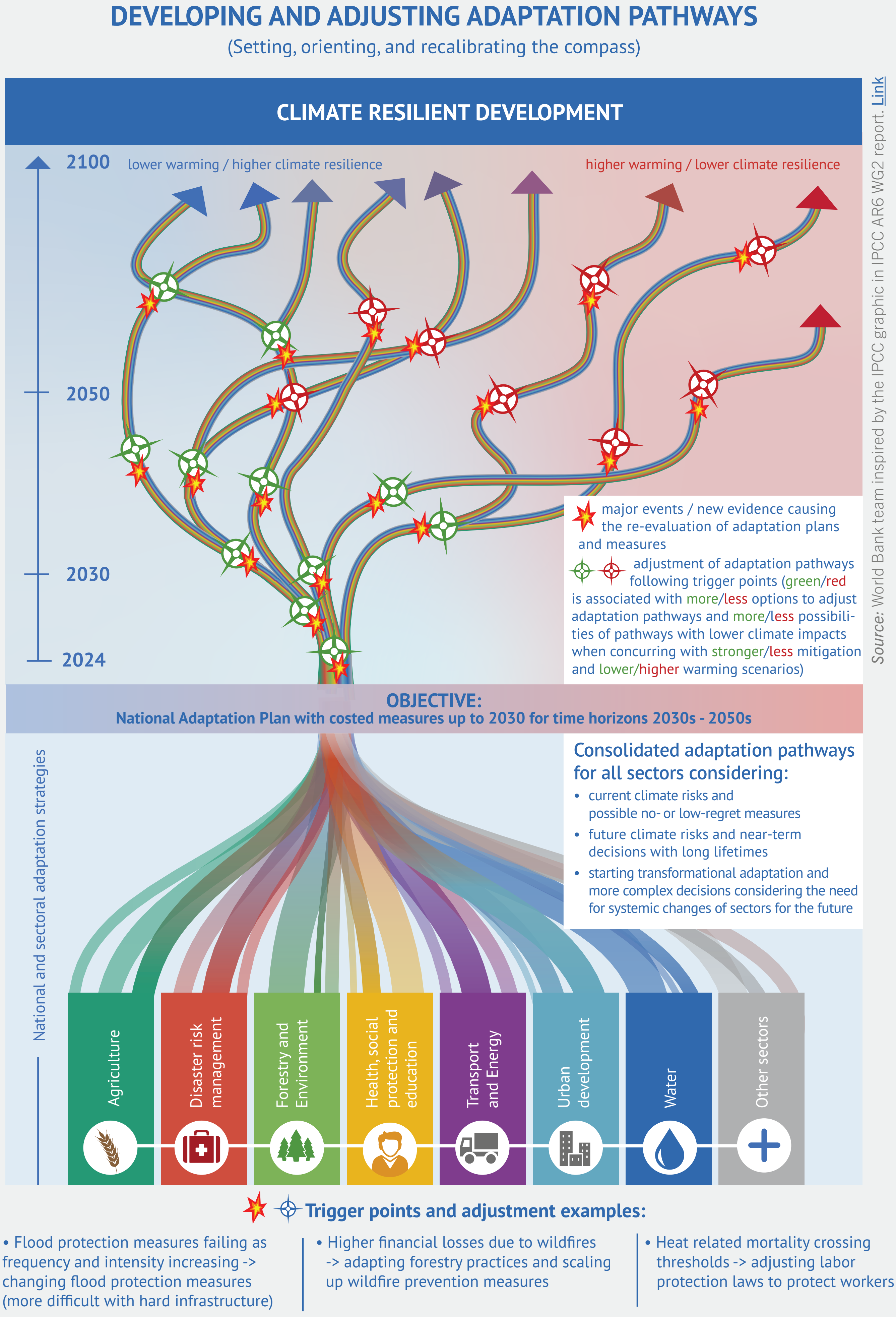
What actions are required to create effective adaptation pathways?

Scaling up investments in climate adaptation requires more and better information on their costs. A knowledge gap regarding the costs of CCA at national and EU levels inhibits countries from taking timely actions, making decisions about CCA investments, and scaling up finance (public and private) to address the current adaptation gap. In the 2023 reporting required by the regulation 2018/1999 from EU Member States to the Commission through the EEA platform.[46] Member States noted substantial technical and resource constraints on developing comprehensive climate risk assessments and studies for CCA costing, as well as on the development of better tagging and reporting systems on climate adaptation expenditures. By enhancing the knowledge base of methodologies and evidence on CCA costing, this report can support the Member States in their process of CCA costing, identifying adaptation funding gaps, and implementing CCA expenditure tagging.

Adaptation pathways can be effectively developed by combining information on current and future climate risks with multidisciplinary expertise. The framework for adaptation pathways varies based on the policy question at hand. The approach for costing a national adaptation program, for instance, differs from that for climate-proofing infrastructure. Some underlying principles remain constant, however. Developing adaptation pathways begins with the evaluation of existing climate risks, adaptation investments, and the effectiveness of current measures. It then considers a broad spectrum of potential climate consequences and the variety of adaptation options available. This process is meant to enable the management of climate impacts adaptively and iteratively, thereby supporting "decision making under uncertainty" (DMUU) approaches. Adaptation pathways mostly set a broad strategic direction (see Figure 1), while the more detailed adaptation programs and measures following that direction need to be developed using the various tools, methods, and information outlined in this report. Identifying and assessing the actions to be taken for adaptation is crucial, taking into account their timing, the breadth of the climate impacts projected, and the urgency of implementation. While cost-benefit analyses of CCA measures are valuable, they should be supplemented with considerations of the urgency of decisions and path dependency—that is, the effect of decisions or events on subsequent decisions and events.

46 *EC. 2018. Regulation 2018/1999.* Link. *EEA. 2023. Is Europe on track with climate resilience?* Link. *See also* Leitner, M. et al. 2023. Technical paper. Link.

Figure 1. Developing and adjusting adaptation pathways in Europe



Source: World Bank team inspired by the IPCC graphic in IPCC AR6 WG2 report. Link.

Building resilient futures in the face of evolving climate risks, including compound, multi-hazard, and disruptive events, requires developing comprehensive investment packages for CCA and DRM with a mixture of options that evolve along with them. Such investment packages should be justifiable in economic terms through a combination of early benefits ('no regrets' options), while also minimizing lock-in, and enabling early action for longer term objectives (option value[47]). National adaptation plans (NAPs) often include an extensive list of broad adaptation measures without prioritization or sequencing. These plans provide a foundation for more detailed sectoral studies, incorporating pathway thinking and moving to investment planning.

Effective adaptation will require more support for developing sectoral adaptation studies and financing strategies. Such studies are essential to inform better and more targeted CCA in sectors and updates of NAPs over time, as well as financial planning for sectoral agencies, line ministries, and ministries of finance. Acknowledging adaptation as an ongoing process means moving beyond lists of technical options and employing a portfolio approach as outlined above, blending nontechnical and technical solutions, and creating the enabling conditions for adaptation at the sectoral or national level. To set the response to short- and long-term challenges, this process must also be iterative and dynamic. While work on these pathways has been most advanced for sea-level rise and coastal policy, the same concepts apply to other environmental issues—for example, to enhancing the resilience of forest ecosystems.

Looking ahead, countries will need to start shifting from studies to inform incremental adaptation to ones that will enable transformational adaptation. Incremental adaptation, on which studies—including adaptation costing studies—have focused to date, aims to maintain current activities and systems. Transformative adaptation (which involves scaling up) and transformational adaptation (which involves moving to different activities or systems) will require going beyond existing approaches toward more strategic analysis and systems thinking, as highlighted in the EU Adaptation Mission, taking into account the long lead times for planning and the likely need for societal and governance change.[48] Changing coastal climate risks, for example, which may necessitate major changes in land use, settlements, and activities, may also require the alteration of institutional and governance structures to deliver societal change.[49] Interest is increasing in systems approaches to addressing such complex and multi-objective policy issues as transformational adaptation. A range of methods is being piloted, including social network analysis, systems dynamic modeling, and others.[50] While these can be useful for mapping risks, their application to adaptation is both complicated and time and resource intensive.

How do we finance and implement adaptation plans?

Adaptation costing studies spur important multi-stakeholder dialogues and inform policy discussion, planning, and budgeting for mainstreaming and scaling up CCA. Across the EU, such costing processes have helped raise awareness, initiate national discussion, support decisions, and improve systems to monitor and track progress on CCA.

47 An "option value" can be understood as a premium individuals are willing to pay for the reduced risk.; Haveman, R.H. and D.L. Weimer. 2001 Cost–Benefit Analysis. Editor(s): Neil J. Smelser, Paul B. Baltes. International Encyclopedia of the Social & Behavioral Sciences. Pergamon. Pages 2845-2851. Linkä
48 IPCC. 2018. Annex I: Glossary. Link.
49 ClimateReadyClyde. 2020. Resilient regions: Clyde Rebuilt. What does transformational adaptation look like? Link.
50 Martinez-Hernandez. 2022. System dynamics modelling and climate change adaptation in coastal areas: a literature review. Link.; Zarghami and Dumrak. 2021. A system dynamics model for social vulnerability to natural disasters: disaster risk assessment of an Australian city. Link.

They have contributed to mainstreaming CCA into line ministries' plans, while the more complex assessments have sought to determine the effectiveness of measures to be selected, prioritized, and implemented. In Austria and Germany, decade-long adaptation studies with multiple building blocks revealed a need for better expenditure tracking at both national and local levels to improve financing for adaptation; these studies took note of the substantial costs and benefits that could also be expected at the macroeconomic level and highlighted possible synergies between CCM and CCA investments.[51] Studies in France, focusing on low-regret measures in the short term, have informed the next National Financial Budget Strategy and longer-term financial and fiscal planning based on various climate scenarios. France has also begun preparations for a 4°C world based on the national debates that informed the updating of the National Adaptation Plan in 2023. Such preparations represent a starting point for larger-scale systemic changes and the setting of pathways for more transformational adaptation.[52]

Adaptation can be more difficult to finance than mitigation, which presents an important role for the public sector to play in addressing financing barriers and creating an enabling environment. While global and European climate finance flows are now large, they are dominated by mitigation; the flows to adaptation are small and mainly from public sources.[53] This means a large gap exists in Europe between the amount needed for adaptation and the current finance flowing. To fill it, a major scale-up is needed of public, private, and blended adaptation finance, involving new actors, new models, and new financial instruments. Several challenges are posed, however, by barriers and constraints to adaptation that include information gaps, market failures, and obstacles related to bankability, policy, and regulation, as well as broader social and cultural conditions. Importantly, generating revenues can be more difficult for adaptation than for mitigation investments; relatedly, it is easier to finance no-regret and incremental adaptation and more challenging to finance anticipatory and transformational adaptation. This means public sources of finance will need to be scaled up, which is important for the public investment strategies and medium-term budget plans. Adaptation costing studies provide the initial information needed for all of this and can be further applied to adaptation investment planning and financing. An opportunity also exists for private investment in some areas (such as market sectors and regulated sectors), although it presents questions as to who pays for the adaptation and how the burden can be equitable.

Policy recommendations and ways forward for EU Member States

Adaptation is "everyone's business." Continuous dialogues are required to mainstream and coordinate adaptation across sectors, including in planning, financial, and fiscal strategies, and to promote more ambitious and comprehensive sectoral strategies to enhance resilience. CCA studies provide a basis for more specific costing of adaptation measures within broader programs or investment portfolios, informing prioritization among measures and over time by enabling identification of synergies and potential tradeoffs and determination of the feasibility of measures with current or increased budgets. Integrating adaptation into short- and long-term financial and fiscal strategies is also essential to discern the implications for the public finances, both for near-term spending plans (that is, for the next five years) and over the longer term, alongside other pressures. The benefits of investing early (and proactively) also must be compared to the higher costs of acting later (and reactively).

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51 Tröltzsch, J., et al. 2012. Link.; IÖW. 2021. Link.; Knittel, N., et al. 2017.Link; Government of Austria. 2022.Spending Review im Rahmen des Aufbau- und Resilienzplans - Modul 1 „Analyse der klima- und energiepolitischen Förder- und Anreizlandschaft".Link.; Eichberger, S., et al. 2023. Budgeting for Climate Action: Lessons from Austria, France, and the European Union. Link.

52 Depoues et al. 2022.; Alexandre, S., et al. 2019. Link.; Eichberger, S., et al. 2023. Budgeting for Climate Action: *Lessons from Austria, France, and the European Union*. Link.; I4CE. 2023. Economic implications of adaptation pathways (upcoming). Link.

53 Climate Policy Initiative. 2023. Global landscape of climate finance 2023. Link.; Frontier Economics. 2022. Barriers to financing adaptation action in the UK. Link.

Institutional actors can help shift the thinking on adaptation from its being an environmental issue to a finance and planning one, with responsibilities assigned across all ministries. More broadly, such dialogue requires coordination across ministries, agencies, and institutes and for policies influencing resilience such as spatial planning to be considered at national and cross-border level. The 2023 EEA report on adaptation progress has identified national adaptation networks, panels, and committees as key to helping Member States with horizontal policy integration, multi-level coordination, scaling of adaptation actions, progress evaluation, and coordination through knowledge networks.[54] These entities can review evidence regularly to inform updates of NAPs and review progress on adaptation investment and remaining gaps. They can also be responsible for member state reporting to the EC on adaptation progress, as required under the EU Climate Law. Finally, these national coordinating entities can be connected to European and cross-country expert networks to ensure they have access to the latest evidence from other countries on modeling, methodologies, climate risk analytics, and CCA costing.

Countries have to adapt to both climate stressors and shocks, and the dots between disaster risk management and climate adaptation programmes should be connected. In practice, this means breaking down the silos and encouraging cross-sectoral collaboration to create synergies and streamline efforts. A concrete example is the creation of effective forest and environment strategies through interdisciplinary and cross-institutional discussions. Reconciling views and openly discussing tradeoffs is complicated but necessary to ensure investment programs can support multiple goals, including climate change mitigation and resilience. Another example is adaptation to heat, which requires coordination among health, building, and urban planning policies, as well as with labor policy. Although NAPs often follow the structures of line ministries, recognizing existing mandates in terms of managing risks and sectoral programs, it can be useful to encourage cross-ministry working. This can help in identifying "soft"—that is, policy, legal, social, and financial—measures, such as early warning, which are low cost but can reduce impacts significantly, alongside hard options, such as enhancing infrastructure resilience, to provide complementary packages of measures. Also essential to consider for all programs are green design features and nature-based solutions, given the high potential for economic co-benefits and, especially, the potential provided by mixing "green" (ecosystem-based) with "grey" (infrastructure-based) measures.[55]

Countries can improve their national climate risk assessments and national adaptation plans and programs in parallel. While granular and downscaled assessments of future climate risks, even at the regional level, can provide useful information, priorities for early adaptation measures should start with an analysis of risks under current climate conditions. Climate risk and impact analytics are key and must be grounded in historical and observed information to support the better identification of early CCA measures, the timing and prioritization of measures, and the calculation of potential early benefits. Climate projections can then be used, but the analysis must take note of the wide spectrum of possible outcomes from future climate impacts derived from warming scenarios and climate (and impact) modeling. As this complexity makes it difficult to define precisely the required levels of adaptation, future risk pathways and an adaptive management approach to address them must be considered. Historical hazard analytics, including national risk assessments (NRAs), as well as extreme scenarios and national studies, are needed alongside more traditional future-oriented climate change studies, such as TRACE, PESETA IV, and upcoming EUCRA results.[56] Moreover, simple yet rapid exposure and vulnerability assessments can contribute timely evidence to raise awareness of the need for more in-depth exploration of risks.

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54 EEA. 2023c.
55 WB. 2023. Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience: A Guideline for Project Developers. Link.; WB. 2019. Integrating Green and Gray: Creating Next Generation Infrastructure. Link.
56 TRACE = Territorial Risk Assessment of Climate in Regions of Europe.

Countries can undertake CCA costing at different levels of analysis to serve different policymaking objectives. At the most aggregated level, macro-level assessments of its costs can support advocacy for CCA by demonstrating that the benefits exceed the costs at the country level, not just at the programme and investment level. Such assessments can be complemented by CCA expenditure tracking, or climate budget tagging. To support the development of effective CCA contingency plans and financial resilience instruments, assessments can also take into consideration extreme scenarios for civil protection and Union Civil Protection Mechanisms (UCPMs) and results from macroeconomic and macro-fiscal analysis. At the sector level, mainstreaming of CCA costing in medium-term planning and budgeting by ministries of finance, line ministries, and locally is useful for improving policy and financial planning for CCA. At the level of directorate-generals or line ministries in particular, more in-depth analysis of climate risks and CCA options and costs can be integrated into strategies and plans to support prioritization. At the most detailed level, decision support tools and costing methods can be used to look at individual programs, projects, or investments.

Lessons from various EU countries provide invaluable insights for better planning and budgeting for CCA. National planning studies like those in France, which estimated early adaptation costs at around €2 billion annually in this decade, have influenced short-term financial strategies as well as medium- and long-term planning. Austria's estimate of €421 million to €573 million and Germany's of €140 billion to €142 billion annually, were the conclusion of years of collaborative research. The studies highlighted the pressing need for improved expenditure tracking and a better understanding of broader macroeconomic implications to further improve such estimations. The new case studies undertaken in this report provide additional insights. In Romania's NAP draft document, overall estimates of CCA measures amount to €19 billion until 2030, and its study helps illuminate approaches for estimating costs and benefits at the macroeconomic level. Results from this research also helped with the determination of adaptation costs of approximately €7 billion for Bulgaria over the next five years.

The studies presented here can enrich national dialogues on multi-hazard investments and financial resilience, as well. For Sweden, the analysis focused on prioritizing and costing a set of early actions for the forestry sector to address the rising risk of wildfires, including potential no-regret options, interventions to address lock-in risk, and early adaptation pathway actions, all of which could be justified based on their net economic benefits. Findings for Croatia on climate proofing underscore the significance of infrastructure upgrades in future programs and the importance of a national dialogue on managing multi-hazard risks, while initial estimates of €123 million to €491 million for climate proofing Romania's transportation networks against flood risks enhance the knowledge base for future in-depth multi-hazard assessments. Together, these studies offer a comprehensive roadmap, informing both sectoral strategies and national adaptation plans for countries embarking on CCA.

Policy recommendations and ways forward for the European Commission

The implementation of the EU Adaptation Strategy and the Green Deal can be spurred by providing more support to countries for identifying bankable and effective adaptation investments. While many EU Member States reported improvements in capacity and the status of national adaptation actions in 2023, several finance-related challenges persist. These include assessing the cost of adaptation; immaturity of monitoring, reporting, and evaluation systems for implementation and financing; lack of a common methodology to assess costs and track financing; absence of dedicated budgets or financing streams for implementing adaptation strategies or plans; and limited availability of dedicated adaptation funds for financing implementation (it is worth noting, however, that some countries have reported having such dedicated funds or portions of funds to finance national or sectoral adaptation actions).[57] The public sector needs to increase finance for adaptation and deploy it more innovatively—for example, by considering new financial instruments and helping to "de-risk" private investment. The public sector can also help by creating the enabling conditions needed by the private sector in terms of information, capacity, policy environment, and incentives. Finally, Member States need to begin moving from lists of adaptation options to costed plans, and beyond this to adaptation investment planning and financing, starting with the identification of bankable pipelines of investments and proceeding to the development of financing strategies. The EC can provide more support to countries for identifying bankable and effective adaptation investments to spur the implementation of the EU Adaptation Strategy and the Green Deal, building on initiatives as the Mission on Adaptation and dialogues on mobilizing climate resilience financing.[58]

Dialogue with ministries of finance can support the development of effective short- and medium-term financial and fiscal strategies that consider adaptation to climate change. Stress tests have been conducted on the potential impacts of climate change on Member State public finances, including on indicators such as debt to GDP levels.[59] These tests have determined that climate change may pose risks to fiscal (debt) sustainability in some countries, and further dialogue with ministries of finance is important to managing them. Several countries are undertaking climate budget tagging and looking at the possible effects of adaptation on spending plans and the public finance. Adaptation costing studies can contribute to such analysis and encourage investment by demonstrating the benefits of early adaptation investment and how it can reduce fiscal risks.

Continued support from the EU will be essential to the effective use of climate risk information in the development of adaptation strategies and plans. The EU is already developing and sharing climate risk analytics through the EUCRA, for example, and through such research initiatives as COACCH and PESETA. Further knowledge sharing could be helpful, especially the provision of more information on adaptation costs and benefits. In addition, more tailored capacity building could support the use of rich EU datasets and climate impact assessments to inform NRAs, sectoral and adaptation studies, and, ultimately, NAPs to scale up adaptation. While improved risk analytics will be useful, however, they will not resolve the complexity of potential climate impacts; adaptation decision-making will need to continue relying on the adaptive management approaches above for the foreseeable future.

EU support and cooperation can enable the uptake of CCA costing assessments. With increasing climate risks, adaptation will need to be scaled up at all levels, from European down to local, and will call for an expansion of investments and an increase in CCA costs. The benefits of improving the practice and uptake of costing studies to enhance the efficiency and effectiveness of adaptation decision-making will be EU-wide. Databases of the costs of CCA measures, case study examples of costs and benefits, and efforts to provide support for costing methods could result in quicker and more robust assessments and, in turn, improve the value-for-money of adaptation delivery. They could also provide a practical starting point while more country-specific, tailored, and granular assessments are becoming available. A menu of tools are already available for instance on managing climate risks.[60]

57 Leitner, M. et al. 2023. Technical paper. Link.
58 EC. 2024. Managing climate risks - protecting people and prosperity. Link.
59 The EC Fiscal Sustainability Report 2021 (DG ECFIN) included an extreme event stress test to assess the risks to public finances—a first step in policy readiness. The results led to the conclusion that climate change may pose risks to fiscal (debt) sustainability in some countries, although these were reported as remaining manageable under (low) global warming scenarios (European Commission. 2021. Fiscal sustainability report 2021. Link.).
60 EC. 2024. Managing climate risks - protecting people and prosperity. Section 3.2. Tools for empowering risk owners. Link.

The EU could also provide tailored assistance with the implementation of relevant EU laws and policies,[61] **such as the EU Climate Law**[62] **or the Nature Restoration Law when adopted.** This may include, for instance, ways to integrate effectively NBSs and a mixture of grey and green solutions in investment packages across Europe, as aligned with the EU's flagship climate and nature policies and the Green Deal. These solutions are often highly context-specific and complex to determine and implement, and they could be promoted more comprehensively in sectors such as agriculture or forestry. For example, in preparation for the Nature Restoration Law when adopted, the EC may consider providing tailored assistance across EC services to support subsequent measures to support the implementation of obligations at the EU and national levels.[63]

This analysis produces some plausible and indicative CCA cost estimates for the EU-27 for the short term (until the 2030s) by extrapolating from existing national studies. No recent quantified comprehensive and consolidated estimates of CCA costs exist at the EU level. Estimating costs at the regional level and making comparisons, scaling, and replicating cost analytics are more challenging for CCA than for climate change mitigation (CCM). Past assessments, like PESETA IV and COACCH, have offered sector-specific climate impact estimates, with limited analysis of CCA costs and benefits in a few sectors.[64] This report derives illustrative short-term adaptation costs for the EU-27 based on national studies (Figure 2).[65] Costs are estimated at €15 billion to €64 billion per year until 2030, with a "central" estimate of €21 billion extrapolated on a per capita basis based on a study for Austria that yielded costs of adaptation in the median range of those found across existing studies for Europe.[66] These estimates may be lower bound as a result of gaps in sectoral and hazard coverage and the ranges of projected climate change impacts. While these estimates are indicative, their magnitude can help to highlight the scale of adaptation finance that may be needed and equate to between 0.1 and 0.4 percent of EU GDP, and a much higher proportion of the public budget. This indicates finance flows need to be scaled up significantly.

61 Such as the DG REFORM's Technical Support Instrument with support based on flagship themes and beyond for single or multi-country engagements.

62 The EU Climate Law requires that Member States integrate adaptation in all policy areas and promote NBS and ecosystem-based adaptation.

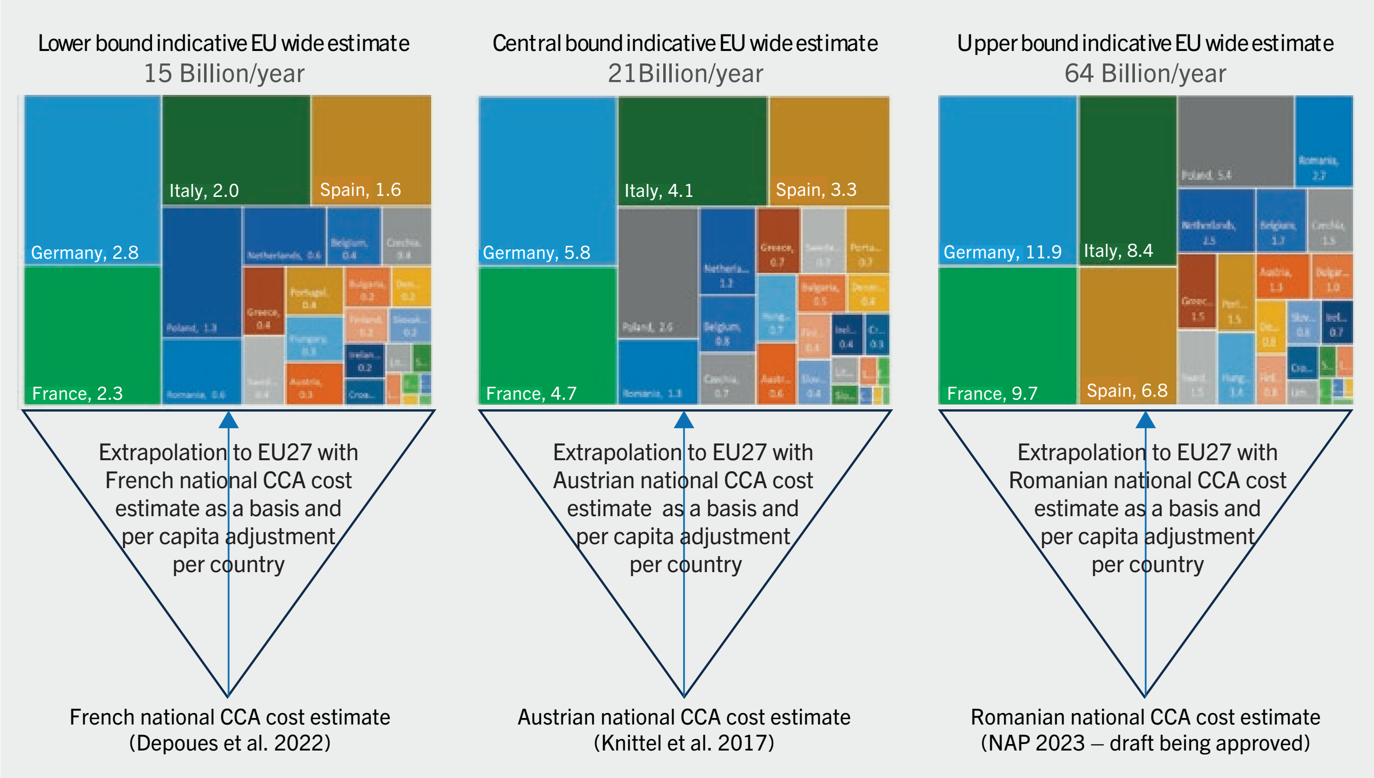
63 EC. 2023. Nature Restoration Law. Link. According to the EC, investment into nature restoration adds €8 to €38 in economic value for every €1 spent, thanks to the ecosystem services that support food security, ecosystem and climate resilience and mitigation, and human health.

64 Lincke *et al.* 2018. D2.3 Impacts on infrastructure, built environment, and transport Deliverable of the H2020 COACCH project. Link.; Lincke and Hinkel. 2018. Economically robust protection against 21st century sea-level rise. *Global Environmental Change* 51, 67–73. Link.

65 Based on national studies for France, Austria, Romania, and UK, with respectively underlying figures from the following studies: Depoues, V. et al. 2022. Se donner les moyens de s'adapter aux conséquences du changement climatique en France: De combien parle-t-on? Link; Knittel, N. et al. 2017. The Costs of Climate Change Adaptation for the Austrian Federal Budget. Link.; Government of Romania. 2022. Extract from the National Action Plan for the implementation of the National Strategy on Adaptation to Climate Change for the period 2023-2030; and Watkiss, P. 2023. The Costs of Adaptation, and the Economic Costs and Benefits of Adaptation in the UK. Link.

66 Jeuken, A., et al. 2016. *EU-wide Economic Evaluation of Adaptation to Climate Change.* Link; De Bruin, K., et al. 2009. "Economic Aspects of Adaptation to Climate Change: Integrated Assessment Modelling of Adaptation Costs and Benefits." Link.

Figure 2. Illustrative Lower to Upper Bound of Annual CCA Cost for the EU-27 to 2030

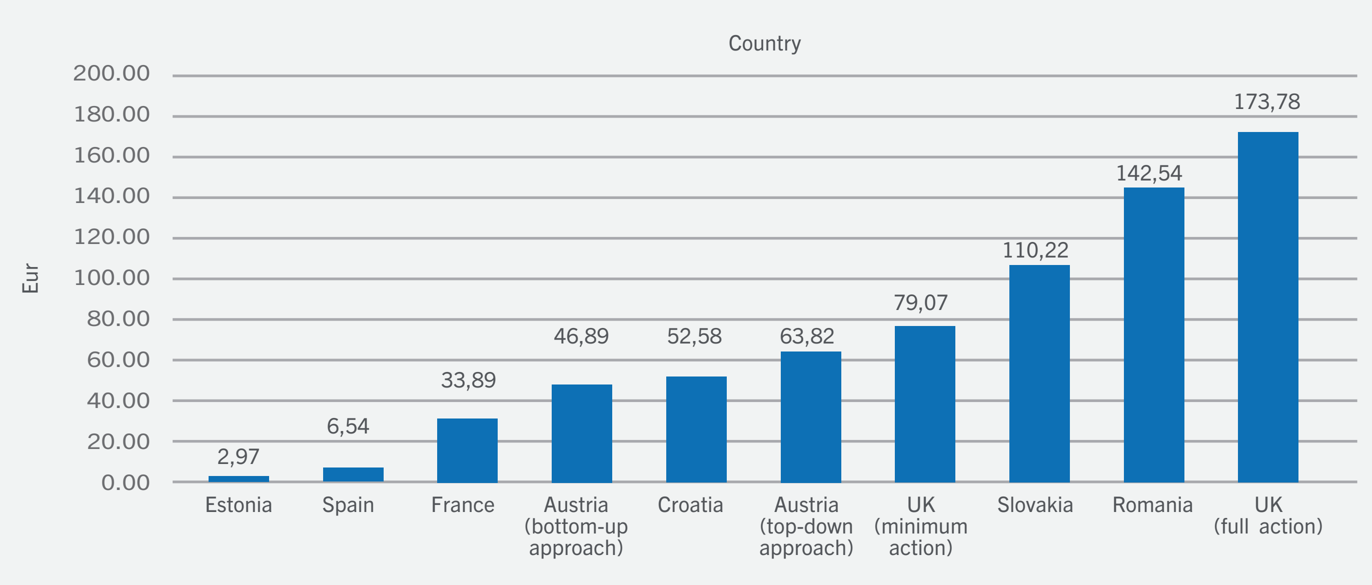


Source: World Bank; Based on Depoues et al. 2022, Knittel et al. 2017, and Government of Romania 2023.
Note: EU-wide estimates are extrapolated from single-country estimates. The left panel of the figure presents a lower-bound estimate of annual CCA costs for the EU-27 (for no-regret adaptation only) for this decade, extrapolated on a per capita basis from the French study (Depoues, V. et al. 2022). The middle panel presents a central estimate of CCA costs per year for the EU-27 for this decade, extrapolated on a per capita basis from the Austrian PACINAS study (Knittel et al. 2017). The right panel presents an upper-bound estimate of CCA costs per year for the EU-27 (for no-regret adaptation only) this for decade, extrapolated on a per capita basis from the drafted Romanian National Adaptation Strategy and Action Plan (this is preliminary, as the NAP is not finalized or approved). These values do not take account of vulnerability or risks in scaling up from the national level and can only be considered indicative.

As EU-level CCA estimates are highly aggregated and stylized, countries are urged to undertake detailed, contextualized national assessments rather than relying solely on approximate regional assessments. Cross-country comparison of CCA costs is challenging. Unlike mitigation, CCA has no quantified global or EU objectives. This means any analysis has to decide what these objectives should be and the balance of the benefits and costs of adaptation, as well as the "acceptable residual impacts" after CCA. Adaptation costs for objectives differ based on economic efficiency, acceptable levels of risk, or risk minimization. Existing estimates from individual countries vary between €3.96 million and €11.6 billion per year, with large disparities in their coverage of risks and sectors (see Figure 3).[67] Because the differences stem from three sets of assumptions—time periods and scenarios, future risk levels, and objectives, assumptions, and methods—these figures are not directly comparable. Nonetheless, useful insights can be gained by comparing results from various approaches. Sectoral- or program-based CCA costing exercises can allow some comparability if similar methodologies are used, while CCA options can also sometimes be compared using results from societal benefit-cost analysis.[68] Based on existing country studies of CCA costs in per capita terms, costs range from around €34 per person per year in France to €64 in Austria and €110 in Slovakia as central values, and €3 in Estonia to €174 in United Kingdom considering extremes. This indicates very different approaches or coverage and suggests a need for countries to undertake detailed national assessments to produce more robust estimates.

67 Estimates are adjusted to 2022 euros and are in annual terms and, thus, may vary from original values in the literature. *See* Annex 1 for original values.
68 WB and EC. 2021a. Link.

Figure 3. Annual CCA Costs Per Capita from Short-Term Policy-First National Assessments



Source: World Bank; see Table 5 in Annex 1.
Note: CCA cost estimates differ from the original unit values in Table 5 in Annex 1. Values are produced in 2022 euros and in per capita terms by dividing the cost estimate by the countries' populations (data obtained from EC. 2024. EU, Eurostat Database).[69] Bulgaria is not included in this figure, as the study (Republic of Bulgaria 2019)[70] provides CCA cost estimates per adaptation option and is thus not comparable with the other studies, which assess CCA costs at the national level in annual terms.

Limitations and considerations for future research

This report is limited in its scope and needs to be considered in the context of broader CCA debates and studies. Evidence on costs of CCA measures in terms of sectors and hazards is limited,[71] and the types of measures covered (such as hard structural versus soft behavioral change as adaptation response; policy measures; and so on) call for in-depth study. This report focuses on hazards, sectors, and "use cases"[72] that are generally less covered in the literature, concentrating on, for example, wildfires and heat adaptation, as opposed to flood risk or sectors such as transportation and building upgrades. It also focuses mainly on countries of southeastern Europe that were selected at the beginning of this project based on criteria that included the added value of analytics, existing dialogue with the countries, and access to climate risk analytics and local expertise. The use cases presented illustrate adaptation from different perspectives (national, sectoral, and programmatic), and the literature is referenced for further insights.

Finally, the key issue of who should bear the costs for CCA and investments is only touched upon in this report, but it will be crucial for future adaptation. To date, adaptation has been largely undertaken by the public sector, but, given the adaptation finance gap, the private sector and households will clearly need to contribute. Beyond methodological aspects, the public/private split of investments requires consideration of national legislation and much more detailed adaptation studies. The subnational responsibilities and implementation of investments also are not explored in this report in detail; other types of studies are needed on subnational variations in impacts, appropriate localized adaptation

69 EC. 2024. EU, Eurostat Database. Link.
70 Republic of Bulgaria. 2019.
71 Organisation for Economic Co-operation and Development (OECD). 2008. Economic Aspects of Adaptation to Climate Change Costs, Benefits and Policy Instruments: Costs, Benefits and Policy Instruments.
72 The concept of use cases was developed in the DG CLIMA study on adaptation modelling and refers to a generalized application of adaptation in a particular decision-making context. This report presents three use cases—national planning, sectoral planning, and programmatic planning—which were determined based on reviews of the literature and of methodology and on consultations.

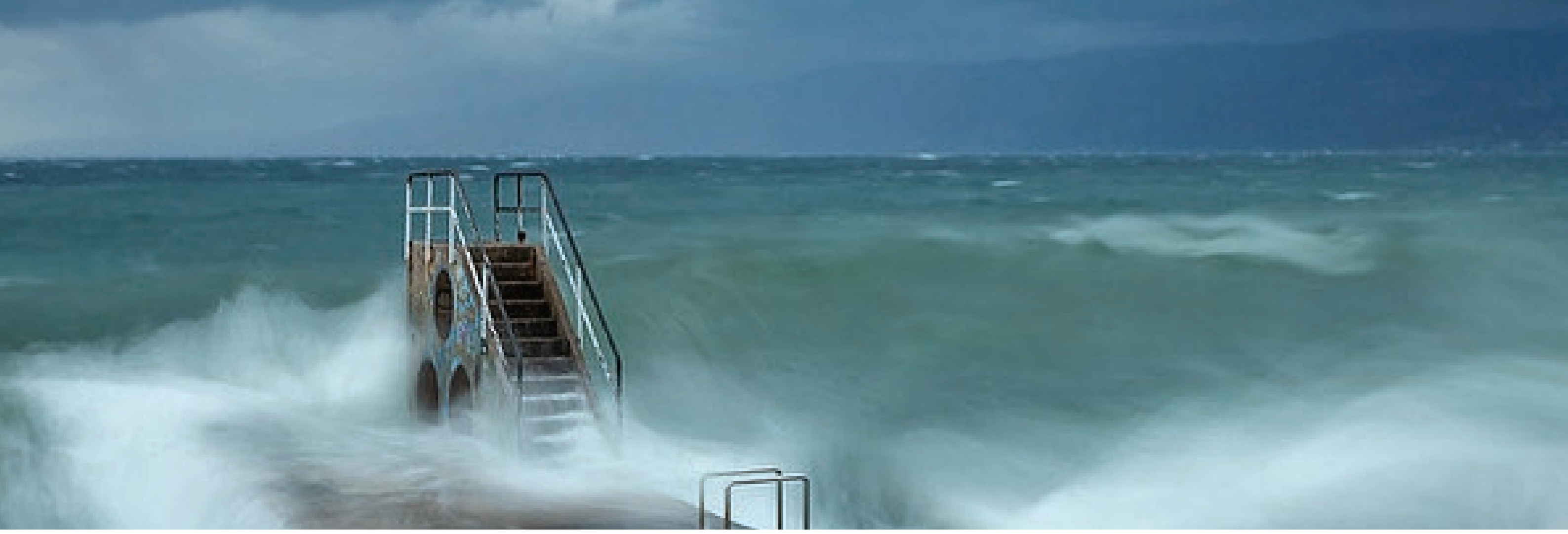
measures, and how to finance adaptation at the local level within countries. The report refers to literature and to forthcoming further studies.[73]

A summary of main challenges, limitations, and opportunities is detailed in Table 1.

Table 1. Summary of main challenges, limitations, and opportunities

KEY CHALLENGES AND LIMITATIONS	WAYS TO MOVE FORWARD
• Lack of information on projected impacts of climate risks for the short to medium term (2030s–50s), particularly to inform sectoral or investment portfolio assessments and including consideration of extremes (wildfires, heatwaves, and so on) • Lack of comprehensive evidence on CCA costs • Difficulties in comparing costs of climate adaptation measures across countries due to use of different methodologies • Lack of knowledge on the benefits of CCA measures needed to enable prioritization and timing as well as assessment of tradeoffs among various measures • Complicated contextualized costing of CCA measures due to lack of analysis at the sectoral level or for investment portfolios, calling for creative solutions that have to be arrived at through a resource-intensive process based on a mixture of literature reviews, data, and information collected on national strategies • Lack of research on CCA measures supporting multi-hazard resilience	• Continue investing in data collection at the national level. • Provide incentive for adaptation studies at the national level. • Support capacity building on costing CCA across Europe. • Encourage the exchange of knowledge and lessons learned as well as the sharing of data and reports—even preliminary insights—on costing of CCA measures to enhance the evidence base. • Evaluate expenditures and budget plans to identify adaptation gaps and track progress. • Conduct further analytics on private versus public sector investment in CCA measures.

73 WB and EC. 2024 forthcoming. *Financially Prepared: The Case for Pre-positioned Finance. See also ACCREU* (assessing climate risks in Europe), which is focusing on the economics of adaptation. Ecologic. 2023. Assessing Climate Change Risk in Europe (ACCREU). Link.



Introduction

Europe urgently needs to scale up investments in climate change adaptation (CCA), given significant losses and damage caused by natural and climate-related hazards. The continent is warming faster than any other global region on Earth,[74] which makes it increasingly subject to crisis weather events, acting directly and/or as a stress multiplier.[75] Between 1980 and 2022 alone, total economic losses from weather and climate-related events already amounted to €650 billion across 27 European Union (EU) Member States.[76] Although Europe has dealt historically with extreme weather, most such events are projected to become more frequent and intense,[77] stretching preparedness and response capacity and resulting in more significant economic loss and harmful effects on welfare.

Economic losses from climate change are projected to continue growing. Under a high emission scenario, EU gross domestic product (GDP) could be 7 percent lower than in the baseline by a conservative estimate.[78] Across all scenarios, by 2070, one-quarter of EU regions could experience GDP losses greater than 5 percent, noting that these estimates do not take tipping points into account.[79] Structural changes will be needed to deal with the systemic impacts to all economic sectors; in fact, evidence suggests the continent is unprepared for the larger disasters already being experienced, as illustrated by the losses from floods in 2021 (amounting to more than €40 billion in Germany),[80] drought in 2022, and increasingly disruptive seasonal heat waves and wildfire seasons. Even under a best-case 1.5° degree warming scenario, certain global, climate, and socioeconomic tipping points[81] may already have been reached. With warming between 2°and 4°C, ten of sixteen tipping points (five global and five regional)[82] could be reached; these include a significant ice loss in the Barents Sea and an ice-free Arctic, which would have a direct impact on Europe.[83]

In this context, it is important for European countries to take action and invest in CCA. Such investments can reduce direct losses from disaster and climate impacts while providing numerous economic, social, and environmental benefits, such as enhanced growth, more trade and job opportunities, gains in productivity, improvements in emission reductions

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74 WMO/Copernicus. 2022. Link.; Pörtner, H.-O., et al. 2022. Link.
75 Collins Dictionary. 2022. *The Collins Word of the Year 2022 - A Year of Permacrisis*. Link.
76 EEA 2023a.
77 Kovats, R. S., et al. 2014. Link.
78 EC. 2024. Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society. Link.
79 Bosello et al. 2020. Link.
80 Prognos. 2022. Extreme weather damages in Germany since 2018. Link.
81 IPCC. WGII AR6 full report. Link; GSI. 2023. Global tipping points report. Link.
82 "Regional" is meant to cover the European region as aligned with climate models; "cross-country" is used, where suitable, to clarify.
83 McKay et al. 2022. Exceeding 1.5°C global warming could trigger multiple climate tipping points. Link.

and air quality, and increases in ecological value and biodiversity.[84] Studies show that adaptation can, for example, be extremely effective in reducing the economic costs of climate change–related coastal and river floods.[85] A recent report from the World Bank and the European Commission (EC) reviewing more than 70 investments across Europe has also shown that investments with a portfolio of measures addressing disaster risks can deliver a triple dividend, with numerous co-benefits.[86]

Tracking the implementation progress of CCA plans may be complicated, however. Common quantified global or EU objectives for CCA are lacking, as are cross-cutting targets for climate risk reduction and "acceptable residual impacts" after CCA (which are societal decisions) and estimates of CCA needs for EU Member States. National plans include some costing of CCA measures, but the coverage is inconsistent, and comparability is difficult. Furthermore, an absence of clear tagging of CCA in expenditures (planned and actual) in budgets[87] makes it difficult to track the implementation of measures and assess investment gaps.

This report directly addresses key knowledge gaps identified in the 2023 climate reporting by EU Member States and the EC, providing valuable insights for the enhancement of EU and national adaptation actions. In the 2023 reporting required by the regulation 2018/1999 from EU Member States to the Commission through the EEA platform on national actions[88] have shown progress related to CCA, including compliance with the EU Climate Law (summarized in Box 15 in Annex 1).[89] The reporting indicates progress in the policy landscape, as countries develop and update climate adaptation policies and legislation to improve monitoring, reporting, and evaluation (MRE), as well as climate risk analytics (CRAs). The reporting identified several knowledge gaps related to the costing of CCA. By providing comprehensive insights and use cases,[90] this report plays a crucial role in supporting EU Member States in their strengthening of national adaptation actions by addressing the following challenges:

- *EU Member States face substantial resource constraints on CCA, including limitations on their ability to conduct resource- and time-intensive CRAs.* While some EU Member States have made progress in multi- and cross-sectoral risk assessments and thematic and sector-specific studies and in filling strategic knowledge gaps in systemic adaptation, the overall rate and extent of progress remain limited. This report and the use cases it presents show ways in which thematic CRAs focused on critical sectors and issues can help support decision-making by filling gaps not addressed by comprehensive cross-sectoral, cross-hazard CRAs.

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84 An EU assessment of the macroeconomic impact of the European Green Deal suggests a projected GDP in 2030 of 0.5 percent above the baseline in the best-case scenario as a result of increased private consumption, due to the use of carbon revenues to reduce value-added tax (VAT) and support energy efficiency investments (EC 2022. Economic impacts of the green transition. Link.). In the EU, employment in renewable energy more than doubled between 2004 and 2018, from 660,000 to 1.51 million jobs. (European Parliament 2022. Economic impacts of the green transition Link.). Meanwhile, investment in adaptation in the EU is expected to create (directly and indirectly) a total of 500,000 additional jobs by 2050 (EC 2014. Assessing the Implications of Climate Change Adaptation on Employment in the EU - Final Report & Annexes. Link.). UN findings reveal that adaptive agricultural measures such as solar-powered irrigation, weather alert systems, and new crop varieties could preclude losses in global agricultural yields by up to 30 percent by 2050 (UN 2023. Climate Action Fast Facts. Link.). Maksimovic, C. 2017. Blue Green Solution: A Systems Approach to Sustainable, Resilient, and Cost-Efficient Urban Development. Link.

85 Lincke et al. 2018. D2.3. Impacts on infrastructure, built environment, and transport Deliverable of the H2020 COACCH project. Link.; Lincke and Hinkel. 2018. Economically robust protection against 21st century sea-level rise. Global Environmental Change 51, 67-73. Link.

86 The triple dividend of resilience investments includes saved lives and avoided losses (dividend 1), induced economic and development benefits (dividend 2), and environmental and social benefits (dividend 3). Benefit-cost ratios typically ranged between 2 to 10. World Bank. 2021. Economics for Disaster Prevention and Preparedness - Investment in Disaster Risk Management in Europe Makes Economic Sense. Link.; Tanner et al. 2015. The Triple Dividend of Resilience. GFDRR/World Bank/ODI Link.

87 Using Rio Markers, for instance (Kovats et al. 2014). The EC sometimes uses Rio Markers to measure and track its environmental and climate-relevant spending and provide statistical reports to the OECD-Development Assistance Committee (DAC) See European Union (EU). 2010. Short Guide to the Use of Rio Markers. Link.

88 EC. 2018. Regulation 2018/1999. Link.; EEA. 2023. Is Europe on track with climate resilience? Link.; *See also* Leitner, M. et al. 2023. Technical paper. Link.

89 See EU. 2021. Regulation (EU) 2021/1119. Link.

90 Defined at the beginning of Chapter 2.

- *A lack of standardization of methodologies for costing CCA makes it difficult for Member States to implement and comply effectively with EU law.* This report aims to empower them by offering valuable guidance, inspiration, and a comprehensive overview of methodologies, along with practical use cases, to support their efforts to achieve compliance.

- *A lack of assessments and common methodologies for CCA costing, as well as of systematic processes to assess costs and track financing of National Adaptation Strategies (NASs) and National Adaptation Plans (NAPs), hinders MRE processes and limits reporting obligations.* Some EU Member States with comprehensive or more advanced CRAs and climate legislation do not consistently provide costing of CCA measures in their NAPs or NASs or track CCA expenditures. Dedicated budgets or financing streams for CCA implementation are rarely included, although some of the strategic and legislative frameworks are currently being revised. By drawing on the experiences of other EU Member States and existing literature, this report significantly contributes to the knowledge base by providing valuable insights into the calculation of CCA costs and presenting systematic methodologies for assessing and tracking financing.

- *Gaps persist at national and sectoral levels in the coverage and quality of the climate risk analytics and costing of CCA measures that inform the tracking and evaluation of CCA expenditures and feed back into policy development.* While most EU Member States report utilizing EU funds for CCA, only six (Germany, Greece, Italy, Latvia, Portugal, and Spain) have established dedicated national adaptation funds for financing national or sectoral adaptation actions. This report improves the knowledge base that inform adaptation investment planning and financing.

- *EU Member States face challenges with regard to horizontal policy integration and multi-level coordination in scaling adaptation actions and conducting evaluation processes.* They recognize the significant role of coordinating actors, however, such as ministries, governmental agencies, or institutes, and the need to emphasize cross-country networking in preparation for climate change impacts. This report contributes in this area by providing valuable arguments and best practices in support of the efforts of these coordinating actors.

- *Better evidence is needed to achieve synergies between CCM and CCA in key sectors.* To align with the objectives of the Energy Union and Paris Agreement, more information is needed about sectors such as forestry, agriculture, energy, and infrastructure. Improved evidence is required to avoid insufficient adaptation action or maladaptation and to include consideration of the role of prevention in adaptation. This report showcases use cases that demonstrate the achievement of such synergies and broader objectives, while also highlighting the benefits of integrating multi-hazard disaster risk considerations and transparently discussing potential trade-offs.

- *Research and support remain insufficient for defining variable adaptation pathways*. Member States need to be able to share examples of adaptation excellence and determine the bankability of adaptation options and the effectiveness and efficiency of CCA measures and progress. This report provides a valuable foundation for further research in these areas, offering a comprehensive overview of the literature and presenting various use cases at different levels.

The report's structure and content are summarized in Figure 4.

Figure 4. Structure and content of the report

Chapter 1:
OVERVIEW OF THE LITERATURE AND METHODOLOGIES FOR COSTING CCA
Understanding the overall process (building blocks), key elements, and analytical approaches

Chapter 2:
EXPANDING THE EVIDENCE BASE ON COSTING CCA WITH "USE CASE"
Showcasing existing examples and select use cases to demonstrate and encourage uptake

BULGARIA USE CASE	ROMANIA USE CASE	SWEDEN USE CASE
Informing NAP and strategic plans • Heat & Wildfire risk • National-level Planning	**Informing NAP and macroeconomic analytics** • Multihazard • National-level Planning	**Spatial vulnerability & benefit cost analysis** • Wildfire risk • Sector-level Planning
CROATIA USE CASE	**ROMANIA USE CASE**	**AURELIA USE CASE (FICTIONAL)**
Climate proof select critical assets • Heat • Transport sector • Programmatic Planning	**Flood proofing and uprgrading transport networks** • Flood risk • Sector/Prorammatic Planning	**Climate proof select critical assets** • Heat/Wildfires • Programmatic Planning

EXECUTIVE SUMMARY & CONCLUSION
Key results, takeaways, and recommendations

This report holds valuable insights for different entities and groups of stakeholders, catering to their specific roles and responsibilities. Each reader can find sections of particular interest, tailored to their individual needs. To assist readers in navigating the report effectively, a reader's guide is provided in Box 1.

BOX 1. READERS' GUIDE

This box serves as a helpful reader's guide, providing an overview of the report's content and directing various stakeholders to the sections that align with their specific interests. It acts as a roadmap, ensuring that readers can easily navigate to the sections most relevant to them.

Line ministries (for example, Ministry of Interior, Ministry of Environment): These readers may find the case studies in Chapter 2 of particular value, as they showcase existing examples and provide insights into the different methodologies and steps used in various use cases. Chapter 3 consolidates the information and presents key insights and policy recommendations applicable to line ministries. The analysis provides guidance on the actions necessary to create effective adaptation pathways and supports the alignment with EU-wide objectives, strategies, and directives. The case studies will also help ministry readers understand trade-offs and consider multi-hazard and sustainability factors when prioritizing interventions, and they offer knowledge and technical capacity relevant to using CCA information to prioritize investments in CCA and CCM, including data on measures, methodologies, and best practices for different hazards and levels of analytics. The analysis shows how EU Member States can undertake CCA costing at different levels of analysis to serve different policy objectives. At the sector level, the mainstreaming of CCA costing (by ministries of finance and line ministries and at the local level) in medium-term planning and budgeting is useful for improving policy and financial planning for CCA. Looking forward, the analysis shows that EU Member States will need to shift from studies to inform incremental adaptation to ones that will enable transformational adaptation.

Coordinating entity on CCA (for example, Ministry of Finance): These readers may find Chapter 1 of special interest, as it provides an overview of key literature and methodologies for costing CCA. Chapter 3 consolidates the information and presents key insights and policy recommendations applicable to coordinating entities. The analysis demonstrates the economic benefits and broader advantages of taking action on both CCA and CCM. Building resilient futures in the face of evolving climate risks requires developing comprehensive investment packages for CCA and DRM that evolve over time. CCA is more challenging to finance than CCM, and the public sector plays an important role in addressing barriers and creating an enabling environment. The analysis shows how EU Member States can undertake CCA costing at different levels of analysis to serve different policy-making objectives. The mainstreaming of CCA costing in medium-term planning and budgeting at the sector level (by ministries of finance and line ministries and at the local level) is useful for improving policy and financial planning for CCA. This information can support overall planning, contribute to further analysis, and help Member States meet requirements for reporting to the EU and international treaty bodies, such as under the Paris Agreement. The analysis may help entities improve their National Climate Risk Assessments and National Adaptation Plans and programs and "connect the dots" between DRM and CCA programs simultaneously.

EU-level stakeholders: These readers may find Chapter 1 practical, as it provides an overview of key literature and methodologies for costing CCA, along with the use cases. Chapter 3 consolidates the information and presents key insights and policy recommendations applicable to stakeholders at the EU level. The information in Chapter 1 will enhance understanding of the impacts of climate change on critical sectors, informing the EU-wide Climate Change Risk Assessment and the EU's progress with respect to the Paris Agreement. Furthermore, the chapter will help readers understand the costs of various CCA options and how to use this information for planning and implementing CCA programs at the national and EU levels. Continual dialogue is required to mainstream and coordinate adaptation across sectors, including in planning, financial, and fiscal strategies, and to promote more ambitious and comprehensive sectoral strategies to enhance resilience. Effective adaptation will require more support for developing sectoral adaptation studies and financing strategies. Macro-level assessments of CCA costs can support advocacy for CCA by demonstrating that the benefits exceed the costs at the country level, not just at the program and investment levels. The assessments can be complemented by CCA expenditure tracking, or climate budget tagging, as well as consideration of extreme scenarios for civil protection and results from macroeconomic and macro-fiscal analysis to develop effective CCA contingency plans and financial resilience instruments.

CCA experts (and/or practitioners broadly interested in CCA costing): This group of readers will find the entire report valuable. Chapter 1 provides an overview of key literature and methodologies and explains the fundamentals of costing CCA, while Chapter 2 provides practical examples and insights into costing methodologies through detailed case studies. Chapter 3 provides an overview of further research and ways forward.

STUDY OBJECTIVE

Scaling up investments in climate adaptation requires more and better information on their costs. A knowledge gap regarding the costs of CCA at national and EU levels inhibits countries from taking timely actions, making decisions about CCA investments, and scaling up finance (public and private) to address current adaptation gap. This gap is widening as adaptation needs—and associated costs—increase relative to the available flows of finance for adaptation.[91] Improved estimation of CCA costs is needed, as is guidance on how to develop methodologies that can inform CCA investment and policy decisions. Such information could help improve the robustness and coverage of EU-wide assessments of CCA investment needs and support decision-making in the prioritization and implementation of CCA measures.

This report informs high-level cross-country strategic dialogue and the development of CCA programs at the national level by addressing four key questions:

91 UNEP. 2021. Link.

1. How are the costs of CCA calculated across Europe, and what purposes in terms of policy making do these estimates serve?

2. What are the magnitude and ranges of the CCA costs estimated for Europe, and how can these estimates be used to inform strategic dialogue and policy making, including as part of developing adaptation pathways following adaptive and iterative risk management principles?

3. Is it possible to compare, scale up, and replicate assessments of CCA costs from specific use cases that were undertaken for national policy making?

4. When assessments and estimates of CCA costs for one country disagree, how can the findings be reconciled with a step-by-step approach and used to provide helpful insights for policy decision-making?

This report shares practical approaches for the costing of climate change adaptation measures. The objective is to increase the knowledge base on CCA by summarizing major costing methodologies in the field and demonstrating how climate change adaptation, and plans for it, can be costed across different sectors. The report includes policy recommendations and showcases lessons learned on assessing the costs of CCA from the perspective of policy makers and technical staff at Member State and EU levels. The resulting analysis can serve as a basis for institutional stakeholders who are evaluating the costs of adaptation with respect to budgets or investment plans; seeking to cost CCA for sectoral programs; or seeking support in the evaluation of strategies or actions related to adaptation objectives under the EU Green Deal, EU Climate Adaptation Strategy, Paris Agreement, and NAPs and NASs, among others.

FOCUS AREAS AND METHODOLOGY

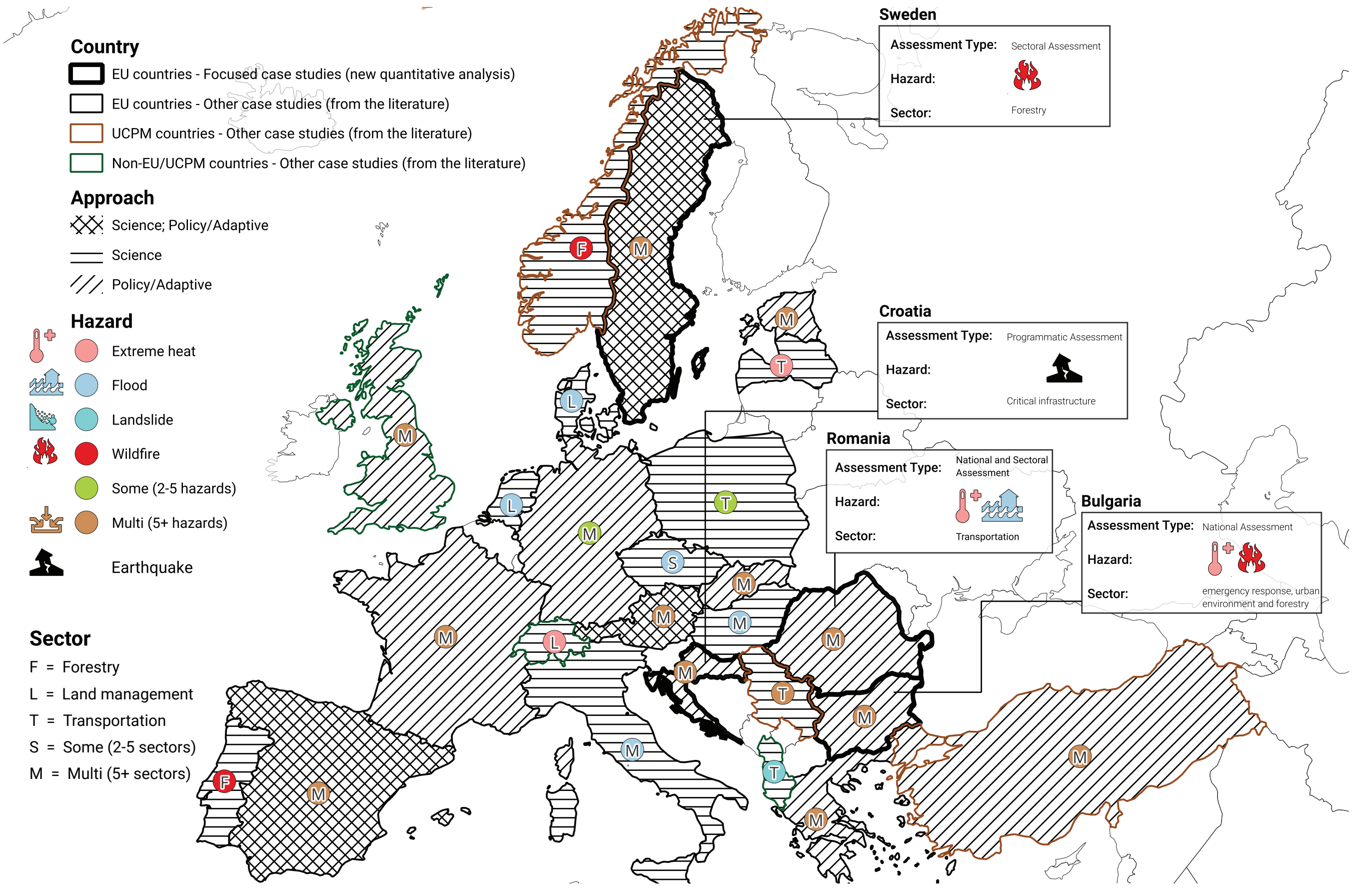
This study includes analysis of weather- and climate-related natural hazards that are expected to intensify because of climate change, including floods, wildfires, and extreme heat and associated impacts, such as air pollution. The analysis focuses on impacts at the national level, as well as results from regional exposure analytics[92] and climate analytics (including EC studies such as COACCH and PESETA IV, national climate analytics, and sectoral studies), and literature on compound, cascading, and multi-hazard risks. It combines information from these sources to show how policy makers can consider it in prioritization and decision-making.

Analytics in this report utilize existing climate change–related assessments, modeling, and scenarios. The study focuses on climate projections for the short term (to the 2030s) and medium term (to the 2050s) and considers moderate- and high-emission scenarios from global and regional assessments based on Representative Concentration Pathway (RCP) 2.6, RCP 4.5, and RCP 8.5.[93] The analysis builds on information from the JRC PESETA[94] IV, Directorate-General for Research and Innovation (DG RTD) projects, European Environment Agency (EEA) studies, Intergovernmental Panel on Climate Change (IPCC) reports, EU regional and country assessments on CCA, the European Climate Prediction (EUCP) Project, nationally determined contributions under the Paris Agreement, NAPs and NASs, NRAs, and assessments from the literature. Generally, case study analytics are based on deterministic or scenario rather than probabilistic risk assessments, but they assess CCA measures considering both slow-onset temperature changes and impacts from increasing climate variability and selected extreme events.

92 WB and EC. 2024. *From Data to Decisions: Tools for Making Smart Investments in Prevention and Preparedness.*
93 IPCC. 2023. *Definition of Terms Used Within the DDC Pages*. Link.
94 PESETA = Projection of Economic Impacts of Climate Change in Sectors of the European Union Based on Bottom-Up Analysis.

For examples and case studies, the report draws on a review of academic research, as well as more than 30 past and ongoing programs and projects across 22 countries (19 EU Member States and 3 non-Member States), covering a wide range of sectors and hazards (Figure 5). In-depth analytics were undertaken for five case studies (Bulgaria, Romania, Sweden, Croatia, and fictional Aurelia) to illustrate analytical processes and methods and derive lessons learned. The drafting of the report included in-depth consultations with stakeholders across the EC and EU Member States (especially with respect to the use case studies), to ensure the alignment of approaches and relevance of findings.

Figure 5. Map of country case studies analyzed and reviewed in the report



Source: World Bank.

The terms and concepts related to climate change adaptation used here are aligned with EU terminology and defined in the glossary at the beginning of the report.

The report complements and is aligned with the approach, data, and methodology used by the European Climate Risk Assessment (EUCRA; see Box 2) and covers the main hazards and sectors identified in the 2023 reporting of Member States on climate adaptation. It includes consideration of "plausible climate scenarios" and adoption of the hazard-sector cross-cutting approach. It covers such EUCRA sectors as forestry, buildings, transportation, and human health and five of EUCRA's storylines (prolonged heat and drought; large-scale flooding; critical infrastructure failures; ecosystem disturbances and carbon sinks; and financial instability) and cross-cutting topics. Also directly or indirectly covered in this report are the top five key future hazards (heat waves, droughts, wildfires, floods, and heavy precipitation) and the top ten key affected sectors mentioned by EU Member States in the latest EEA reports (health, agriculture, forestry, biodiversity, energy, water management, transportation, infrastructure and buildings, tourism, and civil protection).[95]

95 *EC. 2018. Regulation 2018/1999.* Link. *EEA. 2023. Is Europe on track with climate resilience?* Link. *See also* Leitner, M. et al. 2023. Technical paper. Link.

BOX 2. THE EUROPEAN CLIMATE RISK ASSESSMENT (EUCRA)

The European Climate Risk Assessment (EUCRA) is a comprehensive assessment of current and future risks related to climate change in Europe.[96] Started in 2022, the project has a total budget of €1.8 million and is funded by the Directorate-General for Climate Action (DG CLIMA). EUCRA provides a fast-tracked assessment based on a review and synthesis of existing data, literature, and expert knowledge, with results expected to be published in Spring 2024. The assessment will support the identification of key risks that need to be tackled by the next EC (to be elected in 2024) and the next multi-annual financial framework. It will provide an EU-wide point of reference for conducting and updating national or subnational climate risk assessments
.
In thematic fact sheets, EUCRA sets forth eight key climate risks for selected systems and sectors and seven climate-risk storylines. EUCRA considers key climate risks for eight selected systems and sectors in thematic factsheets: biodiversity and ecosystems; marine and coastal systems; water security; food security; human health; energy; built environment; and EU outermost regions. The seven storylines are prolonged heat and drought; large-scale flooding; pests and diseases; critical infrastructure failures; ecosystem disturbances and carbon sinks; disruption of international supply chains; and financial instability.[97] These storylines illustrate how current and future climate risks could trigger new crises and emergencies or exacerbate existing ones.

EUCRA also focuses specifically on complex risk factors, such as cross-border, cascading, and compound risks. The cross-cutting topics it covers include social justice and cohesion, EU competencies and risk ownership, and priorities for action. The climate risks are assessed in terms of their severity for the near term, mid-century, and late century for low- and high-warming scenarios, as well as in terms of confidence in the findings. The near-term analysis includes an assessment of Europe in times of change and extremes and draws on data from the Copernicus and Inter-Sectoral Impact Model Intercomparison Project (ISIMIP).[98] EUCRA also includes a policy readiness analysis for each fact sheet and storyline to assess the urgency for these risks to be tackled by the next Commission.

This report, with its specific focus on costing, needs to be considered in the context of broader CCA debates and studies. Adaptation is a complex topic, and decisions on investments need to be based on societal debates, cross-sectoral studies, cross-hazard risk analytics, economic studies, and adaptation studies. A few key analytical and policy gaps are associated with estimating the costs of adaptation. In light of a spectrum of projected climate impacts, the costs of adaptation may be underestimated, while its social, cultural, and environmental co-benefits are often not quantified because data on them are lacking.[99] As a result, adaptation may be presented as neither efficient nor effective, which could make decision-makers reluctant to invest in adaptation measures. In addition, although studies on adaptation costs at the sectoral level are available, the coverage is uneven, as the studies are often limited to a few sectors, such as agriculture and flood prevention.[100] Moreover, existing cost assessments generally focus more on “hard” structural adaptation measures, as their costs are easier to quantify than those of “soft” behavioral and policy measures.[101] This emphasis may lead to biased, overestimated CCA costs, while crucial “soft” measures, which could potentially yield high returns with relatively low implementation costs, are neglected.

In view of these factors, this report aims to provide as broad an overview as possible. It covers a wide range of sectors and types of adaptation measures and takes into account the socioeconomic and environmental aspects of adaptation. It focuses on hazards, sectors, and use cases that are generally less covered in the literature, concentrating on, for example, wildfires and heat adaptation, as opposed to flood risk or sectors such as transportation and building upgrades. It also focuses mainly on countries of southeastern Europe that were selected at the beginning of this project based on criteria that

96 EEA. 2023b. European Climate Risk Assessment. (upcoming report expected 2024)
97 Berckmans, J. 2023. European Climate Risk Assessment - Building resilience of European societies to climate change risks
98 Inter-Sectoral Impact Model Intercomparison Project (ISIMIP). 2023. ISIMIP.
99 EEA. 2023a. Link.
100 OECD. 2008.
101 OECD. 2008.

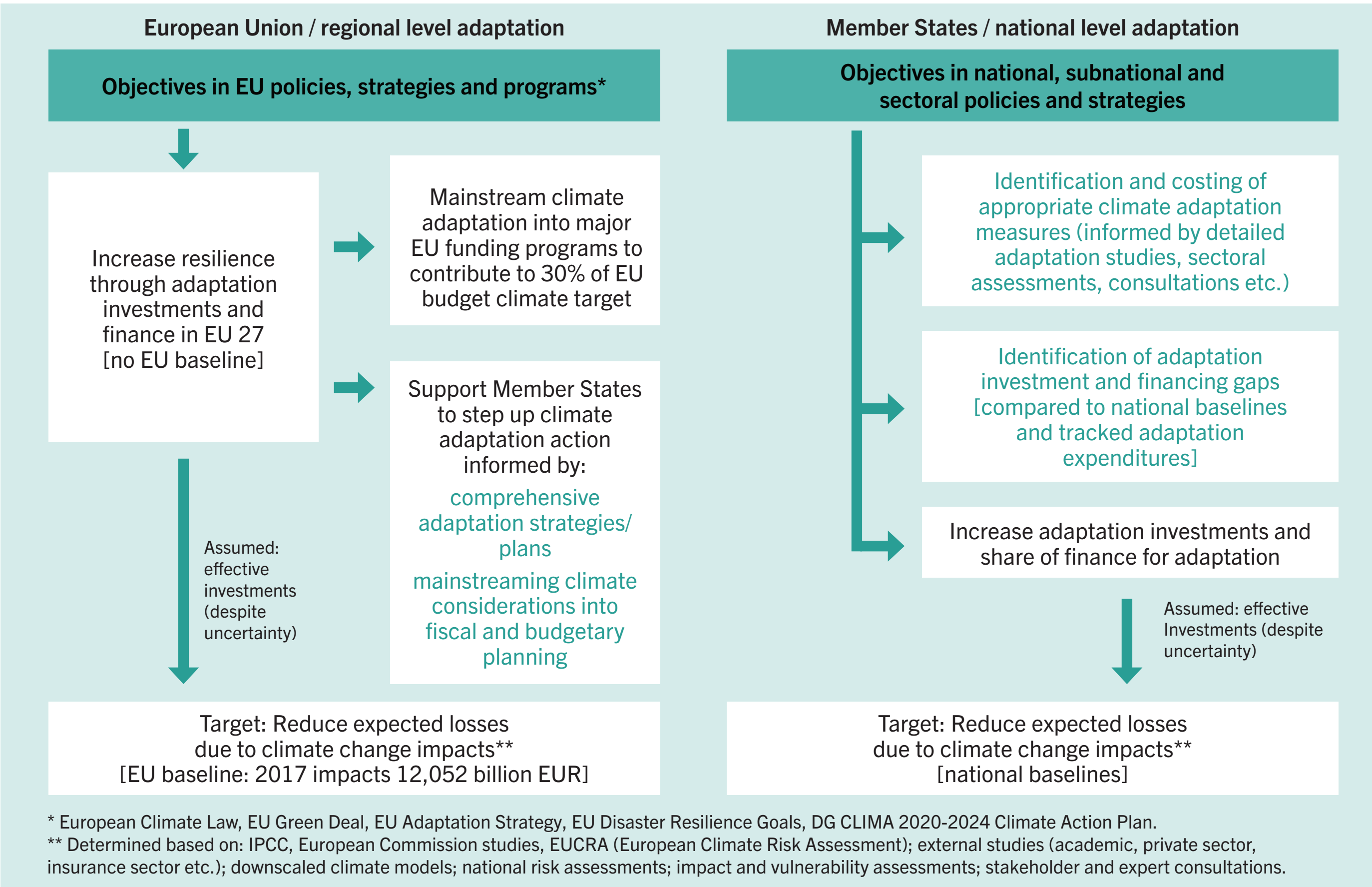
included the added value of analytics, existing dialogue with the countries, and access to climate risk analytics and local expertise.

Finally, this report only briefly considers the issue of who should bear the investment costs for CCA. It focuses mostly on investments that are generally undertaken by the public sector. Discussion of the public/private split of investments would require, beyond methodological aspects, the consideration of national legislation, as well as much more detailed adaptation studies.[102] For those who wish to learn more, the report references literature that has provided insights into this question, along with more details on financial instruments for CCA, including potential risk transfer solutions.[103] Also important to consider is the share of costs to be carried at the local, cross-country, or national level, as political systems may differ considerably between countries. This was considered where possible by exploring, for instance, urban-scale measures; but the costs of, say, governance at the national, cross-country, or local level need to be assessed further. Some examples are provided from the literature and from case studies (such as studies of Germany) that have outlined this in detail.

RELEVANCE AND LINKAGES WITH OTHER RELEVANT RESEARCH AND INITIATIVES

This study contributes information relevant to several EU legislative frameworks, and it complements major EC studies related to CCA, as summarized in Figure 6.

Figure 6. Linkages to EU law and efforts



Source: World Bank based on information from European Commission website.

102 The issue of investments in adaptation and cooperation among the insurance industry, EC, and other actors is currently also discussed by the EC-driven Climate Resilience Dialogue, from which a final report is due in June 2024.

103 WB and EC. 2024 forthcoming. Financially Prepared: *The Case for Pre-positioned Finance.*

First, the report is aligned with the following objectives of the EU Adaptation Strategy:[104]

- *Smarter adaptation, through the use of robust data and risk assessment tools available to all.*[105] This study showcases the use of public datasets and outlines methodologies for assessing climate risks, such as wildfires and extreme heat.

- *Faster adaptation, through support for CCA private and public investments and solutions.* This study provides information necessary to the costing of CCA measures in support of investment decisions in NAPs and NASs. To complement existing research and studies focusing on medium- to long-term timelines (to 2050s and 2100s), it looks mainly at the short-term timelines (to 2030s and 2040s) of most relevance for policy decision-making. The study is aligned with the European Investment Bank Climate Adaptation Plan.[106]

- *Systemic adaptation, through the mainstreaming of CCA into EU policies, national macro-fiscal policies, and local adaptation plans and the promotion of nature-based solutions (NBSs).* This study focuses on the costing of CCA both at the national level, using the macro-fiscal models (f.e. MFMod), and at the programmatic (or investment portfolio) level. It assesses "climate-proofing" options for critical infrastructure and, as feasible, how proposed measures need to align with EC standards, such as building codes and the EU renovation strategy. The study also showcases and emphasizes methodologies to promote NBSs, as well as local studies that can help support the "Mission Adaptation to Climate Change" agenda.[107]

Second, the report complements EUCRA research in the following ways:

- *The study is relevant to five of EUCRA's seven storylines*[108] and cross-cutting topics.[109] It assesses current and future climate risks and impacts in selected European countries (Bulgaria, Romania, Croatia, and Sweden) and proposes corresponding measures to enhance adaptation investment and financial preparedness for climate change. Its use of climate risk analytics to assess the impacts of extreme heat, wildfires, and floods at macro and sectoral levels corresponds with EUCRA's "prolonged heat and drought" and "large-scale flooding" storylines. For Bulgaria and Romania, historical and current heat events are assessed based on national data and existing analytics, while future extreme heat days between 2020 and 2050 under the RCP 4.5 scenario are simulated based on climate models from the Copernicus Climate Change Service. Detailed analytics on current wildfire losses and projected wildfire impacts are undertaken for Sweden based on EFFIS and national data, and current and future flood risks in Romania are assessed using investment and financial flow (IFF) analysis based on vulnerability and risk mapping, with the future risk analytics focusing on the transportation network.

- *The study is relevant to EUCRA's storylines in terms of the climate risks considered.* For the "ecosystem disturbances and carbon sinks" storyline, for instance, the Sweden case study stresses the role of forests and peatlands as carbon sinks and reveals the importance of investing in adaptive forest management and peatland restoration for the purposes of ecological and carbon emission reduction. Benefit-cost analysis undertaken in Croatia corresponds to EUCRA's "critical infra-structure failures" storyline by showcasing the importance of retrofitting selected infrastructure,

104 Climate-ADAPT. 2023b. *EU Adaptation Strategy.* Link.
105 This should be achieved by enhancing the European platform Climate-ADAPT as the European platform for CCA knowledge.
106 European Investment Bank (EIB). 2021. The EIB Climate Adaptation Plan - *Supporting the EU Adaptation Strategy to Build Resilience to Climate Change.* Link.
107 EC. 2023. EU Mission: Adaptation to Climate Change. Link.
108 These include prolonged heat and drought, large-scale flooding, critical infrastructure failures, ecosystem disturbances and carbon sinks, and financial instability.
109 These include stress-testing infrastructure, prioritization of CCA investments, and planning for extreme events.

with consideration of seismic and climate resilience and energy efficiency. The flood risk assessment of the transportation network in Romania also corresponds to this storyline, as it identifies the direct damage that could result from floods on the road network, as well as resulting transportation disruptions and sectoral economic losses, and it estimates the costs and benefits of adaptation options that enhance the climate resilience of the transportation infrastructure, including both traditional engineering measures and nature-based solutions.

- *This study showcases how to conduct detailed assessments at national and sectoral levels.* By identifying adaptation needs and proposing priority CCA strategies based on the results of climate risk analytics, the study could notably assist EUCRA in its Task 7, "Risk evaluation and priorities for action," which aims to identify key adaptation needs and priorities and adaptation-related investment and research needs.

Third, the report supports the global stocktaking exercise under the Paris Agreement, reporting obligations under EU laws, and implementation of the EU sustainable finance agenda. The study offers methodologies for tracking expenditures for the costing of CCA at the national level and offers practical examples.

Fourth, the report provides information relevant to the EU's legislative framework on disaster risk management (DRM), including the Disaster Resilience Goals (DRGs) and Risk Scenarios, the EU Action Plan on Disaster Risk Reduction (DRR),[110] and Recovery Plans. The study contributes by focusing on sectors, assets, and case studies relevant to the civil protection sector and showcasing methodologies for the costing of CCA measures, considering extreme climate events and scenarios.[111] It also reaches beyond EU Member States by providing examples relevant to all Union Civil Protection Mechanism (UCPM) countries.

Fifth, the report supports the implementation of the European Climate Law,[112] the EU Green Deal, and the regulations for land use, land use change, and forestry (LULUCF)[113] for 2021–30. The study focuses on wildfires and the forestry sector and considers in a cross-cutting manner the co-benefits of CCA programs for climate change mitigation (CCM) and the Sustainable Development Goals (SDGs).

Sixth, the report is highly relevant for non-EU countries under the UCPM and beyond. The study can contribute to broader debate on linking DRM and CCA efforts, including how to conduct analytics that consider focus, objectives, analytical tools, and methodologies from both the DRM and CCA sectors.[114]

ADDED VALUE

This study has been designed to add the maximum amount of value to past and ongoing EC projects, with consideration of major analytical and information gaps identified in the recent DG CLIMA adaptation modeling studies.[115] It assesses and addresses the gaps in several ways:

110 Climate-ADAPT. 2016a. *Action Plan on* the Sendai Framework for Disaster Risk Reduction 2015–2030: *A Disaster Risk-Informed Approach for all EU Policies.* Link.; EU. 2019. Decision (EU) 2019/420. Link.; EU. 2021. Regulation (EU) 2021/836. Link.

111 WB and EC. 2024 forthcoming. From data to decisions: tools for making smart investments in prevention and preparedness in Europe.

112 EC. 2023. European Climate Law. Link.

113 EC. 2023. Land Use and Forestry Regulation for 2021–2030. Link.

114 This study can contribute to ongoing and future analytics conducted by the World Bank for its Country Climate and Development Reports (see World Bank 2024. Country Climate and Development Reports (CCDRs). Link.).

115 The study can fill information gaps for the following use cases mentioned in the DG CLIMA study from 2021: A1 (Rapid analysis for CLIMA to support rapid policy response - rapid scripts to look at exposure, vulnerability to different hazards); B4 (Climate change risk assessment for EU investments - extensive analysis of CC risk and adaptation actions e.g. major infrastructure); B5 (Climate change risk assessment for EU investments, rapid analysis - rapid scoping analysis for less sensitive, less capital-intensive projects [rapid]); D12 (Analysis of climate risks for business and finance - portfolio risk analysis, mix of green and traditional investments, identify vulnerable locations [global] [rapid]); and E16 (Analysis supporting national adaptation plans in accordance with EU requirements: risk assessment and options analysis) (Ebrey, R. et al. 2021. *Study on Adaptation Modelling: Comprehensive Desk Review: Climate Adaptation Models and Tools.* Link.; Jeuken, A. et al. 2021. *Study on Adaptation Modelling: Report on Use Cases and Rapid Analysis.* Link.).

- By presenting a menu of methodological approaches for different contexts and decision making questions on adaptation (level of data/ information, number of pre-existing studies, timeline for decision-making, ambition for action from preparing for the worst to climate proofing economies and infrastructure against average changes, and so on)

- By outlining methods that focus on near-term adaptation planning and support the development of adaptation pathways following iterative risk management[116] approaches and based on gradual improvement of information on additional required investments

- By providing results for and covering EU Member States generally underrepresented in the literature on CCA costing (that is, countries in southeastern Europe)

- By presenting innovative, semi-quantitative analytics based on modeling, economic analysis, expert-based judgement, stakeholder consultations, and existing findings from the literature

As a result, the study contributes to policy dialogue and implementation in the following ways:

- By informing national policy-making for costing CCA by using the methodologies it presents and through practical application of its three "use cases"

- By informing the preparation and implementation of CCA at various levels of decision-making and with relevance to different national and programmatic institutional actors, such as ministries of finance, line ministries, and civil protection agencies

- By improving the knowledge base by consolidating information on climate risks from various sources, including NRAs and NAPs, projections based on regional climate models (RCMs) analysis of historical trends, and extreme scenarios

- By providing recommendations based on in-depth case study analytics (for Croatia, Romania, Bulgaria, Sweden, and fictional Aurelia) and case studies from the literature (22 European countries,[117] including Austria, France, Germany, and Spain

116 Watkiss, P., et al. 2014a. Link.

117 Including EU Member States Austria, Bulgaria, Croatia, Czechia, Denmark, Estonia, France, Germany, Greece, Hungary, Italy, Latvia, the Netherlands, Poland, Portugal, Romania, Slovakia, Spain, and Sweden; the UCPM participating state of Türkiye; and the non-EU, non-UCPM states of Switzerland and the United Kingdom.

1. Overview of the Literature and Methodologies for Costing CCA

This chapter provides an overview of the literature and methodologies for costing CCA and summarizes recommendations and lessons learned. The key insights are based on a review of over 30 analytical projects from the past two decades at the regional and national levels. The chapter details the application of different methodologies in three "use cases," focusing on national planning, sectoral planning, and investment portfolio planning, highlights a menu of approaches available, and describes in detail some common principles for developing adaptation pathways following iterative risk management.

KEY TAKEAWAYS AND RECOMMENDATIONS

- **Scaling up investments in CCA requires more and better information on their costs across Europe.** A knowledge gap regarding the costs of CCA at national and EU levels inhibits countries from taking timely actions, making decisions about CCA investments, and scaling up finance (public and private) to address the current adaptation gap. No recent consolidated estimates of the costs of CCA exist at the EU level, and most previous estimates for the EU may be low; this suggests the importance of countries' undertaking detailed assessments at the national level and in a contextualized manner rather than relying solely on high-level, approximate regional assessments. This analysis produces some plausible, and indicative short-term estimates for the EU-27 by extrapolating from existing national studies, providing values that range from €15 billion to €64 billion per year.
- **Countries can undertake CCA costing at different levels of analysis to serve different policy-making objectives.** At the most aggregated level, macro-level assessments of costs can be useful to advocate for CCA—that is, to show benefits exceed costs at the country level, and not only based on programs and investments. Such assessments can be complemented by CCA expenditure tracking, or climate budget tagging. To support the development of effective CCA contingency plans and financial resilience instruments, assessments can also take into consideration extreme scenarios for civil protection and Union Civil Protection Mechanisms (UCPMs) and results from macroeconomic and macro-fiscal analyses. At the sector level, mainstreaming of CCA costing in medium-term planning and budgeting by ministries of finance, line ministries, and locally is useful for improving policy and financial planning for CCA. At the level of directorate-generals or line ministries in particular, more in-depth analysis of climate risks and CCA options and costs can be integrated into strategies and plans to support prioritization. At the most detailed level, decision-support tools and costing methods can be used to look at individual programs, projects, or investments.

- **Lessons from various EU countries provide invaluable insights on approaches to cost adaptation depending on adaptation policy needs.** Cross-country comparison of CCA costs is challenging as, unlike for mitigation, there are no global or EU objectives for CCA. This means any analysis has to decide what these objectives should be and the balance of the benefits and costs of adaptation, as well as the "acceptable residual impacts" after CCA for a spectrum of projected climate impacts. Adaptation costs for objectives differ based on economic efficiency, acceptable levels of risk, or risk minimization. Existing estimates from individual countries vary between €3.96 million and €11.6 billion per year— in per capita terms, from €34 in France to €110 in Slovakia (excluding the extreme values)—with large disparities in their coverage of risks and sectors. Because the differences stem from three sets of assumptions—time periods and scenarios; future risk levels: and objectives, assumptions, and methods—these figures are not directly comparable. Nevertheless, sectoral- or program-based CCA costing exercises can allow some comparability if similar methodologies are used, while CCA options can also sometimes be compared using results from societal benefit-cost analysis.
- **Adaptation pathways can be effectively developed by combining information on current and future climate risks with multidisciplinary expertise.** The framework for adaptation pathways varies based on the policy question at hand. The approach for costing a national adaptation program, for instance, differs from that for climate-proofing infrastructure. Some underlying principles remain constant, however. Developing adaptation pathways begins with the evaluation of existing climate risks, adaptation investments, and the effectiveness of current measures. It then considers a broad spectrum of potential climate consequences and the variety of adaptation options available. This process is meant to enable the management of climate impacts adaptively and iteratively, thereby supporting "decision-making under uncertainty" (DMUU) approaches. Adaptation pathways mostly set a broad strategic direction, while the more detailed adaptation programs and measures following that direction need to be developed using the various tools, methods, and information outlined in this report. Identifying and assessing the actions to be taken for adaptation is crucial, taking into account their timing, the breadth of the climate impacts projected, and the urgency of implementation. While cost-benefit analyses of CCA measures are valuable, they should be supplemented with considerations of the urgency of decisions and path dependency—that is, the effect of decisions or events on subsequent decisions and events.
- **Adaptation costing studies spur important multi-stakeholder dialogues and inform policy discussion, planning, and budgeting for mainstreaming and scaling up CCA.** Across the EU, such costing processes have helped raise awareness, initiate national discussions, support decisions, and improve systems to monitor and track progress on CCA. They have contributed to mainstreaming CCA into line ministries' plans, while the more complex assessments have sought to determine the effectiveness of measures to be selected, prioritized, and implemented. National planning studies like those in France, which estimated early adaptation costs at around €2 billion annually in this decade, have influenced short-term financial strategies as well as medium- and long-term planning. Austria's estimate of €421 million–€573 million and Germany's of €140 billion–€142 billion annually, were the conclusion of years of collaborative research. The studies highlighted the pressing need for improved expenditure tracking and a better understanding of broader macroeconomic implications to further improve such estimations.
- **Building resilient futures in the face of evolving climate risks, including compound, multi-hazard, and disruptive events, requires developing comprehensive investment packages for CCA and DRM with a mixture of options that evolve along with them.** NAPs provide a foundation for more detailed sectoral studies, incorporating pathway thinking and moving to investment planning. Acknowledging adaptation as an ongoing process means moving beyond lists of technical options and employing a portfolio

approach, blending nontechnical and technical solutions, and creating the enabling conditions for adaptation at the sectoral or national level. To set the response to short- and long-term challenges, this process must also be iterative and dynamic. Countries have to adapt to both climate stressors and shocks and "connect the dots" between disaster risk management and climate adaptation programs. In practice, this means breaking down the silos and encouraging cross-sectoral collaboration to create synergies and streamline efforts. Reconciling views and openly discussing trade-offs is complicated but necessary to ensure investment programs can support multiple goals, including climate change mitigation and resilience. While work on these pathways has been most advanced for sea-level rise and coastal policy, the same concepts apply to other environmental issues. Enhancing the resilience of forest ecosystems, for example, necessitates a portfolio approach that considers economic viability by weighing early benefits, minimizing regrets, and starting to plan for long-term shifts.

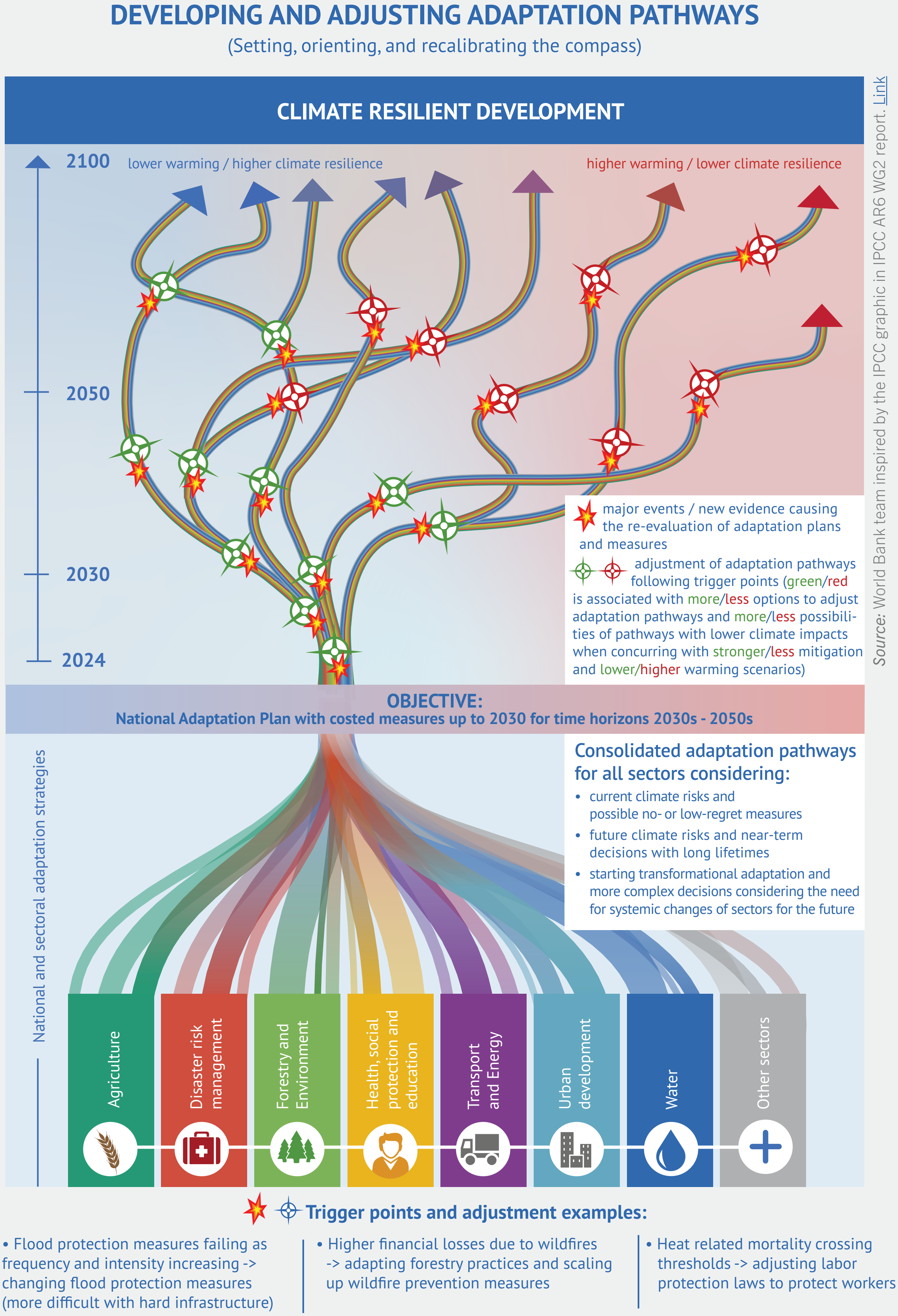
- **Looking ahead, countries will need to start shifting from studies to inform incremental adaptation to ones that will enable transformational adaptation.** Incremental adaptation, on which studies—including adaptation costing studies—have focused to date, aims to maintain current activities and systems. Transformative adaptation (which involves scaling up activities or systems) and transformational adaptation (which involves moving to different ones) will require going beyond existing approaches toward more strategic analysis and systems thinking, as highlighted in the EU Adaptation Mission. It would entail taking into account the long lead times for planning and the likely need for societal and governance change.[118] Evolving coastal climate risks, for example, which may necessitate major changes in land use, settlements, and activities, may also require the alteration of institutional and governance structures to deliver societal change.[119] Interest is increasing in systems approaches to address such complex and multi-objective policy issues as transformational adaptation. A range of methods is being piloted, including social network analysis, systems dynamic modeling, and others.[120] While these can be useful for mapping risks, their application to adaptation is both complicated and time- and resource-intensive.
- **EU support and cooperation can enable the uptake of CCA costing assessments.** With increasing climate risks, adaptation will need to be scaled up at all levels, from European down to local, and will call for an expansion of investments and an increase in CCA costs. The benefits of improving the practice and uptake of costing studies to enhance the efficiency and effectiveness of adaptation decision-making will be EU-wide. Although a menu of tools are already available, databases of the costs of CCA measures, case study examples of costs and benefits, and efforts to provide support for costing methods and how to effectively use climate risk information available also at the regional level (such as in COACCH, PESETA, and EUCRA studies) could result in quicker and more robust assessments and, in turn, improve the value-for-money of adaptation delivery. Support may also include, for instance, ways to integrate effectively NBSs and a mixture of grey and green solutions in investment packages across Europe, as aligned with the EU's flagship climate and nature policies and the Green Deal. These could also provide a practical starting point while more country-specific, tailored, and granular assessments are becoming available. National coordinating entities on CCA and sectoral experts can also be further connected to European and cross-country expert networks to ensure they have access to the latest evidence.

118 IPCC. 2018. Annex I: Glossary. Link.
119 ClimateReadyClyde. 2020. Resilient regions: Clyde Rebuilt. What does transformational adaptation look like? Link.
120 Martinez-Hernandez. 2022. System dynamics modelling and climate change adaptation in coastal areas: a literature review. Link.; Zarghami and Dumrak. 2021. A system dynamics model for social vulnerability to natural disasters: disaster risk assessment of an Australian city. Link.

Building blocks for costing CCA measures

Adaptation pathways can be effectively developed by combining information on current and future climate risks with multidisciplinary expertise. The framework for adaptation pathways varies based on the policy question at hand. The approach for costing a national adaptation program, for instance, differs from that for climate-proofing infrastructure. Some underlying principles remain constant, however. Developing adaptation pathways begins with the evaluation of existing climate risks, adaptation investments, and the effectiveness of current measures. It then considers a broad spectrum of potential climate consequences and the variety of adaptation options available. This process is meant to enable the management of climate impacts adaptively and iteratively, thereby supporting "decision-making under uncertainty" (DMUU) approaches. Adaptation pathways mostly set a broad strategic direction (see Figure 7), while the more detailed adaptation programs and measures following that direction need to be developed using the various tools, methods, and information outlined in this report. Identifying and assessing the actions to be taken for adaptation is crucial, taking into account their timing, the breadth of the climate impacts projected, and the urgency of implementation. While cost-benefit analyses of CCA measures are valuable, they should be supplemented with considerations of the urgency of decisions and path dependency—that is, the effect of decisions or events on subsequent decisions and events.

Figure 7. Developing and adjusting adaptation pathways in Europe



Source: World Bank team inspired by the IPCC graphic in IPCC AR6 WG2 report. Link.

Building resilient futures in the face of evolving climate risks, including compound, multi-hazard, and disruptive events, requires developing comprehensive investment packages for CCA and DRM with a mixture of options that evolve along with them and can be justified in economic terms. These can be framed in terms of three complementary building blocks:

- *No-regret actions.* Europe already incurs large economic costs from climate extremes and variability, and these are growing. Reducing these costs with (targeted) low- and no-regret actions, such as enhancing early warning systems, will yield net economic benefits today.

- *Climate-smart design, especially to address lock-in.* In some cases, taking advantage of cost-effective opportunities for early action can avoid locking in large economic costs in the future. These opportunities arise with actions or decisions that involve long lifetimes or path dependency and will be difficult or costly to reverse later—for example, the designing of new infrastructure that is climate resilient.

- *Low-cost preparatory and early actions taken to improve future decisions, effectively providing option value.* This involves developing adaptive management plans (that is, adaptation pathways) for decisions that have long lead times or involve possible large-scale but uncertain impacts in the future. The development of long-term coastal plans, for example, can be the start of more transformational adaptation, as it must take into consideration broader issues, such as societal perspectives and governance, in addition to technical options.

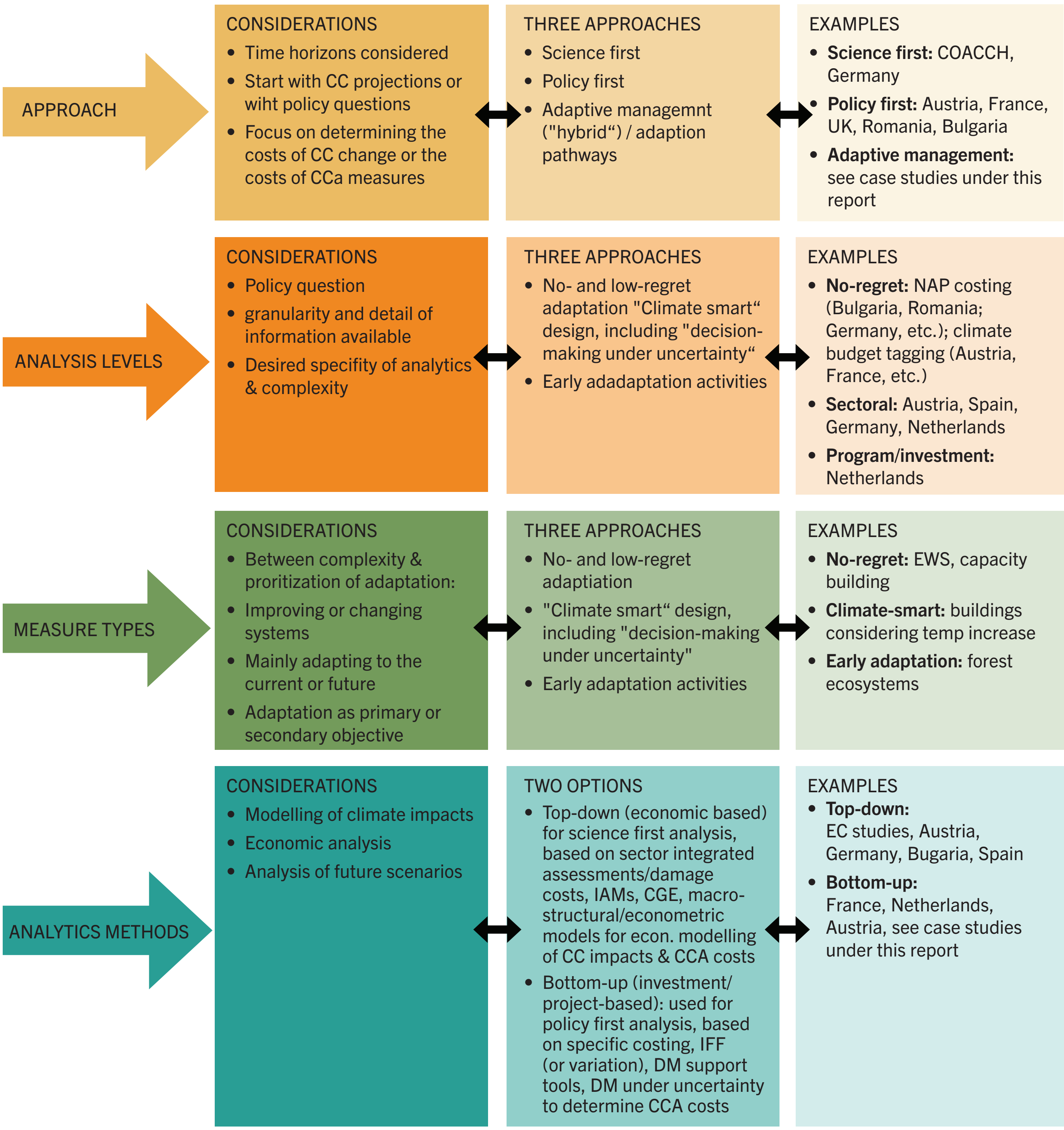
Looking ahead, countries will need to start shifting from studies to inform incremental adaptation to ones that will enable transformational adaptation. Incremental adaptation, on which studies—including adaptation costing studies—have focused to date, aims to maintain current activities and systems. Transformative adaptation (which involves scaling up activities or systems) and transformational adaptation (which involves moving to different ones) will require going beyond existing approaches toward more strategic analysis and systems thinking, as highlighted in the EU Adaptation Mission, taking into account the long lead times for planning and the likely need for societal and governance change.[121] Changing coastal climate risks, for example, which may necessitate major changes in land use, settlements, and activities, may also require the alteration of institutional and governance structures to deliver societal change.[122] Interest is increasing in systems approaches to addressing such complex and multi-objective policy issues as transformational adaptation. A range of methods is being piloted, including social network analysis, systems dynamic modeling, and others.[123] While these can be useful for mapping risks, their application to adaptation is both complicated and time and resource intensive.

A menu of approaches, frameworks, and methodologies is available to cost CCA measures. Figure 8 shows the flow of decisions needed to cost CCA measures according to different needs, objectives, and available resources, and information, which will be further described in this section. There is no single blueprint or approach for costing CCA, and the appropriate method depends on the specific objectives and the level and types of CCA cost assessment. As a first step, it is important to define the aim of the CCA costing—that is, whether it is to support financial planning, sectoral planning, implementation of NAPs or NASs, reporting on CCA expenditures, or assessment of the cost-effectiveness of CCA programs, among others. This choice drives the selection and use of the appropriate approach, methodology, and steps. The selected approach to CCA costing affects, in turn, the parameters considered, such as the time horizon for cost estimates. Key approaches include a "science-first"

121 IPCC. 2018. Annex I: Glossary. Link.
122 ClimateReadyClyde. 2020. Resilient regions: Clyde Rebuilt. What does transformational adaptation look like? Link.
123 Martinez-Hernandez. 2022. System dynamics modelling and climate change adaptation in coastal areas: a literature review. Link.; Zarghami and Dumrak. 2021. A system dynamics model for social vulnerability to natural disasters: disaster risk assessment of an Australian city. Link.

or "top-down" (modelled or economic-based) approach, which focuses more on how CCA pathways could cost-effectively minimize potential residual impacts in the future; a "policy-first" or a "bottom-up" (investment needs-, program-, or project-based) approach, focusing more on assessing the current CCA needs—for example, in the next National Adaptation Plan cycle or multi-annual plan—to inform short-term decision-making and the divisions between budget lines; and an "adaptive management" ("hybrid") approach, to allow for better planning and adjustment of CCA plans, implementation, and budget planning as more information becomes available.

Figure 8. "Building blocks" and flow of decisions for costing CCA measures

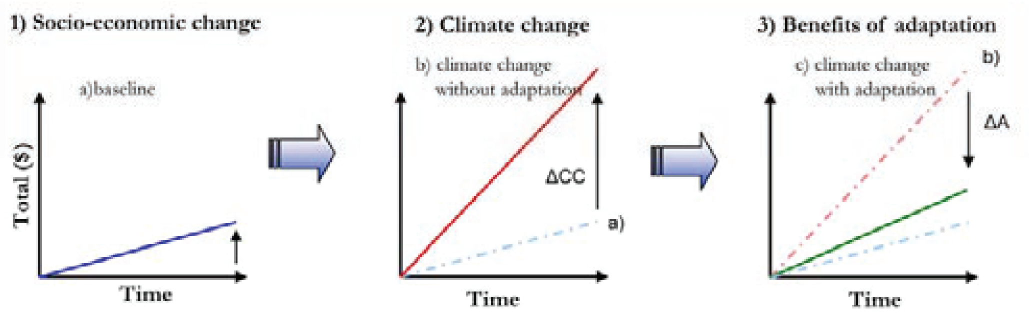


Source: World Bank.
Note: CC = Climate change; DM = Decision-making; EQ = Earthquake.

OBJECTIVES AND AMBITION OF ADAPTATION

The objective of any CCA costing analysis is crucial and will affect key parameters, including the level of adaptation, the cost, and the residual impact after adaptation. At the start of a CCA costing analysis, decision-makers have to choose their objective and, hence, the type of analysis. In simple terms, the costs of CCA can be assessed by estimating the current and future impacts of climate change, to what extent adaptation can reduce these impacts (the benefits), and how much this action might cost.[124] A further trade-off arises with the impacts of climate change that remain after adaptation—that is, the level of residual damage—because reducing impacts to zero through adaptation is often costly or impossible (Figure 9).

Figure 9. Benefit and Costs of Adaptation and Residual Impacts of Climate Change



Source: UNFCCC 2007,[125] adapted from Boyd and Hunt 2004.[126]

CCA costs and benefits can help inform policy and investment decisions, but the economic rationale for adaptation has to be identified, and it must deliver value for money.[127] Investing in adaptation involves challenges from an economic perspective. First, for anticipatory (proactive) adaptation, benefits arise in few cases and thus, due to discounting, can be low (in present value terms) compared to upfront costs. Second, the projected impacts under climate change can vary according to the scenarios considered, which means a risk of underinvesting or overinvesting in adaptation—that is, a potential for regrets.

Multilateral development banks, such as the European Investment Bank and the European Bank for Reconstruction and Development, have devised typologies for looking at adaptation investment projects.[128] These are important because they recognize that adaptation can differ among levels of complexity and in terms of the focus of the investment:

- *Climate resilience (climate-proofing) of projects involves integrating adaptation into investments, with adaptation as a secondary objective.* An example of climate-proofing is the inclusion of adaptation measures in a planned road project. The aim is to assess adaptation options (and their marginal costs and benefits) to manage climate risks to the underlying investment to ensure it delivers its primary benefits in a changing climate. The multilateral development banks, including those in Europe, have developed climate risk management (CRM) systems for climate-proofing investments. These frameworks have been in place for many years and are now evolving to meet the

124 UNEP. 2016. Adaptation Gap Report 2016 Link.; See also UNEP. 2023. As climate impacts accelerate, finance gap for adaptation efforts at least 50% bigger than thought. Link.; Climate-ADAPT. 2023d. Tools - Assessing adaptation options. Link.

125 United Nations Framework Convention on Climate Change (UNFCCC). 2009b. *Potential Costs and Benefits of Adaptation Options: A Review of Existing Literature*. Link.

126 Boyd, R., and A. Hunt. 2004. Costing the Impacts of Climate Change in the UK: *Overview Guidelines*.

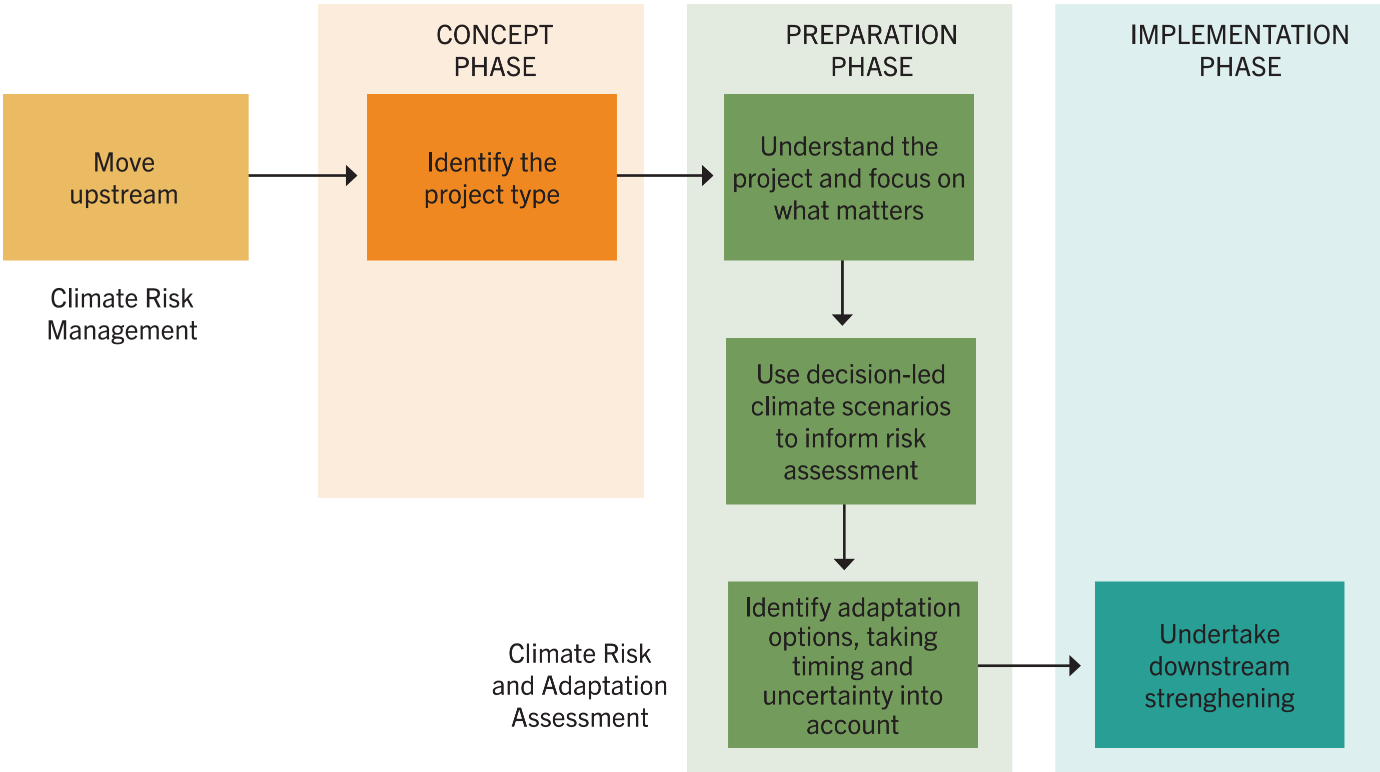
127 UNFCCC. 2009a. *Assessing the Costs and Benefits of Adaptation Options*. Link.

128 EIB. 2022. *Climate Change Adaptation and Economics and Investment Decision-making in the Cities - "How to Guide" and Case Studies*. Link.; European Bank for Reconstruction and Development (EBRD). 2023. The EBRD Climate Adaptation Action Plan 2023–2025. Link.

need to adopt a programmatic (upstream approach) and to encourage consideration of how best to identify risks and integrate adaptation (Figure 10).[129]

- *Adaptation projects involve targeted investments to address climate risks and deliver adaptation, with adaptation as the primary or principal objective of the project.* An example is a new coastal protection scheme to manage rising sea levels. In this case, the economic benefits of the investment are the adaptation benefits it delivers, which are assessed against the adaptation costs (although, it should be noted, an adaptation project can also include co-benefits, or a project can have several primary objectives, one of which is adaptation).

Figure 10. Guiding principles of climate risk management for climate-proofing projects



Source: Watkiss, P. et al. 2020.

To date, the focus of CCA has been on incremental adaptation, as in the examples mentioned above, with little evidence or economic analysis of transformational adaptation. Most studies and adaptation costs relate to incremental adaptation—that is, to allowing current activities and systems to function under climate change. Climate-proofing investments have been emphasized, delivering smaller-scale or marginal adaptation projects that maintain the status quo. Box 3 defines incremental versus transformational adaptation.[130] There has been no economic analysis of more transformational adaptation—that is, of more systemic actions that aim to do different things, such as in response to the limits of adaptation (see later discussion).

129 Watkiss, P. et al. 2020. Principles of Climate Risk Management for Climate Proofing Projects. Link.
130 Fedele, G. et al. 2019. *Transformative Adaptation to Climate Change for Sustainable Social-Ecological Systems.* Link. UNFCCC. Concepts, approaches and examples of Transformational adaptation. Link. Roka, K. 2018. Climate Change Adaptation. Link.

BOX 3. INCREMENTAL VERSUS TRANSFORMATIONAL ADAPTATION

- Incremental adaptation is adaptation that maintains the essence and integrity of a system or process at a given scale.[131]

- Transformational adaptation is adaptation that changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts.[132] Linked to transformational adaptation is transformative change, which is systemwide. It goes beyond technological change through the consideration of social and economic factors that, with technology, can bring about rapid change at scale.[133]

Adaptation costs vary with the level of ambition or the objective and whether an objective can be set from the perspective of economic efficiency or risk levels. As Figure 9 shows, adaptation is associated with trade-offs among its costs, its benefits, and the residual damage after it. The choices involved have to be made by policy-makers or society, rather than through an appraisal of options. An example are the choices that need to be made in setting an adaptation objective for protection from coastal or river flooding. In simple terms, this is a choice between how much to spend on adaptation versus how much residual risk are stakeholders prepared to accept. In more specific terms, the choice can be among several objectives:[134]

- *Maintenance of existing protection infrastructure* involves additional maintenance costs in the future but no additional enhancement or new infra-structure (that is, business as usual / do nothing). In this case, the costs are low, but of course residual damage is high, and it increases over time with climate change.

- *Protection to a constant relative risk level (acceptable risk)* involves setting a risk protection standard to protect, for example, against a 1-in-100-year event. The costs of protecting to this same level increase over time, as additional infrastructure investment is needed to deliver the same protection under a changing climate.

- *Maintenance of a constant absolute risk level* means maintaining a constant level of residual damage, which involves more protection and higher adaptation costs, resulting both from socioeconomic change (and with a rise in assets at risk) and increasing climate change.

- *Protection to a risk-intolerant level* means reducing average annual losses to very low levels, leading to very low residual damage but involving very high costs.

- *Protection to the (economic) optimal level of adaptation involves* investment in adaptation to the point where the marginal costs and benefits are equal—that is, the economically optimal response. It usually leads to lower levels of adaptation and costs, as investments are not in highly costly actions, but residual damage is higher. Defining the optimal level is very difficult, however, because of the wide range of potential climate change impacts, so pursuit of this objective may lead to maladaptation.

The differences in adaptation costs among these objectives can be significant.[135] One study reports these costs for river floods can vary by a factor of four between the economically optimal action and that which results in the least residual damage.[136] Similar differences exist for coastal protection.[137] Also important to stress is that adaptation objectives are not set consistently among countries or among

131 Mach, K. J. et al. 2014. "Annex II: Glossary." Link.
132 Mach, K. J. et al. 2014.
133 Möller, V., R. et al. 2022. "Annex II: Glossary." Link.
134 Watkiss, P., and R. A. Betts. 2021. "Method." Link. Nicholls, R. J. et al. 2019. Global Investment Costs for Coastal Defense through the 21st Century. Link.
135 Aerts, J. C. G. H. 2018. A review of cost estimates for flood adaptation. Link.
136 Ward, P. et al. 2017. "A Global Framework for Future Costs and Benefits of River-Flood Protection in Urban Areas." Link.
137 Nicholls et al. 2021. A global analysis of subsidence, relative sea-level change and coastal flood exposure. Link.

hazards within individual countries, so adaptation costs can vary substantially. The inconsistency reflects current practice across Europe among countries (the Netherlands, for example, has much higher coastal protection standards than other Member States) and within countries (for instance adaptation choices depending on spatially diverse impacts of heat and floods within countries). Some objectives may be based on outcomes from a benefit-cost analysis (that is, the benefit-cost ratio of various measures), while others—for instance, those involving the risk of fatality—may be based on acceptable risk protection levels (noting that even the latter can vary, for example, between a 1-in-100 or 1-in-1,000-year standard). In short, setting adaptation objectives is context-specific, and it is not possible or realistic to impose specific framing and risk-preference levels across all hazards and countries in the EU.

APPROACHES TO COSTING CCA

Modeling adaptation in stylized medium- and long-term studies is not the same as doing so in near-term, real-world policy analysis. While many modeling studies tell us adaptation is extremely effective in reducing climate impacts in the 2050s, they do not tell a policy-maker "what to do today." There are three main types of studies in the adaptation cost literature aim (see Figure 11):[138]

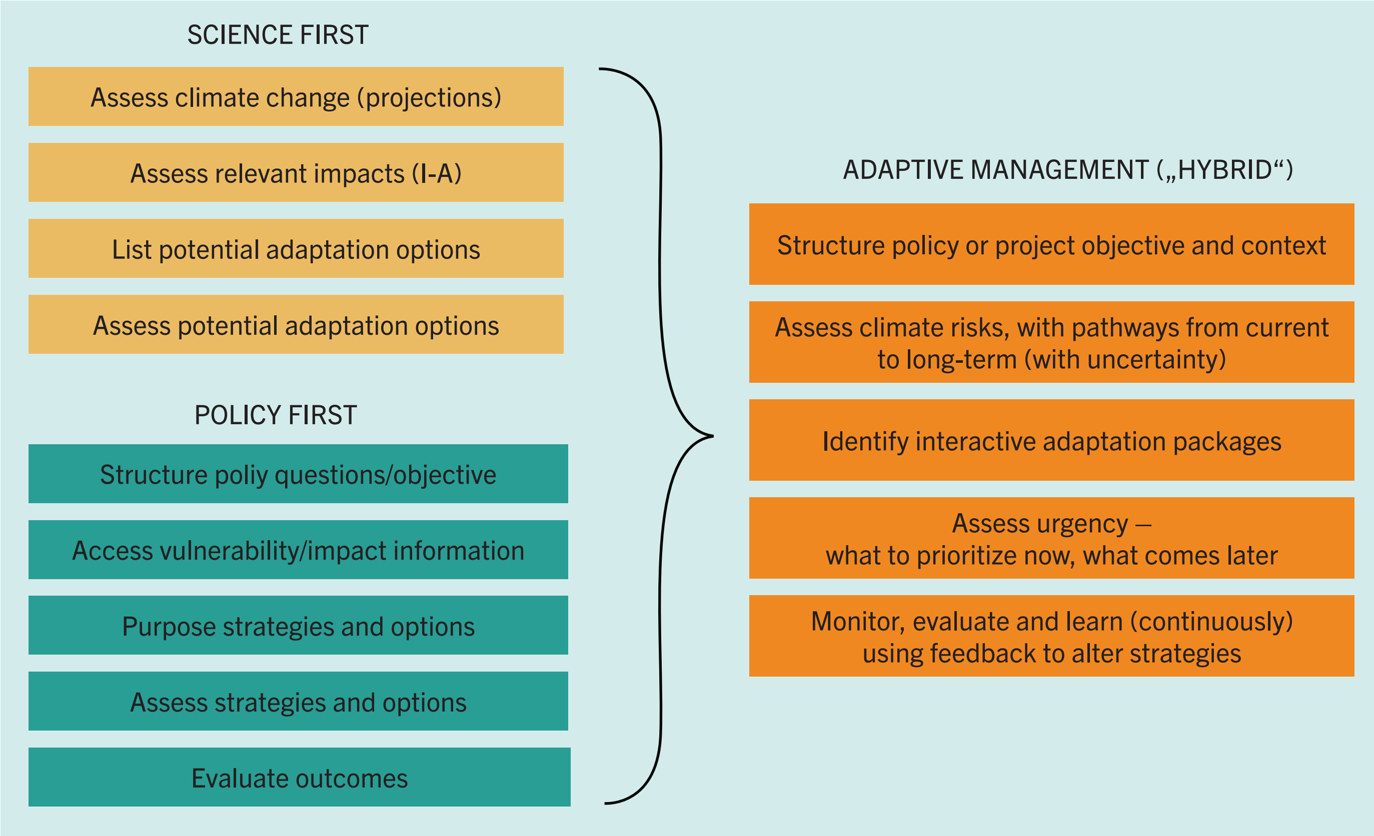
- Science-first studies start with climate model projections (hence, "science first"), then model impacts of future time slices in the medium to long terms (for example, for the 2050s and 2080s), and then model technical adaptation options and their costs. Examples include the studies of coastal or river flood adaptation reported in many European and national studies.

- Policy-first studies are directed specifically toward supporting adaptation decisions in the near term and grounded in policy or project decisions. Examples might include the actions specified in a country's National Adaptation Plan priorities for the next five years or the consideration of adaptation in a project investment decision, such as a new hydropower plant under construction.

- Adaptive management ("hybrid") studies consider both policy and science, often using adaptation pathways approaches. Examples might include studies that look at the space-time clustering for selected infrastructure or those that consider no-regret measures first while more information on adaptation options for different sectors is becoming available.

138 Ranger, N. et al. 2010. "Adaptation in the UK: A Decision-Making Process"; ECONADAPT. 2016. *The Economics of Climate Change Adaptation.* Link.

Figure 11. Science-first, policy-first, and hybrid (adaptation pathways) approaches



Source: Modified and reproduced from EconAdapt, adopted from Dessai and Hulme (2017)[139] and Watkiss et al. (2014a).

Science-first studies[140] **can raise awareness and provide "headline" estimates of the costs and benefits of adaptation.** They can serve advocacy purposes by highlighting the costs of inaction and providing useful information for high-level planning. Most such studies make use of sector biophysical and integrated assessment models (IAMs), and sometimes these results are fed into macroeconomic models. The CCA measures considered are technical and generally based on medium timelines (to 2050s) and long timelines (to 2100s), in line with climate model outputs. This is, broadly, the same approach followed by European Commission (EC) studies such as COACCH[141] and PESETA IV. Science-first studies tend to be normative research and consider technical adaptation options based on expert and engineer assessments. A spectrum of projected climate impacts is often addressed based on an "if-then" framework, in which the analysis is run for one emissions scenario and climate model projection at a time for multiple runs (and, in theory, for many runs across the ensemble in some studies). The consideration of existing adaptation in modeling frameworks also varies, so the analysis may not reflect risk reduction measures already in place—for example, studies of the health effects of extreme heat may not factor existing heat-alert schemes into assessments of impacts or additional adaptation. Overall, these studies show that CCA pays off, and they can be a starting point for national dialogue to encourage more detailed adaptation studies—a perspective followed in part in Chapter 2, use case 1, for the case study on Romania. Science-first studies do not, however, provide all the information needed for real-world policy and adaptation decisions.

139 Dessai S., and M. Hulme. 2017. "Assessing the Robustness of Adaptation Decisions to Climate Change Uncertainties: A Case Study on Water Resources Management in the East of England." Link.
140 Watkiss et al. 2014a.
141 CO-designing the Assessment of Climate Change Costs (COACCH). 2021. The Economic Cost of Climate Change in Europe: Report on Policy Results. Link.

Policy-first studies[142] **recognize that national policy-makers and project investors need to decide today.** They can support decisions on, for example, what to prioritize in a national plan for the next five years or how to include climate resilience in the design of a hydropower plant with a long lifetime. These studies pursue the adaptation objective with a "real-world" policy or project focus. They require an advanced understanding of climate change impacts, non-climate policy, and existing adaptation. They also include consideration of nontechnical or soft options (green versus grey), as well as the enabling activities needed to deliver adaptation, including capacity building and policy, standards, and market-based instruments to support delivery.

Adaptive management ("hybrid") approaches that combine the science and policy approaches can also inform real-world adaptation decisions in the short term, as these policy-first decisions increasingly are made using adaptation pathways for policy or sector analysis.[143] "Adaptation pathways" is a generic term denoting the analysis of adaptation options over time for evolving levels of risk. It has been applied in several different ways:

- *Adaptation roadmaps and pathway frameworks* consider portfolios of adaptation that change over time to allow analysis of the timing and sequencing of adaptation and identify priorities.

- *Adaptive management,* also called iterative risk management, is an iterative cycle of monitoring, research, evaluation, and learning—that is, a process to improve future management strategies.

- *Dynamic adaptation route maps* focus on DMUU and identify adaptation tipping points (or turning points)—the points at which particular actions are no longer adequate.[144]

At the project level, the use of such tools as DMUU for investment decisions is growing more prevalent, as is the application of iterative risk management (or adaptive management) approaches in policy studies (Box 4); the latter help with the prioritization and sequencing of adaptation over time as part of a cycle of learning, evaluation, and revision. Most models are built only in a limited manner to represent cascading impacts from interacting climate hazards. (Computable general equilibrium, or CGE, models can be suitable, but many assumptions have to be made). One way to ensure short-term policy relevance and enhance the scientific basis of adaptation studies is to look at the clustering over space and time of selected assets, sectors, or infrastructure with climate stressors or natural hazards.[145] Elements of the hybrid approach are considered in the case studies presented in the next chapter.

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142 Watkiss et al. 2014.
143 Haasnoot, M. et al. 2013. "Dynamic Adaptive Policy Pathways: A Method for Crafting Robust Decisions for a Deeply Uncertain World." Link; Reeder and Ranger 2011.; Climate-ADAPT. 2023c. How to factor in uncertainty. Link.
144 Hassnoot, M. et al. 2013. Dynamic adaptive policy pathways: A new method for crafting robust decisions for a deeply uncertain world. Link.
145 See studies on critical infrastructure in Annex 1 and Bonnafous, L., and Lall, U. 2021. "Space-Time Clustering of Climate Extremes Amplify Global Climate Impacts, Leading to Fat-Tailed Risk." Link.

BOX 4. ADAPTATION PATHWAYS AND ADAPTIVE MANAGEMENT

To improve their planning for climate change adaptation, several European countries are conducting analyses that combine science-first and policy-first approaches. Austria[146] and Germany[147] have undertaken such studies for decades, producing a wealth of information. In other countries, high-quality studies exist for certain sectors and climate hazards—for instance, flooding in the Netherlands and drought in Spain—but are lacking for others. A few countries, such as France,[148] have started taking the policy-first approach, and further sectoral assessments are being developed. In some cases, an assessment is carried out using several methodologies to allow for comparison of results and learn about different processes (for example, Austria's PACINAS[149] top-down and bottom-up assessments for national budgeting).

Some international studies have also considered the analysis of average changes of climate impacts resulting from climate change and possible tail events, i.e. rare occurrences that are well outside of the norm (for example, hurricanes in Jamaica),[150] as well as compound risks and cascading impacts, but this practice is still in its infancy, as most climate hazards present few data points of extreme value representative of rare tail events.[151]

ANALYSIS LEVELS FOR CCA COSTING

Science-first, policy-first, and adaptive management studies can be undertaken at several levels. For a climate change adaptation study, the level depends on the level and granularity of the climate information available, the details of sectoral studies, and/or the policy question or objective at hand. Currently, national studies tend to be quite broad, while project investment decisions are quite specific. This section focuses on policy-first and hybrid approaches, as these are used throughout the report. Examples from past studies using the science-first approach, such as the COACCH project, are also showcased to provide an overview.

At the national level, studies may involve the costing of adaptation priorities identified in a country's climate risk assessment and National Adaptation Plan. This pertains especially to the investment needed to deliver the first cycle of adaptation (that is, the first five years). The methods applied in such studies range from simple costing of prioritized options to cost-benefit appraisal (although the latter is rare). Adaptation measures are mostly considered in terms of what makes sense in the current political context. Taking into account trade-offs and weighing numerous sectoral and national or local priorities, analyses may also examine no-regret adaptation options known in the literature, such as early warning systems. They may also look at national adaptation expenditure, or climate budget tagging,[152] allocating shares of expenditure to adaptation and then extrapolating outcomes from these based on climate change impact scenarios. While analyses of NAP costs and climate budget tagging exercises can be beneficial for improving inter-ministerial discussion and collaboration, they are often conducted at quite high levels and therefore would require more in-depth sectoral studies that would have been developed previously to taking decisions on adaptation. Some approaches consider multi-hazard implications and cross-sectoral aspects, and recent interest has turned to developing storylines. These

146 Steininger, K. W. et al. 2015. "Climate Change Impacts at the National Level: Known Trends, Unknown Tails, and Unknowables." .
147 Tröltzsch, J. et al. 2012. *Kosten und Nutzen von Anpassungsmaßnahmen an den Klimawandel - Analyse von 28 Anpassungsmaßnahmen in Deutschland*.; Institute for Ecological Economy Research (IÖW). 2021. *Economics of Climate Change Adaptation - Work Package 3: Enhancing the Macroeconomic Model PANTA RHEI and Simulation of Climate Change Impacts and Adaptation Strategies.*
148 Depoues, V. et al. 2022.
149 PACINAS = Public Adaptation - Investigating the Austrian Adaptation Strategy.
150 Nordhaus, W. 2011. The Economics of Tail Events with an Application to Climate Change. ; Weitzman, W. 2011."Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change. ; Nordhaus, W. 2012. Economic Policy in the Face of Severe Tail Events. ; Weitzman, W. 2014. "Fat Tails and the Social Cost of Carbon."
151 Wagner, G., and Weitzman, M. L. 2018. "Potentially Large Equilibrium Climate Sensitivity Tail Uncertainty." Arif, M. et al. 2021. "Evolving Extreme Events Caused by Climate Change: A Tail Based Bayesian Approach for Extreme Event Risk Analysis." ; Zscheischler, J., S. et al. 2018. "Future Climate Risk from Compound Events." ; Flyvbjerg, B. 2020. "The Law of Regression to the Tail: How to Survive Covid-19, the Climate Crisis, and Other Disasters."
152 The CCA cost estimates produced were, for example, used to inform national green budgeting in France (Alexandre, S. et al. 2019. Green Budgeting: Proposition de méthode pour une budgétisation verte. Link.).

approaches are broadly what countries have followed to create NAPs and set nationally determined contributions under the Paris Agreement and national and local budgeting for three-to-six-year planning. This perspective is followed in part in Chapter 2, use case 1, for case studies on Bulgaria and Romania, along with elements of a hybrid approach.

At the sectoral level, studies may involve more detailed identification and the costing of sector adaptation strategies and plans. They may include the integration of climate adaptation strategy and policy (mainstreaming) and of adaptation into sector medium-term and investment plans. Following the science-first approach, sectoral assessments usually examine the effect of climate change on one or a few specific sectors, such as agriculture, forestry, and transportation. After the climate risks and impacts are assessed, either through detailed modeling or by using "lighter" methods, adaptation measures designed specifically for the sector are proposed. This perspective is followed in part in Chapter 2, use case 2, for the case study on Sweden.

At the program, investment portfolio, or project level, studies may involve detailed decision support tools. Examples include DMUU and other such tools that focus on flexibility and robustness and on the value of information, the minimizing of regrets, or the encouragement of diversification or portfolios.[153] These studies usually consider multiple scenarios and climate models over the lifetime of the investment and then identify adaptation options (and costs and benefits) by applying such techniques as robust decision-making, decision scaling, real option analysis, and dynamic adaptation pathways. These approaches are needed because—unlike in DRM studies—the spectrum of projected climate change impacts makes probabilities or probabilistic approaches difficult to generate. No single approach is "best"; the applicability depends on the type of project, climate risk, and decision. Dynamic adaptation pathways, for example, tend to align well with coastal adaptation, whereas decision scaling is used more for water sector decisions. This perspective is followed in part in Chapter 2, use case 3, for case studies on Croatia and Romania, as well as the fictional example of Aurelia.

TYPES OF CCA MEASURES

For policy and hybrid studies and at all levels of analysis, different types of climate adaptation measures can be considered. They support decisions with impacts on planned expenditures in the short to medium terms, rather than hypothetical decisions for mid-century. The adaptation economics literature has identified types of early investments that are likely to pass a cost-benefit test. Watkiss and Betts (2021), for example, enumerate three kinds of early adaptation that are supported by strong economic rationales (Figure 12, Figure 13).[154]

1. Measures that address the current adaptation gap with "no-regret" or "low-regret" actions that reduce risks associated with current climate extremes and variability, as well as build future climate resilience.

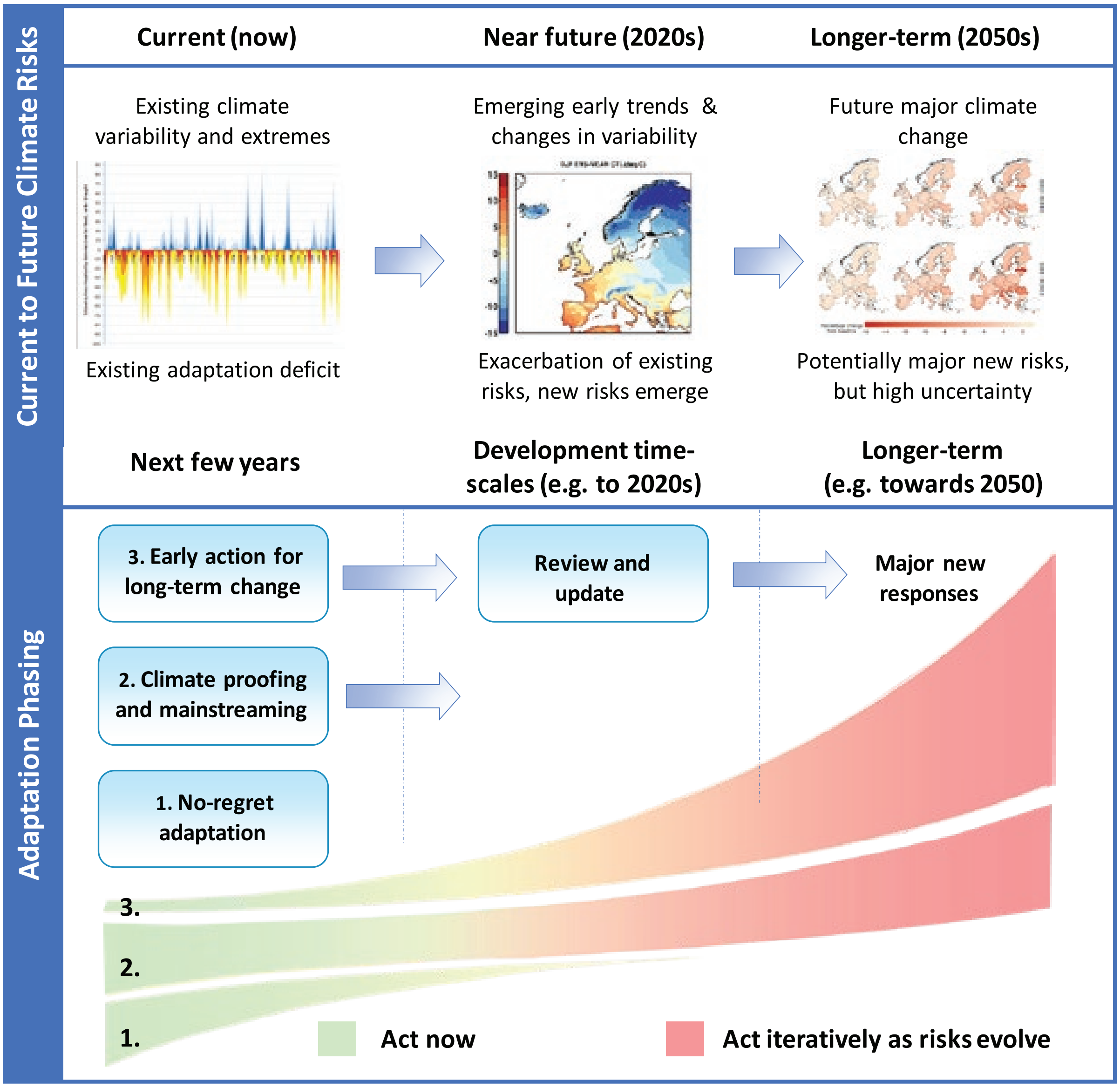
2. Early interventions to ensure adaptation is considered in near-term decisions with long lifetimes—such as decisions to climate proof infrastructure—and therefore reduce the risk of "lock-in"; these may include the application of DMUU concepts, such as flexibility and robustness.

3. Fast-tracking of early adaptive management (adaptation pathway) activities, especially for decisions that have long lead times or involve major future change; this can enhance learning and allows the use of evidence in forthcoming decisions (option value).

153 Watkiss et al. 2014.
154 Watkiss, P., and Betts, R. A. 2021. "Method." Link.

At the national level, for most risks, a portfolio of adaptation actions is needed. This means a combination of all three "building blocks," each with a different timescale of risk and investment. No- and low-regret options are implemented and deliver benefits now, while addressing lock-in involves immediate decisions but targets risks that will arise in the future, and early adaptive management seeks to inform future investment for future risks. While all involve some action in the next five years, the nature of the investment is different.

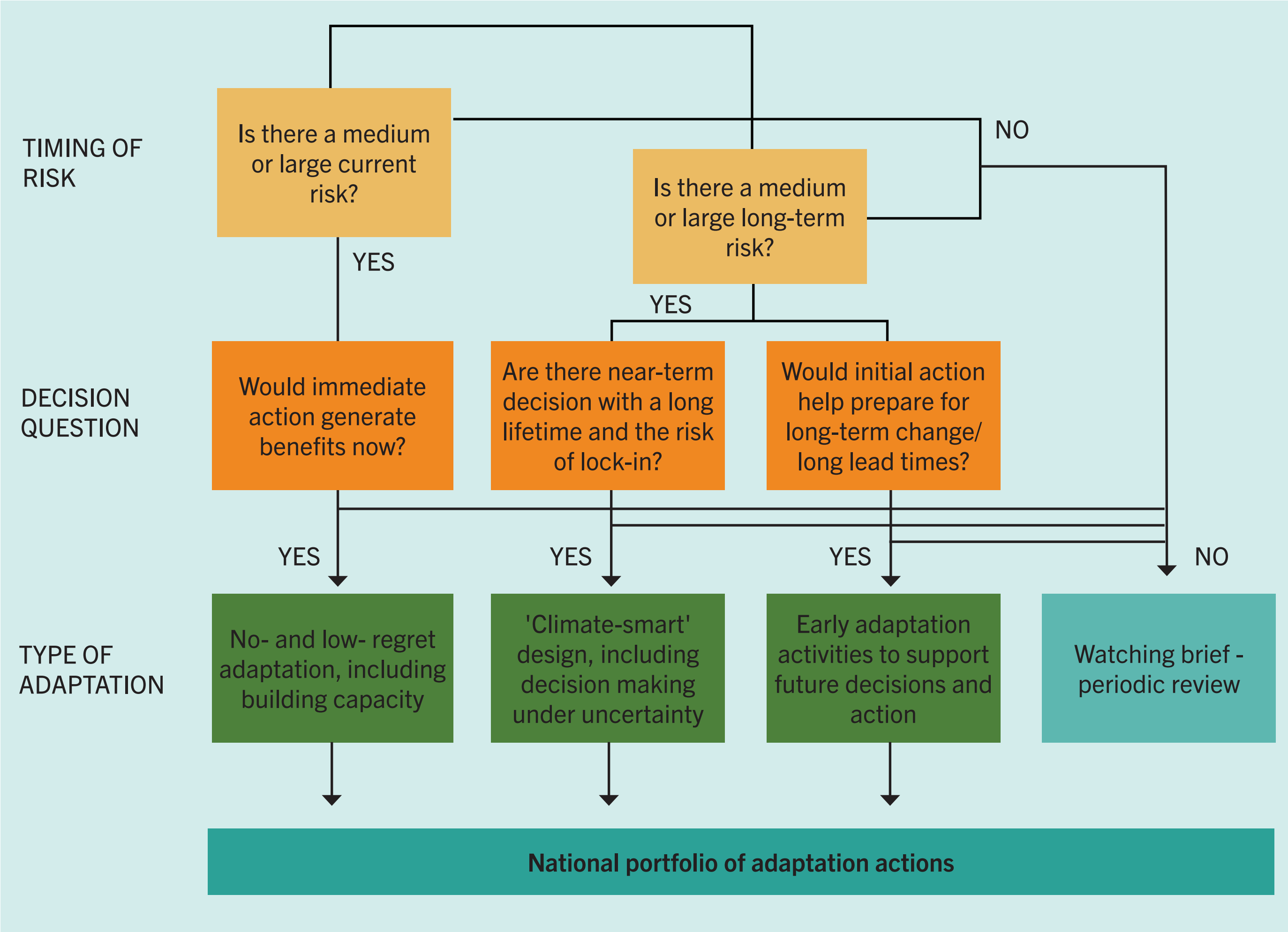
Figure 12. Iterative risk management and options for early adaptation



Source: Overall figure adapted and updated from Watkiss et al. 2014b.[155] The included graphs/maps included in the overall figure are: current climate/top left (from Watkiss et al. 2014b) and near future/top middle and longer term/top right (from IMPACT2C 2015).

155 Watkiss et al 2014b. *The use of new economic decision support tools for adaptation assessment: A review of methods and applications, towards guidance on applicability.* Climatic Change. Link.

Figure 13. Three types of early adaptation with strong economic rationales



Source: Early adaptation priority framework in CCRA3. Watkiss (2021), updated from Warren et al. (2016).

When defining a portfolio of adaptation actions, the potential benefits and costs must be carefully weighed. While it is essential to consider green design features in all programs, as aligned with the Green Deal and other strategies, they can be complex and may involve trade-offs. Green solutions can impose costs—for instance, opportunity costs of land or maintenance costs—that are important to include. A mixture of green and grey adaptation solutions may be preferable to ensure adaptation is most effective and delivers co-benefits, as well. It is important to identify the main objectives of the programs and investments and then carefully evaluate the benefits, as these are generally quite localized and investment- and context-specific. They also depend on whether the main goal is adaptation or risk reduction, as opposed to mostly climate-proofing or other objectives. Examples are outlined in Box 5.

BOX 5. CONSIDERING BENEFITS IN THE COSTING OF CCA MEASURES

Acting on climate adaptation can be economically beneficial and have broader benefits, as well. Investments can reduce direct losses resulting from disaster and climate impacts while enhancing growth and providing trade and job opportunities, productivity gains, emission reductions and air quality improvements, ecological value, and biodiversity.[156] Studies show that adaptation can, for example, be extremely cost-effective in reducing economic losses from climate change–related coastal and river floods.[157] A recent report from the World Bank and the EC reviewing more than 70 investments across Europe has also shown that investments with a portfolio of measures addressing disaster risks can deliver a triple dividend, with numerous co-benefits.[158]

Triple dividend benefits, which can be achieved for a number of DRR investments, are less obvious for CCA investments because the latter present more trade-offs. Much has been made of the potential triple dividend of resilience, and this is also being cited in the context of adaptation. In practice, not all individual adaptation actions deliver a triple dividend, and there are often important trade-offs. Seawalls, for example, may provide high levels of coastal protection, but they may also lead to coastal "squeeze," causing the loss of natural habitats. Alternatives with greater economic benefits, such as nature-based solutions, tend to be more effective at lower risk levels.[159] Trade-offs may also exist between the costs of various options—notably, capital, operating, and opportunity costs—and some of the additional policies needed around protection and enforcement. It is possible, however, both to provide greater resilience and generate substantial social and environmental co-benefits by combining portfolios of measures—for example, grey and green measures.

Considering benefits is important when selecting, prioritizing, and designing CCA measures, particularly when they integrate green elements. This is illustrated by two practical examples.

When a city wishes to adapt to climate change

Local urban decision makers pursuing climate change adaptation need to consider, among other things, average temperature changes, localized vulnerability to various climate-related risks (in addition to others, such as seismic risk), and urban heat island (UHI) effects.[160] Starting with local development strategies and plans, the city can consider a portfolio of measures, some of which may have trade-offs. Planting trees in a city, for instance, can be highly beneficial if implemented at scale, providing considerable cooling effects, as well as other benefits, such as energy savings, air quality improvements, and recreational value.[161] But if the opportunity costs of land use for large green spaces are high, or planting requires "retrofitting" of infrastructure—for instance, on the sides of streets—or is implemented piecemeal and according to a design unsuitable for addressing multiple climate risks, the effort may be costly and not achieve desired outcomes.

It is important, therefore, to ensure that such projects can at least have the value of demonstrating approaches and types of investments to be potentially then replicated at scale. For green roofs or white, blue, or green design and measures,[162] it may be more suitable to develop standardized criteria or regulations so they are considered for new buildings, or to consider multifunctional measures that are highly effective in cooling, enhancing energy efficiency, and addressing other hazards or environmental problems (such as flooding and air pollution).[163] When implemented based not only on knowledge drawn from the literature but also on localized assessments, these

156 An EU assessment of the macroeconomic impact of the European Green Deal suggests that the GDP in 2030 is projected to be 0.5% above the baseline in the best-case scenario as a result of increased in private consumption due to use of carbon revenues to reduce value added tax (VAT) and to support energy efficiency investments. In the EU, employment in renewable energy has more than doubled from 660,000 to 1.51 million jobs between 2004 and 2018. (EC. 2022. Economic impacts of the green transition. Link.); Meanwhile, investing in adaptation in the EU is expected to create a total of 500,000 additional jobs (direct and indirect) by 2050. (EC. 2014. Assessing the Implications of Climate Change Adaptation on Employment in the EU - Final Report & Annexes. Link.); UN findings reveal that adaptive agricultural measures such as solar-powered irrigation, weather alert systems, and new crop varieties could avoid losses in global agricultural yields by up to 30 percent by 2050 (UN. 2023. Climate Action Fast Facts. Link.).

157 Lincke et al. 2018. D2.3. Impacts on infrastructure, built environment, and transport Deliverable of the H2020 COACCH project. Link.; Lincke and Hinkel. 2018. Economically robust protection against 21st century sea-level rise. Global Environmental Change 51, 67-73. Link.

158 World Bank. 2021. Economics for Disaster Prevention and Preparedness - Investment in Disaster Risk Management in Europe Makes Economic Sense. Link.

159 Dadson SJ et al. 2017. A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. Proc. R. Soc. A 473: 20160706.

160 WB. 2020a. Analysis of Heat Waves and Urban Heat Island Effects in Central European Cities and Implications for Urban Planning. WB, Washington, DC. Link.

161 Soare, A. L., et al. 2011. "Benefits and Costs of Street Trees in Lisbon, Portugal." *Urban Forestry & Urban Greening* 10 (2): 69–78.

162 Vienna case study in WB and EC 2021; white, blue, green measures are defined in the glossary.

163 LifeMedGreenRoof. 2023. *LifeMedGreenRoof Project - Constructing Two Demonstration Green Roofs to Illustrate the Potential of Meeting Environmental and Energy Targets.* Malta Competition and Consumer Affairs Authority. 2017. *Green Roofs - Criteria for the Planning, Construction, Control and Maintenance of GREEN ROOFS.* ICS: 27.160.

measures often yield the highest benefits in terms of reduced vulnerability, demonstration value, and/or health and well-being. Ways may also be considered to reduce indoor temperature, such as passive cooling,.[164] while early warning systems and heat action plans are crucial to reducing heat-related mortality and morbidity, especially among the elderly, people with chronic conditions, and other vulnerable populations.[165]

When forestry and civil protection agencies wish to reduce wildfire and other risks

Adaptive forest management and improvements in forest resilience (such as diversifying tree and plant composition and varying the heights of and spacing between trees) can yield substantial benefits, including reducing the risks of wildfire, air pollution, and greenhouse gas emissions and increasing biodiversity.[166] Such adaptation measures have been adopted in many European countries. A pilot payment scheme in Portugal, for example, encourages private forest owners to plant native, fire-resilient species in fire-prone areas.[167]

Nevertheless, benefits from adaptation need to be carefully evaluated, as adaptation may include trade-offs in terms of reducing the economic and ecological value of the forests. In practice, various stakeholders are weighing these potential costs against objectives other than reducing fire risks, such as CCA (carbon storage potential), timber production, and recreational value, and other DRR measures, such as fuel breaks[168] and management. While some countries have already initiated studies, many more are needed to identify forest management strategies that can achieve multiple goals and still be effective against extreme and compound risks. These risks include natural hazards such as heat and wildfires, and other compounding factors such as forest health tipping points and die-off.[169]

ANALYTICAL METHODS FOR COSTING CCA MEASURES

Various methodologies can be used for the analysis of climate impacts and adaptation measures to address them. The advantages and disadvantages of two types of approaches—five top-down and five bottom-down—can be summarized as follows:

- **The top-down approaches are modeled or economic based:** (a) sector integrated assessment and ; (b) IAMs; (c) computable general equilibrium modeling; (d) macro-structural modeling; and (e) econometric modeling.

o **Advantages:**

+ They have been applied mostly as part of cross-country or global studies, as well as in several country case studies in Europe (Austria, Bulgaria, Germany, Spain).

+ They are theoretically sound and thoroughly quantitative in analyzing impacts.

o **Disadvantages:**

– They are used mostly for climate hazards and sectors where relationships in terms of impacts and adaptation effectiveness are well known

– Looking at variability and extreme hazard scenarios can be complicated and costly.

164 Viguie, V., et al. 2020. "Early Adaptation to Heat Waves and Future Reduction of Air-Conditioning Energy Use in Paris." *Environ. Res. Lett.* 15: 075006.

165 Hunt, A., et al. 2017. "Climate and Weather Service Provision: Economic Appraisal of Adaptation to Health Impacts." Hasan, F. et al. 2021. "Effective Community-Based Interventions for the Prevention and Management of Heat-Related Illnesses: A Scoping Review".

166 Müller, M. M. et al. 2020. *Forest Fires in the Alps - State of Knowledge, Future Challenges and Options for an Integrated Fire Management. .;* Keskitalo, E. et al. 2015. *The Role of Forestry in National Climate Change Adaptation Policy: Cases from Sweden, Germany, France and Italy*.

167 OECD. Forthcoming. "Taming Wildfires in the Context of Climate Change: The Case of Portugal".

168 Fuel breaks are strips or blocks of vegetation that have been altered to slow or control a fire and slow the spread of fire.

169 Reyer, C et al. 2015. Forest resilience and tipping points at different spatio-temporal scales: approaches and challenges. Journal of Ecology, Vol. 103, No. 1 (January 2015), pp. 5-15.

- The adaptation analysis is highly stylized, usually focused on technical options, and centered on a 2050s horizon.

- They are generally complex, with a high need for data and expertise (economic impact assessments, sectoral assessments, adaptation effectiveness, and so on).

- **The bottom-up approaches are investment needs, program or project based:** (a) sector-, program-, project-, and activity-based costing; (b) investment and financial flow (IFF) analysis; (c) variation of IFF analysis; (d) decision support tools; and (e) DMUU.

  - **Advantages:**

    + They have been applied in several country case studies in Europe (Austria, Germany, France, Netherlands) and worldwide, mostly as part of national studies.

    + They provide practical information on adaptation to inform financing and implementation.

    + They are simple and can be adapted or tailored; can be applied using semi-quantitative approaches; and have a low to medium need for data (economic impact assessments, sectoral assessments, and assessments of adaptation effectiveness).

  - **Disadvantages:**

    – They focus on existing challenges, in addition to known projections and climate risks.

    – They produce long lists of CCA measures, rarely considering economic efficiency and centered on actions for this decade or a short-term horizon.

    – The comparability of findings is generally limited, as they are tailored to country contexts. However, using similar methodologies for certain use cases can reduce this problem and allow for more comparability.

DISAGGREGATED ELEMENTS OF THE COSTS OF CCA MEASURES

After having taken the decisions above on overall approaches and methodologies, the costing of CCA measures comprises an additional choice on what types of costs to consider. This process will depend on the type of adaptation intervention and will vary depending on whether its focus is a no-regret adaptation action, a climate-smart decision, or an adaptive management approach. The simplest way to describe the process is to use the example of a no- or low-regret measure, which can generally be assessed in a number of steps, although the steps will vary considerably with the context, information at hand, and exact measure costed:[170]

- **Step 1:** Identify the "sub-costs" of a measure. The sub-costs of an early warning system for heat, for example, would include (a) the fixed cost of setting up the early warning system (IT system, change of regulation, adjustment costs of the system, opportunity costs for economic actors to adjust to the regulation, and so on); (b) implementation cost (forecasting, full- or part-time operating staff, maintenance of the IT system, cybersecurity (if necessary), monitoring and evaluation to ensure enforcement and compliance, and so on); and (c) operating/resource/opportunity costs (health care and care home workers taking action when warnings are triggered, media announcements, operations that provide extra care to the vulnerable groups, and so on). While all three types of costs are covered in the literature, the fixed and implementation costs are generally easier to transfer for other case study analytics, while the operating costs are context- and location-specific and therefore need additional surveys and consultations to determine them for each case study specifically.[171]

170 EC. 2021. Better regulation toolbox: "Chapter 8 – Methodologies for Analyzing Impacts in Impact Assessments, Evaluations, and Fitness Checks." Link.

171 Chiabai, A. et al. 2018. "Valuing Deaths or Years of Life Lost? Economic Benefits of Avoided Mortality from Early Heat Warning Systems."; Hunt et al. 2017.

- **Step 2:** For all the sub-costs, identify lower and upper bounds. These are relevant to the country context, area, hazard, and/or sector and should be determined from (a) literature reviews; (b) databases; (c) expert estimations; and (d) surveys and/or consultations with stakeholders.

- **Step 3:** Add up the sub-costs to estimate the costs over the period of implementation. The total cost can be expressed as an annual average or as a present value after discounting. This may require estimating changes in costs over time, including as a result of climate change (that is, how often the early warning system is likely to be triggered per year in 2030 or 2050 versus 2024).

- **Step 4:** Consider the division of costs among various economic actors. The additional hours of work for health care workers, for example, may be carried by the public sector for public hospitals or by the private sector for private clinics; opportunity costs for construction workers may have to be carried by construction companies. Direct costs linked to the intervention may arise from legal provisions, or indirect costs may be observed in upstream or downstream markets or experienced by various stakeholders not directly targeted by the initiative or regulation.[172]

The costing of adaptation investments, which involve longer lifetimes and include those with potential lock-in risks or path dependencies, is more complicated, because a spectrum of projected climate impacts must be considered. The costing of such measures as climate-proofing new infrastructure investment or determining the level of dedicated adaptation investment is challenging because of the potential for regrets (that is, for under- or overinvesting in adaptation). In this case, the costing often has to be aligned with, for example, the DMUU method used as part of a robust decision-making approach. Similarly, actions that are part of an adaptive management approach, including adaptation pathways, present additional costing challenges.

In Germany, for instance, various costs were calculated and considered in the prioritization of CCA measures based on multicriteria analysis. Costs for 28 CCA measures were calculated based on (1) one-time capital expenditure (for measures to reduce extreme heat impacts, this might include replacing road asphalt with heat-resistant materials and converting to green roofs); (2) ongoing costs (such as additional required maintenance work on roads, annual maintenance work on green roofs, and time spent by private households to maintain infrastructure); and (3) transaction costs (expenditures for permitting a green roof, planning work for levee construction, and so on).[173] With regard to measures that are policy instruments, consideration also had to include (1) costs of the political process (developing the policy instrument); (2) inception costs (changes to systems according to regulation); (3) administration and implementation costs (mostly for enforcement) and monitoring and evaluation costs (monitoring of enforcement effectiveness and compliance or necessity to adapt the instrument, costs of fining for enforcement, and so on); and (4) opportunity costs (reduction of economic activity as a result of regulation and so on). These costs were then considered in an overall multicriteria analysis to prioritize CCA measures in the country.[174] As the costs were based on ordinal scales (low-medium-high), multipliers (X times higher cost compared to another compared measure), or monetary cost ranges, the sum of the costs expressed in monetary values represented a lower bound.

172 EC 2021.
173 GoG Umweltbundesamt. 2020. *Vertiefte ökonomische Analyse eiinzelner Politikinstrumente und Maßnahmen zur Anpassung an den Klimawandel.* Link.
174 The 10 criteria considered for MCA were (1) climate impact filter, (2) governmental action, (3) temporal urgency, (4) system relevance, (5) effectiveness, (6) costs, (7) implementability, (8) acceptance, (9) flexibility, and (10) synergies and conflicts with other policy areas.

IDENTIFYING ADAPTATION GAPS: LINKING CCA COSTS OF MEASURES TO CCA EXPENDITURES AND FINANCING

Stakeholders recognize that filling the adaptation gap will require a major scale-up of public, private, and blended adaptation finance, involving new actors, new models, and new financial instruments. Global and European climate finance flows are now very large, but they are dominated by mitigation; the flows to adaptation are small and mainly from public sources.[175] This means a large gap exists in Europe between the amount needed for adaptation and the current finance flowing.

To fill it, a major scale-up is needed of public, private, and blended adaptation finance, involving new actors, new models, and new financial instruments. Several challenges are posed, however, by barriers and constraints to adaptation. These barriers include information gaps, market failures, and lack of bankability, policy constraints, and misaligned regulation, as well as broader social and cultural aspects that influence risk aversion and balancing trade-offs for decision making. Importantly, generating revenues can be more difficult for adaptation than for mitigation investments; relatedly, it is easier to finance no-regret and incremental adaptation and more challenging to finance anticipatory and transformational adaptation. This means public sources of finance will need to be scaled up, which is important for public investment strategies and medium-term budget plans.

Adaptation costing studies provide the initial information needed for all of this and can be further applied to adaptation investment planning and financing. Stress tests have been conducted on the potential impacts of climate change on MS public finances, including on indicators such as debt to GDP levels.[176] These tests have determined that climate change may pose risks to fiscal (debt) sustainability in some countries, and further dialogue with ministries of finance is important to managing them. Several countries are undertaking climate budget tagging and looking at the possible effects of adaptation on spending plans and the public finance. Adaptation costing studies can contribute to such analysis and encourage investment by demonstrating the benefits of early adaptation investment and how it can reduce fiscal risks. An opportunity also exists for private investment in some areas (such as market sectors and regulated sectors), although it presents questions as to who pays for the adaptation and how the burden can be equitable.

Examples from Europe: Elements considered by countries in practice for costing CCA impacts

Different countries have used many different types of CCA costing assessments at various levels (national, sectoral, and programmatic). These range from systematic studies building on complex scientific assessments to more ad hoc or partial assessments. Some examples are presented below.

NATIONAL-LEVEL PLANNING

In France, two recent national studies[177] used an adaptive management (policy-first) approach to CCA costing that helped initiate a national debate and prompt further studies. A first set of 18 budgetary measures was derived to be included in the next

175 Climate Policy Initiative. 2023. Global landscape of climate finance 2023. Link.; Frontier Economics. 2022. Barriers to financing adaptation action in the UK. Link.

176 The EC Fiscal Sustainability Report 2021 (DG ECFIN) included an extreme event stress test to assess the risks to public finances—a first step in policy readiness. The results led to the conclusion that climate change may pose risks to fiscal (debt) sustainability in some countries, although these were reported as remaining manageable under (low) global warming scenarios (European Commission. 2021. Fiscal sustainability report 2021. Link.).

177 Depoues et al. 2022.

National Financial Budget Strategy and serve as the initial building blocks for preparing, enhancing, or operationalizing existing CCA actions over the following five years. France focused on no- and low-regret measures, costs of processes, and the plans needed, as well as early technical options; together, these analyses could provide a plausible lower bound for CCA costs (an additional cumulative amount of financing for adaptation of at least €2.3 billion per year). These studies have to be seen in the context of an ongoing national debate on how to prepare early for a 4°C world. Moreover, as a leader in green budgeting, France also based estimates of future climate spending under favorable and unfavorable climate scenarios partly on estimated costs of CCA found in previous studies[178] and analyzed the impacts of regular and tax expenditures on different climate and environmental objectives.[179] In addition, sectoral assessments are currently underway, with initial focus on the building, transportation infrastructure, and agricultural sectors; these studies are drawing on national debates to weigh the potential benefits and costs of adaptation, as well as decide what are the "acceptable residual impacts" after CCA.[180]

In the United Kingdom, a 2023 study[181] assessed the costs of major adaptation measures for the decade 2020 – 2030 and presented both planned and anticipatory actions. The largest costs of CCA measures were associated with addressing coastal and river flooding, overheating, and risks to water supply, the infrastructure, and the natural environment. The cumulative costs of addressing these major risks were estimated at £4.5 billion (€5.3 billion) per year for this decade (0.2 percent of the EU-27 GDP). This represented the minimum level of action needed to tackle current risks and start planning for the future and was equivalent to an annual adaptation cost of €35 billion per year for the EU-27 this decade when extrapolated to Europe. The report also highlighted that this amount covered only around 20 percent of the 60 risks and opportunities identified in the UK's climate change risk assessment. The analysis indicated, therefore, that a plausible upper level of planned adaptation costs for the UK, to tackle all risks this decade, would be about £10 billion (€11.6 billion) per year.

In Austria and Germany, studies undertaken for decades, using first a science-first and later policy-first as well as adaptive management approaches, have supported advocacy for and prioritization of CCA measures at the national and local levels. For both countries, the quality of these studies has been high, and they have produced a wealth of information. In Germany (population around 83 million in 2021), the annual costs of CCA have been estimated at €140 billion–€142 billion[182] and in Austria (population around 9 million) €421 million–€573 million.[183] The studies have applied different methodologies to inform CCA at various levels and for various policy objectives (financial resilience policies, sectoral planning, informing NAPs, and so on). Moreover, more recently, both countries reviewed their financial flows to enhance the efficiency of green spending.[184] The results in Germany helped convince the national government that adaptation could reduce projected climate damage considerably at the national—not only the local—level, with synergies between mitigation and adaptation. In Austria, the results suggested that 11.4 percent of public expenditures and 11.5 percent of revenues were related to the country's climate, energy, and environmental objectives, which was in line with the country's National Development Strategy. An extensive process to identify Austria's expenditures on CCA showed that implementation of the National Adaptation Strategy did not include additional adaptation budget but, rather, reshuffled current expenditures, and that most entities, particularly at the local level, had only

178 Alexandre, S., et al. 2019. Link.
179 Eichberger, S., et al. 2023. *Budgeting for Climate Action: Lessons from Austria, France, and the European Union.* Link.
180 I4CE. 2023. Economic implications of adaptation pathways (upcoming). Link.
181 Watkiss. 2023.
182 Tröltzsch, J., et al. 2012. Link.; IÖW. 2021. Link.
183 Knittel, N., et al. 2017. Link.; value adjusted to 2022 EUR and different from original report.
184 Government of Austria. 2022. *Spending Review im Rahmen des Aufbau- und Resilienzplans - Modul 1 „Analyse der klima- und energiepolitischen Förder- und Anreizlandschaft".* Link.

limited knowledge of expenditures for adaptation in absolute or percentage terms. This finding led to follow-up nationally funded programs to determine more specifically and prioritize CCA measures that would support implementation.[185]

In Croatia, the implementation costs of CCA measures were assessed as a part of the country's National Adaptation Strategy to establish the financial mechanisms for adaptation.[186] The assessment suggested the total amount of investment needed between 2020 and 2040 for the implementation of the measures proposed in the National Adaptation Strategy was about HRK 27 billion (€3.6 billion). The cost estimate covered measures in eleven sectors, with more than half of the estimated amount allocated to the implementation of "structural" measures, especially in such key sectors as agriculture, forestry, and water management and, to a lesser extent, in energy and tourism. Measures in the agricultural and forestry sectors were considered "no-regret" options that would generate positive impacts in combating climate change and whose implementation was already planned. The assessment provided an overview of the total amount of investment needed for adaptation, while more precise costs of measures and activities, as well as sources of funding, were to be assessed in the action plans and implementation documents of the National Adaptation Strategy. The case study and results from new research for Croatia are presented in Chapter 2.

In Sweden, Slovakia, and Spain, national authorities conducted the costing of CCA measures, with a focus on near-term (five-year) budgetary planning. In 2007, Sweden's Commission on Climate and Vulnerability suggested that about SEK 210 million (€18.4 million) was needed for CCA investment from 2007 to 2012 (this amount would be SEK 260 million, or €22.8 million, if a new subsidy for investments to protect against natural disasters were included);[187] the case study and results from new research for Sweden are presented in Chapter 2. In Slovakia, the National Adaptation Strategy estimated that a total investment in adaptation of around €3 billion, covering budget for operation programs, was needed between 2014 and 2020.[188] In Spain, the National Adaptation Plan estimated a total investment in adaptation at around €1.5 billion from 2021 to 2025. This amount covers investment in eighteen sectors, with the largest expenditures in the water sector (€525.6 million), environment and biodiversity (around €320 million), coastal and marine environment (€277.7 million), urban planning and construction (€205.7 million), and transportation (€114.6 million).

In Greece, two studies were undertaken to assess the cost of adaptation from a long-term science perspective. In 2016, the Greek National Adaptation Strategy[189] suggested the cumulative cost of adaptation until 2100 would be about €123 billion, covering a variety of adaptation measures in seven key sectors, among them forests, agriculture and fishing, tourism, transportation, and buildings and infrastructure. An earlier study by the Bank of Greece[190] assessed the costs of adaptation and its effects on the Greek economy under a high-intensity climate scenario, using the general equilibrium model GEM-E3 and benefit-cost analysis (BCA). The results showed estimated cumulative costs of adaptation for the period 2011–2100 of €28 billion based on a 0 percent discount rate and €67 billion based on a 2 percent rate. The study also showcased the high benefit of adaptation in terms of climate loss avoided, finding that the €67 billion investment in adaptation could lead to a cost savings of €123 billion (at 2008 constant prices), compared to an inaction scenario. A theme common to the two Greek assessments was

185 The government of Austria is establishing a system to track the implementation of and changes in actual expenditures for climate adaptation. This is supported by efforts to improve information collection systems at the local level and by a project funded by Austria National Bank to determine how expenditures will evolve over time; trade-offs; and synergies; and to improve evidence on adaptation measures and costs related to heat and flood risk mitigation.
186 Government of Croatia. 2020. Climate change adaptation strategy for the period up to 2040 with a view to 2070. Link.
187 Government of Sweden. 2007. Sweden facing climate change – threats and opportunities. Link.
188 Government of Slovakia. 2018. Climate Change Adaptation Strategy of the Slovak Republic. Link.
189 Government of Greece. 2016. National Strategy for Adaptation to Climate Change. Link.
190 Bank of Greece. 2011. The Environmental, Economic and Social Impacts of Climate Change in Greece. Link.

that they both considered climate impacts in the far future and reflected the significant amount of investment needed for adaptation, given the intensified risks and impacts of climate change over the period assessed.

In Bulgaria, initial high-level sectoral assessments were substantially expanded to complement the country's National CCA Strategy and Action Plan for 2019–30[191] **and its National DRM Plan of 2022**[192] **and to serve as the basis for prioritizing and costing their respective programs.** While the CCA Action Plan provided an estimate of the expected cost of each measure, these estimates were designed to serve as general guidelines and predominantly divided into broad budget cost categories (low: up to €1 million; medium: €1 million–€100 million; or high: above €100 million). Hence, these figures are not comparable with those produced by other assessments, such as in Austria, France, and Germany, whose CCA cost estimates were provided at the national scale in annual terms. The case study and results from new research for Bulgaria are presented in Chapter 2.

In Romania, an assessment was undertaken at the national level as part of the process of elaborating Romania's NAP and CCA Strategy and its Action Plan for 2023–30 to showcase the costs of selected adaptation measures in 13 sectors.[193] Preliminary estimates of CCA costs presented in the draft strategy and corresponding action plan totaled €19 billion for the thirteen sectors for the time period covered; for six key sectors,[194] around €15 billion would need to be allocated.[195] Sectors with the largest estimated costs included water resources (€5.42 billion), agriculture (€4.5 billion), forestry (€2.3 billion), and transportation (€1.9 billion). Other sectors and topics covered by the strategy included biodiversity and ecosystem services, health, population and air quality, cultural heritage, and insurance as a CCA instrument. The draft strategy and action plan were elaborated through the national project RO-ADAPT, based on the latest information available, which made it possible to establish forecasts and scenarios in terms of impacts of and adaptation to climate change, as well as adaptation objectives for the medium and long terms. These documents resulted from a collaboration between the Ministry of Environment, Water, and Forests and a consortium led by the National Meteorological Administration. The case study and results from new research for Romania are presented in Chapter 2.

SECTORAL-LEVEL PLANNING

In Austria, Spain, and the Netherlands, assessments were undertaken to analyze the sectoral impact of hazards and estimate the cost of adaptation in multiple sectors as additional public adaptation expenditure needed until 2050.[196] In Austria and Spain, the assessments considered the effects of climate change on agriculture and forestry and the impact of river floods, while in the Netherlands the impact of river and coastal floods was considered across sectors. The results suggested estimated costs of adaptation for Austria, Spain, and the Netherlands of, respectively, €0.24 billion, €0.33 billion, and €1.15 billion. Follow-up studies based on these results were conducted to inform decision-making in adaptative sectoral planning and provide associated cost estimates, including investment, maintenance, and operating costs.

191 Government of Bulgaria. 2019. *National Climate Change Adaptation Strategy and Action Plan.* Link.
192 Government of Bulgaria. 2019. *National Disaster Risk Management Plan*. Link.
193 For the purpose of this report, Romania's 'NAP' refers to the Action Plan of the draft National Strategy for Climate Change Adaptation, which has been published for public consultation on the Ministry of Environment, Water and Forests' website in August 2023. At the time of completion of the present report, the draft Strategy and Action Plan are in the process of being approved, based on the revisions following the consultations. The numbers analyzed and presented in this report rely on the draft Strategy and Action Plan version from August 2023, which may eventually differ from the final version to be approved by the Government of Romania. Link. 2023. Extract from the draft National Action Plan for the implementation of the National Strategy on Adaptation to Climate Change for the period 2023-2030 (draft as of August 2023). Link. Expected approval in April-May 2024.
194 Water resources, agriculture, forestry, localities/urban systems, energy, transport, tourism and industry.
195 Excluding the Transport section, for which data was not available.
196 Van der Wijst, K. et al. 2021. D4.3 *Macroeconomic Assessment of Policy Effectiveness.* Link.; Watkiss, P., and Preinfalk, E. 2022. "The Economics of Climate Adaptation in the EU: New Evidence from Recent Research." Link.

In the United Kingdom, the sectoral impact of peatland fires and cost effectiveness of potential CCA measures to address wildfire risk were assessed.[197] The study sought to provide evidence for the Third National Adaptation Programme (NAP3) and focused on wildfire risk for peatlands as carbon stores (N5). Following a science-first approach, it first examined the current and future economic costs of peatland fires, fire suppression and restoration costs, as well as the costs of carbon emissions and air pollution. The results suggested the estimated current cost of peatland wildfires at £34 million–£192 million (€40 million–€225 million) per year, while the costs in 2050 ranged from £100 million to £600 million (€117 million–€702 million) per year, with potential for exceeding £1 billion (€1.17 billion). Several wildfire management and adaptation options were considered, such as peatland restoration, wildfire response training programs and wildfire management plans, as well as public awareness campaigns, with the costs and benefits of adaptation assessed through BCA. For instance, with an estimated cost ranged from £1.4 million–£6.7 million (€1.6 million–€7.8 million), the national training program was identified as a no-regret option that would reduce wildfire risks while generating numerous private benefits. The approach was one that could be replicated in other countries with fire-prone forest or peatland areas and was applied in Sweden's study to demonstrate analytical steps taken and data needs.

In Sweden, an assessment undertaken by the Swedish Commission on Climate and Vulnerability examined the costs of climate change damage and of implementing climate action in different sectors, such as agriculture, water, forestry, transportation, and buildings and critical infrastructure.[198] Depending on the sectoral needs and the various types of hazards and adaptation measures assessed, the CCA costs were found to vary greatly from, for instance, SEK 20 million (€1.73 million) per year for enhancing the climate resilience of railway networks to SEK 7.5 billion (€650 million) for drinking water adaptation. The assessment also suggested that the opportunity for carrying out detailed cost calculations and cost-benefit analyses was limited. Meanwhile, because of the spectrum of climate projections and the lifetime and future development of adaptation measures, the results have primarily been used to provide general guidelines and show possible magnitudes of CCA costs. The case study and results for Sweden are presented in Chapter 2.

PROGRAMMATIC PLANNING

To inform CCA strategies in the Netherlands, a project-based assessment was undertaken of the unit costs of adapting coastal defenses in low-lying delta areas.[199] Based on cost reports and benefit-cost analysis of existing adaptation projects, the assessment identified and estimated the costs for different flood defense measures, such as coastal and river dikes, storm surge barriers, dams, and sand dunes. The results of the assessment suggested the cost per meter of height for raising the sea dikes, for instance, ranged from €15.5 million to €22.4 million per kilometer in urban areas and from €4.5 million to €12.4 million per kilometer in rural areas. As it was based on actual project data, this assessment estimated higher all-in costs than earlier studies. It demonstrated how programmatic assessments could be used to provide closer estimates of CCA costs, as they could better reflect real situations in areas where situations are commonly not ideal.

In Spain, a quantitative, scenario-based BCA was undertaken for two heat wave adaptation measures (a green roof and a heat-health warning system) as part of the BASE[200] **project funded by the EU.**[201] The measures pertained to a wide range of sectors, including water, agriculture, health, biodiversity, and the ecosystem, and the study assessed their costs

197 Watkiss, P. 2022. Analysis Phase: Wildfire Risk to Carbon Stores (Peatland) and Adaptation Response.
198 Government of Sweden. 2007. Link.
199 Jonkman et al. 2013. "Costs of Adapting Coastal Defences to Sea-Level Rise- New Estimates and Their Implications." Link.
200 "BASE" stands for "Bottom-up climate Adaptation Strategies towards a sustainable Europe."
201 Meyer, V., et al. 2015. BASE Report: *Economic Evaluation of Adaptation Options.* Link.

and benefits under different climate scenarios (RCP 4.5 and RCP 8.5) and socioeconomic scenarios. For the green roof, it estimated an initial cost ranging from €279 million to around €1.5 billion and a maintenance cost ranging from €98 million to around €2 billion over the period 2020–2100. The estimated initial cost for the heat-health warning system ranged from €0.4 million to €21.3 million, with additional costs ranging from €7.1 million to €12 million. The assessment showed that CCA estimation is highly sensitive to the choice of socio-climatic scenario and discount rate, so these aspects need to be carefully considered when undertaking assessments.

In the UK, the objective of a study published under the commission of the Committee on Climate Change was to identify potential low-regrets options for climate change adaptation in the residential buildings sector.[202] The study assessed the costs and benefits of a variety of adaptation measures for residential buildings that reduce losses from three types of climate events: water stress, floods, and overheating. Cost curves were developed for different residential adaptation options to present their costs and benefits. In addition, worst- and best-case climate scenarios were assessed through sensitivity analysis. The study showed that the CCA costs could vary greatly, depending on the types of measures and climate scenarios. The unit cost of a new-build water efficiency package, for instance, could range from almost negligible to £6,274 (€7,232) per property, with standards of 110 and 105 liters per person per day identified as low-regret options. As for benefits, the analysis considered, in addition to enhanced climate resilience, the wider benefits of adaptation, including enhanced energy efficiency, reduced electricity and carbon costs, and impacts to human health avoided. Based on its findings, the study presented a list of low-regret options with benefit-cost ratios higher than 1, or in other words for every 1€ spent you would get more than 1€ back. This presentation of prioritized measures was meant to support decision-making in the enhancement of climate resilience of residential buildings.

LESSONS LEARNED FROM COUNTRY EXAMPLES

Since the process of CCA costing can take time and money, the benefits and potential quality of the results should be weighed against the investments in resources and time. In some countries such as Austria, France, Germany, and Italy, research programs have been implemented over the past five to ten years, or information has become available from EU research programs (for example, COACCH and EconAdapt), which include modeling of granular climate change impacts and the costs and benefits of technical options for CCA. These have contributed information for programs at the national level but may sometimes have lacked information immediately relevant for five-year financial planning; this is why, in Austria and France, specific research programs have been implemented (I4CE, PACINAS, and so on) to identify CCA costs from a budgeting perspective. In others, such as Bulgaria, lack of data and information has made more complex assessments infeasible but NAPs have been informed by program-based analysis to estimate the costs of the activities.

In some cases, time and effort spent on studies over many years have brought numerous benefits. With regard to national-level planning, in Austria[203] and Germany[204], comprehensive studies on the cost of CCA based on impact studies have taken around two decades and involved approximately 10 research projects. These studies have provided valuable insights and played a crucial role, for example, in influencing the national government in Germany that implementing adaptation measures can significantly reduce climate damages at both national and local levels, with synergies between mitigation and adaptation. Studies helped to also identify several

202 Committee on Climate Change. 2019. Updating an assessment of the costs and benefits of low-regret climate change adaptation options in the residential buildings sector - Final Report. Link.

203 Tröltzsch, J., et al. 2012. Link.; Knittel, N., et al. 2017.Link; Government of Austria. 2022.Spending Review im Rahmen des Aufbau- und Resilienzplans - Modul 1 „Analyse der klima- und energiepolitischen Förder- und Anreizlandschaft". Link.; Eichberger, S., et al. 2023. Budgeting for Climate Action: Lessons from Austria, France, and the European Union. Link.

204 IÖW. 2021. Link.

challenges in the implementation of adaptation plans, including a limited knowledge of adaptation expenditures and difficulty leveraging additional budget instead of reallocating existing resources, particularly at the local level. Follow-up nationally funded programs helped to bridge these information gaps to determine more specifically CCA expenditures and prioritize CCA measures to support implementation.[205]

The studies considered CCA costs for a range of policy horizons. The study in France[206] that estimated adaptation costs at €2.3 billion per year focused on identifying and costing no-regret measures that could be implemented immediately with minimal additional budget. The authors advised further in-depth sectoral studies based on national debates to help weigh the potential benefits and costs and decide on acceptable levels of residual climate impacts. This was different from the studies in Austria and Germany that—broadly speaking—considered first the ideal levels of CCA costs to minimize potential climate change impacts in a way that would make economic sense. These studies started with longer horizons (to the 2050s), with follow-up studies then considering measures that could be implemented in the short term, also based on consultations with stakeholders across ministries and from academia.

Estimates for CCA costs differed greatly, depending on the methodologies used and adaptation measures covered. The national assessment for Austria, for instance, revealed that the costs of CCA differed even for the same sector, depending on the methodology used (€421 million per year based on a bottom-up approach and €573 million per year based on a top-down approach). The French I4CE study that consideredresented options presented an adaptation cost of only €2.3 billion per year,[207] while the costs for more comprehensive adaptations in the United Kingdom totaled an estimated €11.6 billion per year.[208] Extrapolating the results to the European level could provide[209] a plausible range of €15 billion–€78 billion per year for the EU-27.

These studies are only indicative, as costs of adaptation will vary greatly with country and thus need to be assessed carefully according to the country's vulnerability and climate risks. Meanwhile, in the longer term (for 2050 and later), existing science-first studies (albeit limited in number) have provided varied adaptation cost estimates; examples of the range in the literature include one estimate of US$32 billion–US$56 billion (€27 billion–€47 billion) annually in a study from 2005[210] and another study from 2009 of US$155 billion–US$509 billion (€158 billion—€518 billion) annually from 2025 to 2185.[211] Because many of these costs would arise in later decades, they may indicate there is higher adaptation costs in the future and thus imply a need for rapid scale-up of expenditure.

The abovementioned studies have informed policy dialogue and planning for climate change adaptation. They have contributed to the mainstreaming of CCA across line ministries' plans. Now, more complex assessments have to be undertaken to assess the effectiveness of measures (for instance, various types of investments and how they should be timed to enhance CCA and resilience). The costing of adaptation for national policy requires multiple evidence lines and studies and it develops over time as more evidence emerges. The demand for this type of information is likely to increase significantly as the EU and its Member States increase adaptation investments in multiannual expenditure programs and as the finance needs for adaptation rise.

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205 The government of Austria is establishing a system to track the implementation of and changes in actual expenditures for climate adaptation. This is supported by efforts to improve information collection systems at the local level and by a project funded by Austria National Bank to determine how expenditures will evolve over time; trade-offs; and synergies; and to improve evidence on adaptation measures and costs related to heat and flood risk mitigation. In addition, climate adaptation is supported at local level through the nation-wide program KLAR! - Climate Change Adaptation Model Regions for Austria (Government of Austria. 2024. Climate Change Adaptation Model Regions for Austria. Klima- und Energiefonds. Link.)

206 Depoues, V. et al. 2022.

207 Depoues, V. et al. 2022.

208 Watkiss, P. 2023. Link.

209 Knittel, N. et al. 2017.

210 Jeuken, A. et al. 2016.

211 EU. 2017. Climate mainstreaming in the EU budget: Preparing for the next MFF - final report Link. based on De Bruin et al. 2009.

Although no current studies on transformational adaptation exist, initial efforts have been made to bring about more systemic changes. In France, policy-makers have started a process to prepare for a 4°C world, and in May 2023 they initiated a survey in the country.[212] The Environment Ministry aims to define a reference trajectory for CCA for the pessimistic 4°C scenario, which would serve as a basis for defining and strengthening policies. Early national debates and research have provided inputs to update the country's next National Climate Change Adaptation Plan (Plan National d'Adaptation au Changement Climatique). Although only a starting point for large-scale systemic changes, this provides an example of raising awareness of higher-end outcomes, starting societal discussions, and setting initial pathways.

Few studies have been conducted or methodologies applied to estimate the share of CCA costs among various economic actors. Few studies have outlined clearly and in detail how the various types of costs of CCA measures will be divided among various levels of government and what transaction costs may be involved for coordination and for further budget allocations, if needed, from the national to local levels. Although the rapid increase in private investment in adaptation and climate resilience[213] makes consideration of the division of the cost burden between the public and private sectors crucial when implementing CCA measures, this division is only mentioned in limited studies. A recent study[214] in Germany, for instance, assessed the implementation and transaction costs of CCA measures incurred by the state, companies, and households, but it did not clearly show how the cost was split between the public and private sectors. In Portugal, where Forest Intervention Zones (Zona de Intervenção Florestal, or ZIF) are considered promising as a forest management plan for CCA and wildfire risk reduction, implementation of the plan faces a significant challenge in terms of how to split the CCA costs between the government and private landowners, as adaptation measures such as the removal of trees for fuel breaks or less flammable vegetation require a trade-off in the form of future losses in harvest incomes for private landowners, without financial compensation from the government.[215] The public sector must, therefore, promote further private CCA investments, which can be done by creating enabling conditions, supporting the de-risking of private investment, incentivizing risk transfer mechanisms (insurance), or developing public-private partnerships. Private sector CCA investments can also be incentivized through regulatory mechanisms, such as obligations for contingency plans, abidance by building codes, or action requirements in case of an EWS trigger, and risk assessment guidelines for consistency, among others. More research is needed to provide more guidance and details on effective financial instruments for climate adaptation, including insurance, to tackle various climate hazards.[216]

212 Government of France. 2024. "France adapts" ("La France s'adapte"). Link. Garric, A. 2023. "Climate Change: France Launches Public Consultation to Prepare for a 4°C Rise." Link.
213 Tall, A. et al. 2021. *Enabling Private Investment in Climate Adaptation and Resilience: Current Status, Barriers to Investment and Blueprint for Action.* Link.
214 GoG Umweltbundesamt. 2020.
215 Beighley, M., and Hyde, A. C. 2018. *Portugal Wildfire Management in a New Era – Assessing Fire Risks, Resources and Reforms.* Link.
216 See among others: WB and EC. Forthcoming. *EDPP2 - Component 3 - Bringing National and Regional Finance to Scale*.

CCA costs at European level: Status quo and further evidence required

CURRENT EVIDENCE AT EU LEVEL ON CCA COSTS RANGES

No recent, comprehensive estimates of CCA costs yet exist at the EU level.[217] The results and related policy recommendations from EU-wide assessments of current and future climate risks and impacts that are currently underway (EUCRA, TRACE) will only be finalized in 2024. The EC has started addressing the gap between EU-wide assessment and that of individual countries through research, knowledge sharing, and capacity building.[218] The PESETA IV studies, for instance, have assessed the impacts of climate change and climate-induced hazards on different sectors based on different climate and socioeconomic projections and provided estimates of the costs and benefits of potential adaptation measures for some hazards, such as coastal flooding.[219] Costing assessments are challenging, however, and information and knowledge gaps remain. Among others, near-term EU-wide assessments of CCA investment needs are lacking and assessments also have incomplete coverage of sectors. There is also a lack of studies estimating CCA needs related to the disaster risk management sector, including the climate-proofing of critical infrastructure.[220] Such assessments would also be important in achieving the objectives of the Critical Entities Critical Entities Directive (2022/2557), and where relevant, the amended Network and Information Systems (NIS2) Directive (2022/2555).[221]

Countries are at different levels of adaptation planning and implementation, and only a few have developed cost estimates for CCA at the national level to inform strategies and policies.[222] In general, most national and sector studies focus on impact assessments and the economic costs of climate change rather than the costs (and benefits) of reducing these potential impacts and minimizing residual impacts—that is, climate adaptation costs (see Table 4 in Annex 1).

This reflects the much greater difficulty of estimating the costs and benefits of CCA than of mitigation. Mitigation addresses a common global burden (tons of CO_2), and mitigation measures can be assessed and compared directly across sectors and locations, using cost-effectiveness and marginal-abatement cost curves. In contrast, adaptation is a response to multiple site- and context-specific climate risks. These risks are dynamic; they change over time and are subject to a spectrum of projected climate impacts, both as a result of scenario differences (for example, between 2˚C and 4˚C pathways) and of differences between climate model outputs. Adaptation is also normally an extension of existing activities. It pursues multiple goals and tends to be mainstreamed into existing policies, programs, and plans rather than implemented as a new top-down objective and policy.[223] Adaptation assessments need, therefore, to be grounded in country and sector contexts. In addition, there is insufficient information on the effectiveness of adaptation options in reducing risks, and adaptation involves a broader mixture of technical and nontechnical options. This means analysis to support adaptation decisions typically uses extended BCA or methods that merge quantitative and qualitative rather than cost-effectiveness approaches, and adaptation is usually

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217 Detailed recent assessments exist on CCM but not for CCA. The most recent source is a 2017 Commission study on climate mainstreaming in the Multiannual Financial Framework (MFF), which refers to two previous incomplete and outdated studies that estimated CCA needs at €30 billion–€500 billion. The most recent PESETA IV and COACCH reports also give a broad idea of needs and net benefits but not of granular financial/economic costs (Forster, D. et al. 2017. *Climate Mainstreaming in the EU Budget: Preparing for the Next MFF: Final Report.* Link.; EC. 2021. JRC PESETA IV. Link.; COACCH. 2021. The Economic Cost of Climate Change in Europe: Report on Policy Results. Link.).

218 *EEA. 2022. Towards 'Just Resilience': Leaving No One Behind When Adapting to Climate Change*. Link; EEA 2020b.

219 Feyen et al. 2020.

220 Hallegatte, S. et al. 2019. Lifelines: *The Resilient Infrastructure Opportunity.* Link.

221 EU. 2022. Directive 2022/2557/EU. Link.; EU. 2022a. *Directive 2022/2555/EU.* Link.

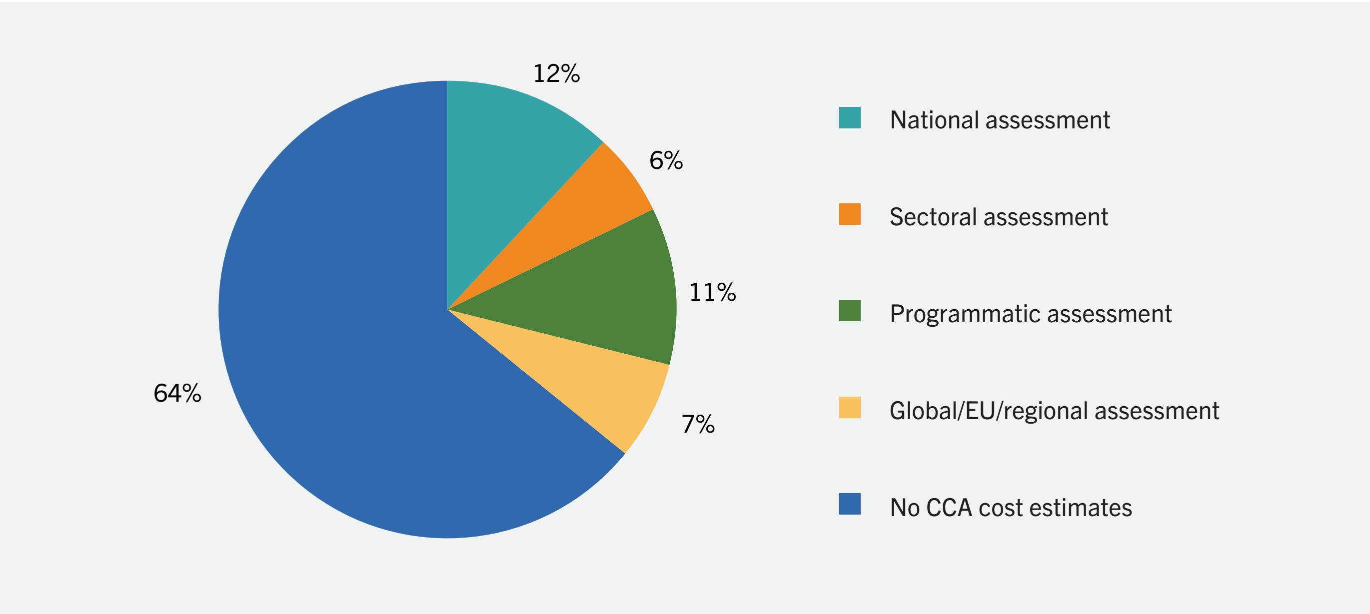
222 EEA. 2023a.

223 Watkiss et al. 2014a.

framed as a "process" of iterative adaptation over time.[224] Finally, limited access to information on public budgets and adaptation expenditures at the national and subnational levels complicates the task and leads to lengthy processes with substantial needs for consultation.[225]

A review of the literature reveals limited coverage of near-term CCA costs and indicates incomplete coverage of climate hazards and sectors. Of the more than 120 literature reports reviewed for this study, only about 30 (covering 17 European countries) have CCA cost estimates (see Figure 14 and Figure 15). The cost assessments can be categorized into three types—national planning, sectoral planning, and programmatic planning (also referred to as investment portfolio planning), which are described in detail in Chapter 4—and they cover a range of hazards, such as floods, wildfires, droughts, and extreme temperature and weather events. For national planning, most of the assessments consider multiple climate hazards, while those for sectoral and programmatic planning generally focus on adaptation costs and investment needs for one specific hazard. With respect to sectoral coverage, all of the national assessments reviewed cover multiple economic sectors, from three sectors in Austria[226] (top-down approach) to thirteen each in Germany[227] and Romania.[228] Some consider CCA costs for all sectors or the economy overall. As for sectoral planning, most assessments focus on adaptation in the agricultural, forestry, land, and DRM sectors, while common sectors for programmatic planning include agriculture, water, land management, and transportation. These tend to be more affected by climate change and climate-induced hazards and thus are more often covered in the assessments.

Figure 14. Total studies reviewed by type of assessment



Source: World Bank.

224 Dimitríjevics, A., B. Döhring, J. Varga, and J. in 't Veld. 2021. "Economic Impacts of Climate Change and Mitigation." *Quarterly Report on the Euro Area (QREA), Directorate General Economic and Financial Affairs (DG ECFIN)*, EC 20 (1): 23–38. Link.

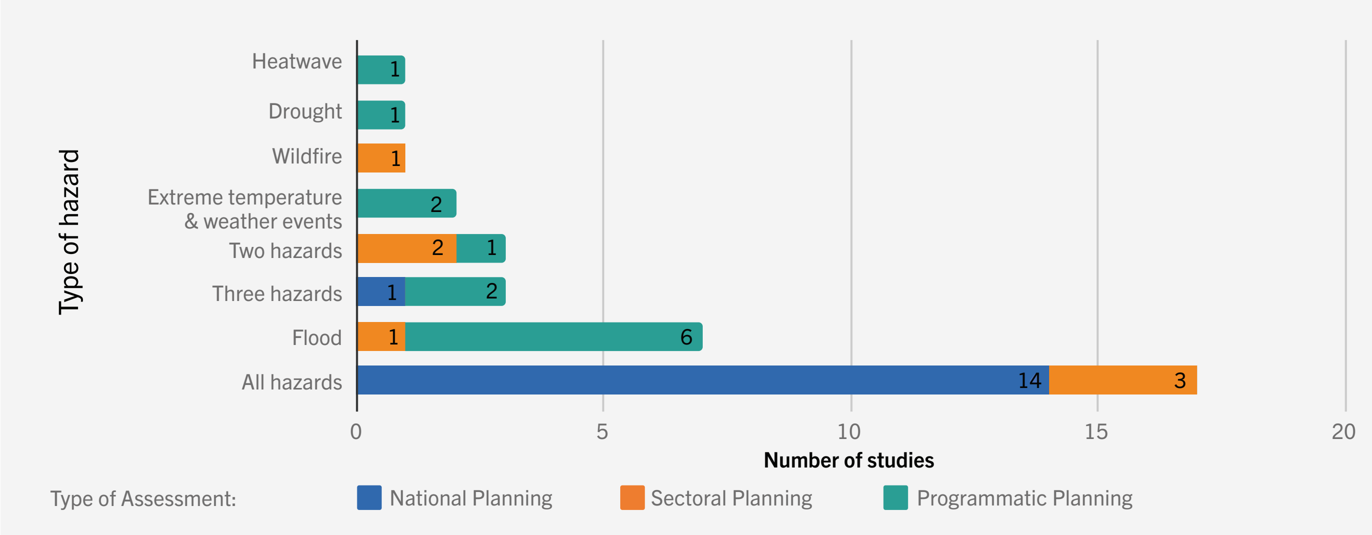
225 EEA 2023a.

226 Knittel et al. 2017.

227 Tröltzsch et al. 2012 and IÖW 2021.

228 Government of Romania. 2023. Draft National Action Plan for the implementation of the National Strategy on Adaptation to Climate Change for the period 2023-2030 (draft as of August 2023). Link. Expected approval in April-May 2024.

Figure 15. National-level studies reviewed by type of assessment and hazard



Source: World Bank. See Table 5 in Annex 1.

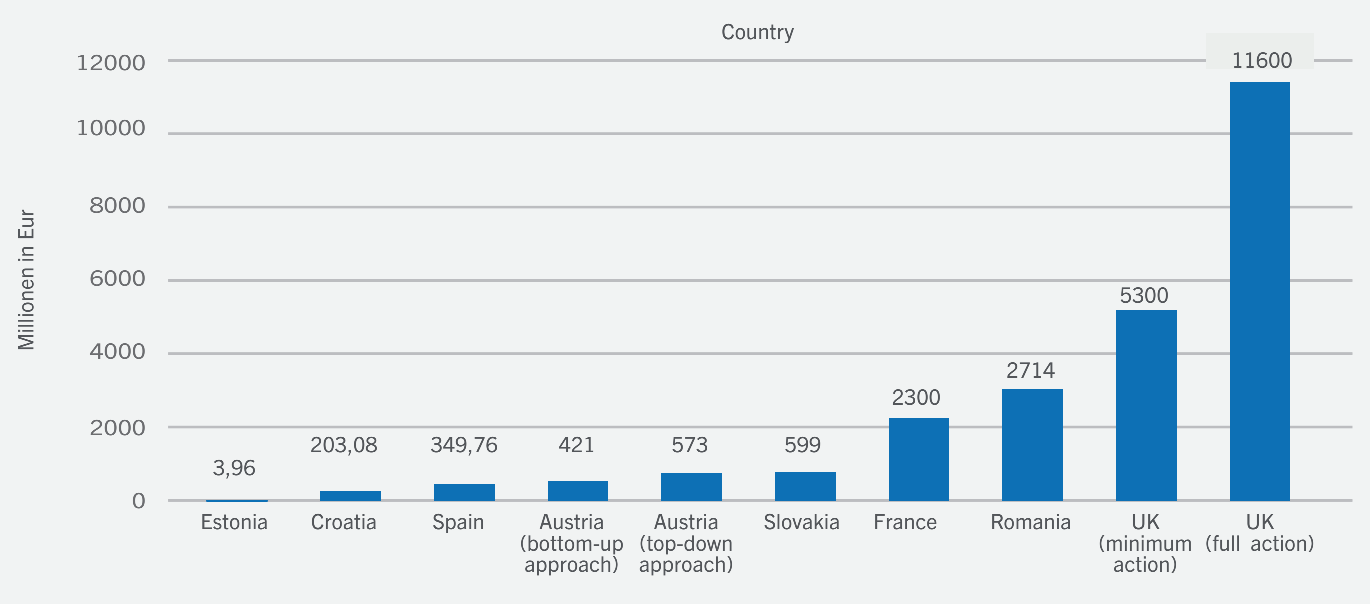
Existing estimates of CCA costs vary, and these ranges should be considered with caution, as the studies are not directly comparable. Some of the estimates, for example, represent short-term costs of adaptation for this decade, while others provide values up to the year 2100. When put into context, however, results of these studies can provide the potential range of investment needs for different adaptation measures, especially if the adaptation measures in the studies have the same implementation period (see Table 5 and Table 6 in Annex 1 for more details). Preliminary costs of CCA options for this decade in France,[229] for instance, are estimated at €2.3 billion per year for no-regret adaptation,[230] compared to an estimated €421 million–€573 million per year in Austria,[231] €2.7 billion per year in Romania,[232] and €3.96 million per year in Estonia also for this decade.[233] is It should be noted that the comparability of the cost estimates is also affected by studies' respective focus on the different types of adaptation options.[234] Nevertheless, results from existing analytics can still help highlight certain key points and provide insights for future analysis.

NATIONAL-LEVEL ESTIMATES

At the national level, assessments of CCA costs have been carried out in many European countries; most are near-term policy analyses of selected adaptation measures to inform national policy or budgetary decisions. A common theme for these studies is that they cover a wide range of sectors. Most cover five to ten sectors, while some cover thirteen or more sectors in the economy. The results reveal that, depending on the sectors and measures considered, the annual cost of adaptation could vary hugely across countries, ranging from €3.96 million to €11.6 billion.[235] Figure 16 and Figure 17 present the annual CCA costs and costs per person, respectively, determined by short-term policy-first national assessments.

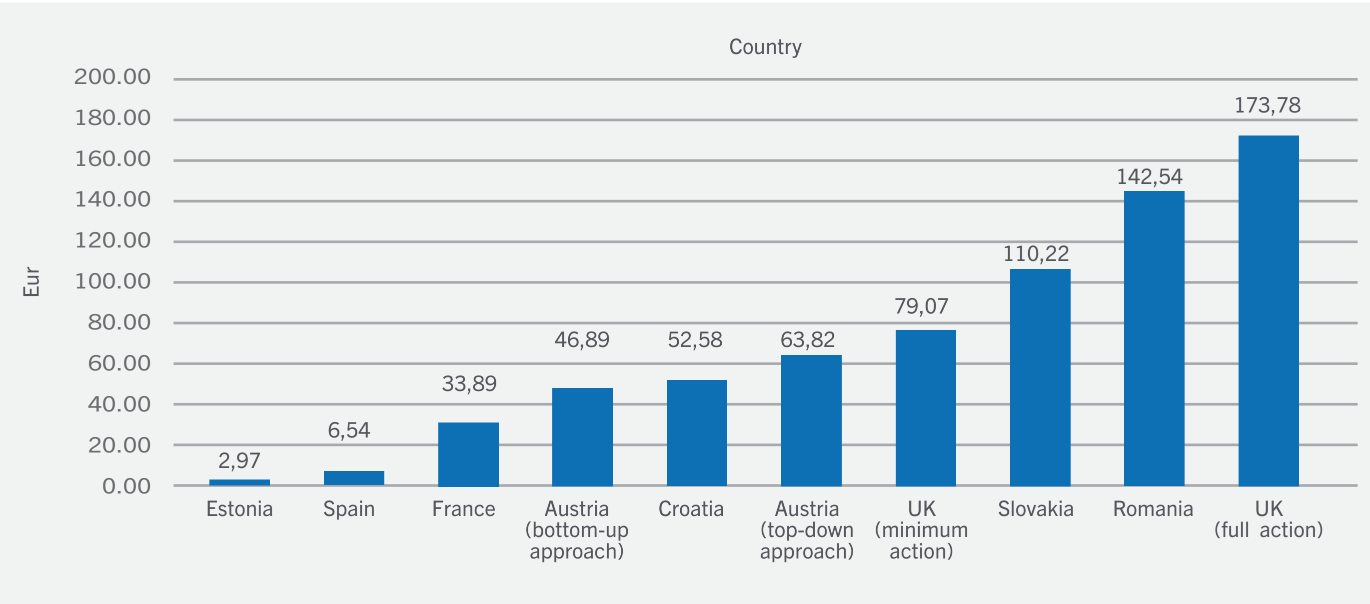
229 Estimates are adjusted to 2022 euros and in annual terms and thus may differ from original values in the literature, which can be found in Annex 1.
230 Depoues et al. 2022.
231 Knittel et al. 2017.
232 Government of Romania. 2023. Draft National Action Plan for the implementation of the National Strategy on Adaptation to Climate Change for the period 2023-2030 (draft as of August 2023). Link. Expected approval in April-May 2024.
233 Republic of Estonia, Ministry of Environment. 2017. Climate Change Adaptation Development Plan until 2030. Link.
234 The estimate for France, for example, considers only no-regret options, while that for Germany considers all types of adaptation measures.
235 Estimates are adjusted to 2022 euros and in annual terms and thus may differ from original values in the literature, which can be found in Annex 1.

Figure 16. Annual CCA costs from short-term policy-first national assessments



Source: World Bank. See Annex 1, Table 5 .
Note: CCA cost estimates differ from original unit values in Table 4 in Annex 1. Values in this figure are in 2022 euros. Bulgaria (Republic of Bulgaria 2019)[236] is not included in this figure, as the study provides CCA cost estimates per adaptation option and is thus not comparable with the other assessments, which estimate CCA costs at the national level in annual terms.

Figure 17. Annual CCA costs per capita from short-term policy-first national assessments



Source: World Bank. See Table 5 in Annex 1.
Note: CCA cost estimates differ from original unit values in Table 4 in Annex 1. Values are in 2022 euros and calculated in per capita terms by dividing each cost estimate by the country's population (data obtained from Eurostat Database).[237] Bulgaria (Republic of Bulgaria 2019)[238] is not included in this figure, as the study provides CCA cost estimates per adaptation option and is thus not comparable with the other assessments, which estimate national CCA costs at the national level in annual terms.

236 Republic of Bulgaria 2019.
237 EU, Eurostat Database. Link.
238 Republic of Bulgaria. 2019.

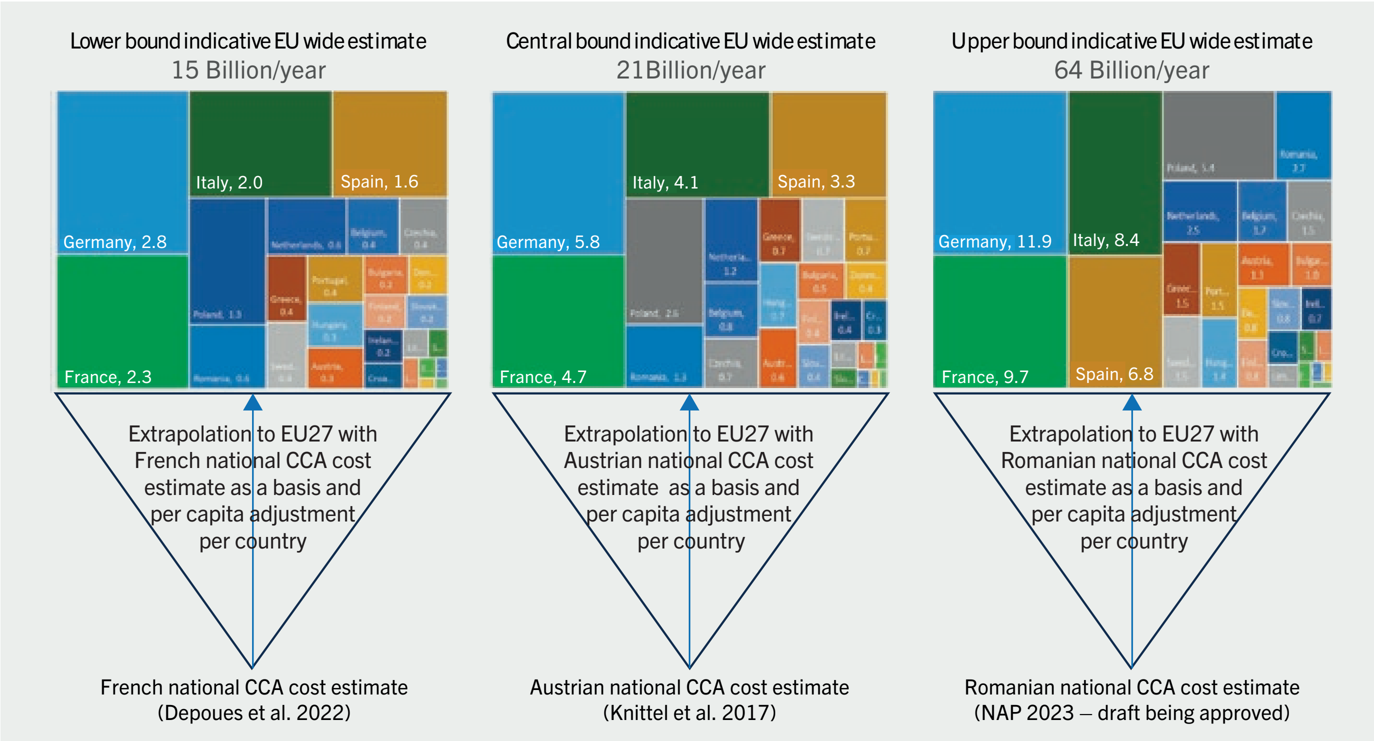
EXTRAPOLATING FROM COUNTRY EVIDENCE TO THE EUROPEAN LEVEL

Results from selected short-term policy-first assessments can be extrapolated to the European level. The ideal theoretical approach for extrapolation would be to replicate a similar type of study, with similar results per capita as those produced for different country contexts, but at European level. The theoretical ideal approach is not possible given lack of information. Also, costs of CCA will vary from country to country according to vulnerability, and the extrapolation of values based on certain countries may therefore underestimate the costs of adaptation in other countries more prone to climate risks. Despite the limitations, the analysis has aimed to showcase plausible benchmarks of the likely adaptation costs for this decade for the EU-27 that can serve as indicative estimates.

Accordingly, adaptation cost estimates for the EU-27, could range from €15 billion to €64 billion per year. This includes a "central" estimate of €21 billion, extrapolated on a per capita basis based on a study for Austria that yielded costs of adaptation in the median range of those found across existing studies for Europe. This equates to between 0.1 and 0.4 percent of the EU-27 GDP (Figure 18). These values are based on three recent country studies (for Austria, France, and Romania) that have focused on adaptation costs for this decade. The three case studies took different approaches, which were summarized in the section "Examples from Europe," above. The French study estimated the cost of adaptation to be at least €2.3 billion per year which focused on immediate no- and low-regret measures and included the costs of the processes and plans needed, as well as early technical options. In Austria, a bottom-up assessment estimated the costs of implementing 132 adaptation measures identified in 14 key areas of the Austrian National Adaptation strategy; they totaled €421 million per year.[239] Meanwhile, in Romania, a bottom-up assessment of measures included in the Action Plan for the implementation of the National Adaptation Strategy estimated that approximately € 2.7 billion per year would be expected to be allocated to CCA measures from 2023 to 2030.[240] Therefore, the studies respectively provide plausible lower, central/medium, and upper bounds of adaptation costs. These studies can be compared to a UK study, which indicated a plausible upper level of planned adaptation costs to tackle all risks this decade of about £10 billion (€11.6 billion) per year.

239 Knittel et al. 2017.
240 Government of Romania. 2023. Draft National Action Plan for the implementation of the National Strategy on Adaptation to Climate Change for the period 2023-2030 (draft as of August 2023). Link. Expected approval in April-May 2024.

Figure 18. Illustrative lower to upper bounds of annual CCA costs for the EU-27 until 2030



Source: Based on Depoues et al. 2022; Knittel et al. 2017; and Government of Romania 2023.
Note: EU-wide estimates are extrapolated from single-country estimates. The left panel of the figure presents a lower-bound estimate of annual CCA costs for the EU-27 (for no-regret adaptation only) for this decade, extrapolated on a per capita basis from the French study. The middle panel presents a central estimate of CCA costs per year for the EU-27 for this decade, extrapolated on a per capita basis from the Austrian PACINAS study. The right panel presents an upper-bound estimate of CCA costs per year for the EU-27 (for no-regret adaptation only) this for decade, extrapolated on a per capita basis from the draft Romanian National Climate, Change Adaptation Strategy and Action Plan dated August 2023[241]). These values do not take account of vulnerability or risks in scaling up from the national level and can only be considered indicative.

Another challenge to the comparability of results is the use by several studies of a long-term science perspective to assess the cost of adaptation at the national or EU level. Such assessments consider climate impacts in the far future (2100 and beyond) and reflect the significant needs for annual investment in adaptation that could occur in the light of future climate risks and impacts. The estimates vary greatly across studies, as they depend heavily on the choice of methodological approaches and key assumptions. Table 2 presents examples of CCA cost estimates from the long-term science studies reviewed.

241 Romania's draft National Strategy for Climate Change Adaptation and its Action Plan have been published for public consultation on the Ministry of Environment, Water and Forests' website in August 2023, as part of the official approval process. At the time of completion of the present report, the draft Strategy and Action Plan are in the process of being approved, based on the revisions following the consultations. Therefore, the numbers analyzed and presented in this report rely on the draft Strategy and Action Plan version from August 2023, which may eventually differ from the final version to be approved by the Government of Romania. Government of Romania. 2023. Draft Decision on the approval of the National Strategy on Adaptation to Climate Change for the period 2023-2030. Link.

Table 2. Annual CCA cost estimates from selected long-term science first assessments

COUNTRY	REFERENCE	ANNUAL CCA COST
EU-27	Jeuken et al. 2016	€27–47 billion
	EU 2017 based on De Bruin, Dellink, and Agrawala 2009	€158–518 billion from 2025 to 2185
Germany	Tröltzsch et al. 2012	€140–142 billion until 2100
Greece	Bank of Greece 2011	€310–750 million until 2100
	Government of Greece 2016	€12.3 billion until 2100

Source: References included above; more information on studies included in Table 5 and Table 6 in Annex 1.

SECTORAL-LEVEL ESTIMATES

For sectoral and programmatic planning (also referred to as investment portfolio planning), assessments generally focus on the impact of one specific hazard on sectors or assets and estimate the costs of the corresponding adaptation measures. Sectoral assessments are usually intended to help line ministries implement policies and investment plans or allocate national budget lines to their sectors, while the objective of programmatic assessments is to prioritize measures and investments within CCA programs or track program costs.[242] These two types of assessments cover many common sectors, such as agriculture, water, urban and land management, transportation, and DRM. For certain sectors, such as biodiversity and ecosystem services, studies assessing the costs of potential adaptation measures are still limited.

The results of these assessments suggest CCA costs vary greatly, depending on the sector covered, the project scope, and the types of adaptation options. Adaptation measures for river or coastal floods, for example, generally have high CCA costs, especially for physical protective infrastructure. For green measures, the costs tend to be much lower (see Table 3 for examples of estimates from flood assessments reviewed). Other aspects of adaptation, however, such as the cost-effectiveness of the measures, should also be considered when conducting programmatic assessments. For adaptation in the agricultural and health sectors, the costs tend to be modest, while those in the transportation sector vary greatly depending on the project scale, ranging from €519 million for a railway network electrification project in Latvia[243] to €2 billion for upgrading sections of a pan-European railway in Romania.[244] The review of existing assessments here presents the possible range of CCA costs for different sectors, although it should be noted that the estimates are not fully comparable because of the diverse scope and scales of the assessments.

242 This study focused mainly on major national and sectoral assessments most relevant to the analysis. A review of all sectoral assessments, flood risk management plans, national adaptation plans, and other hazard plans of all EU Member States (most of them usually only in local languages) is beyond the scope of this project.
243 EC. 2018. *Climate Change Adaptation of Major Infrastructure Projects.* Link.
244 EC. 2018.

Table 3. CCA Cost Estimates from selected assessments for floods

COUNTRY	REFERENCE	CCA COST
Spain	Scussolini et al. 2013	€210 million for grey measures and €0.03–10 million for soft measures
Czech Republic	Scussolini et al. 2013	€0.21 million to (mainly) €44.4 million, depending on the adaptation options
	Climate-ADAPT 2016	€145.9 million for grey measures
Denmark	EEA 2023a	€217 million for hybrid adaptation measures (green and grey infrastructure)
Poland	Climate-ADAPT 2018	€217 million for hybrid adaptation measures (green and grey infrastructure)

Source: World Bank. See Table 5 in Annex 1.

Chapter summary: Toward scaling up and improving CCA cost assessments

SUMMARY OF APPROACHES AND METHODS

The development of adaptation pathways for different levels of decision-making can set a broad strategic direction and can be supported by various tools, methods, and information. The framework for adaptation pathways will vary with the policy question, but a common principle is that the process starts with current risks and looks at future pathways, considering the diversity of projected scenarios for climate impacts, and encourages adaptive management and iterative learning. Climate risk analytics can then be used to provide information on future climate and in the application of such approaches as "decision-making under uncertainty" (DMUU). Evidence on costs and benefits of CCA measures can help inform these pathways, but they should be supplemented with considerations of the urgency of decisions and path dependency—that is, the effect of decisions or events on subsequent decisions and events.

Following broad principles, several approaches can be used across country contexts, sectors, and climate hazards. This chapter showed the flow of decisions needed to cost CCA measures according to different needs and objectives and the resources and information available. There is no single blueprint or approach for costing CCA, and the appropriate method depends on the specific objectives and the levels and types of assessment. Broadly, with adaptation pathways, analysis should begin by defining well the adaptation problem and adaptation objectives, rather than by focusing on climate models. For national policy, the focus should be more on understanding current and future adaptation costs and looking at the use of economics to improve policy implementation. For project investments, it should emphasize adaptation objectives and key performance indicators (KPIs) and the consideration of tools such as DMUU.

A review of the literature and of CCA costing across European countries provides many good examples and an overview of the costs found in different contexts. The range of the costs found can be explained by differences in framing objectives, definitions of adaptation, underlying assumptions, and methods. Presently, a shift is underway in the approach to CCA costing, and countries have already made adjustments in their adaptation studies. Policy-oriented studies focus more on soft adaptation interventions rather than hard infrastructure investments alone, as the former tend to cost less and be easier to adjust as information and data become available (as, for example, in Bulgaria and Romania). They also are beginning to consider the policy levers and enablers that are needed to deliver adaptation in practice (capacity, policy or standards, market-based instruments, and so on). For countries such as Austria, France, and Germany that are more advanced in terms of assessment, the reconciliation of findings of CCA costs in assessments and the consideration of governance and budgeting at the sectoral and local levels have been important.

RESEARCH GAPS AND OPPORTUNITIES FOR FURTHER STUDIES

The existing literature on CCA costs is unevenly distributed across sectors, hazards, and types of adaptation measures. Studies are often limited to a few sectors (such as agriculture and water) and hazards (such as floods and extreme heat), but, even for those, measures are rarely comprehensively costed.[245] For other vulnerable sectors, such as biodiversity and ecological services, or on questions such as how to adapt effectively to heat impacts on labor productivity and at urban scales, evidence on the cost of adaptation is still limited. Very few studies also exist that account for the compounding and cascading effects of climate change or consider the cross-cutting themes or cross-sectoral dialogue on CCA implementation, including how to prepare for and prevent wildfires and adapt forestry sectors. Moreover, existing cost assessments generally concentrate more on "hard" structural adaptation measures than on "soft" behavioral and policy measures, as their costs are easier to quantify.[246] For flood risk prevention and adaptation, for instance, more literature is available on assessing the costs of structural grey measures than nature-based solutions or capacity building. This imbalance may lead to biased, overestimated CCA costs and a neglect of soft measures that could yield high returns with relatively low implementation costs. At the same time, the impact of other hazards, such as heat and wildfires, on critical infrastructure and how this should be considered in building codes and retrofitting is seldom addressed. This report has aimed to fill in some of these gaps, particularly through case studies on certain "use cases" (Chapter 2), but many more studies are needed to ensure a comprehensive literature and evidence base that could truly support cross-learning.

This chapter could only touch upon how the results of cost studies should be updated over time and on important elements of planning and implementation, such as adaptation finance. When undertaking and updating a CCA cost assessment, it is important to identify the informational sources that explain the spectrum of projected climate impacts and the methodological assumptions that are crucial to decision-making. Well-founded cost assessment also requires an understanding of the extent to which plausible alternative assumptions or manifestations of uncertain variables can change the conclusions that are reached and assist policy-makers in making effective CCA investments. Moreover, improving quantitative estimates of social, cultural, and environmental co-benefits of adaptation is important for continued improvement of the evidence needed to shape effective packages of adaptation measures, including, for example, green-grey and soft and hard measures.

Finally, the key issue of who should bear the investment costs for CCA and investments has only been touched upon in this report, but it will be critical for future adaptation. To date, adaptation has been largely undertaken by the public sector; but, given the adaptation finance gap, the private sector and households will clearly need to contribute.

RECOMMENDATIONS GOING FORWARD

Given increasing awareness of the urgency to invest in certain CCA measures in Europe and the projected scale-up in adaptation costs, greater emphasis on costing assessments is a priority. A review of the literature has shown that the evidence base on CCA costing in Europe is still limited and has disproportionately comprised science-first, top-down studies. NAPs provide a foundation for more

245 OECD. 2008.
246 OECD. 2008.

detailed sectoral studies, incorporating pathway thinking and moving to investment planning until the 2030s, and a gradual scaling-up over time based on climate risk information and scenario analytics. Acknowledging adaptation as an ongoing process means moving beyond lists of technical options and employing a portfolio approach, blending technical and nontechnical solutions, and creating the enabling conditions for adaptation at the sector or national level. To set the response to short- and long-term challenges, this process must also be iterative and dynamic. Countries have to adapt to both climate stressors and shocks and "connect the dots" between disaster risk management and climate adaptation programs. In practice, this means breaking down the silos and encouraging cross-sectoral collaboration to create synergies and streamline efforts.

Across the EU, CCA costing processes have helped to raise awareness, initiate national dialogue, support decisions, and improve systems for monitoring and tracking progress on CCA. As most of the next two decades of climate change are already locked in, adaptation will need to be scaled up, irrespective of progress toward the Paris Agreement goals. This implies that expenditure on adaptation will have to increase (or more of other budget lines will have to be reallocated to it), and countries will need to develop costing analysis as the rising expenditure becomes a bigger issue for the public finances. Investing in studies will generate fiscal benefits by providing more and better analysis of how to prioritize adaptation and the trade-offs involved. Much can be learned from the Austrian and German examples in terms of developing methods and advice that enable Member States to fast-track costing assessments and build up the community of practice on these issues through, for example, ministries of finance, as well as climate focal points.

Moving ahead, countries need to start shifting away from studies to inform incremental adaptation to ones that will enable transformational adaptation. More strategic analysis of climate risks and climate programming needs to be encouraged at the country and thematic levels and, as highlighted in the EU Adaptation Mission, aligned with the IPCC, to deliver more transformative and transformational adaptation. This includes delivery at scale and doing different things as soft or hard limits to adaptation emerge. This remains a major gap in adaptation costing that is likely to be important going forward.

2. Expanding the Evidence Base on Costing CCA with "Use Cases": Results and Lessons learned

This chapter summarizes key lessons learned based on three "use cases": national planning, sectoral planning, and programmatic (also referred to as investment portfolio) planning. In addition to the review of existing examples described in Chapter 1, in-depth use case analytics were undertaken for Bulgaria, Croatia, Romania, Sweden, and the fictional Aurelia to illustrate CCA costing and derive lessons from practical applications. The chapter also summarizes the methodologies and approaches used in other countries, across Europe and beyond, and discusses the feasibility of comparing, scaling up, and replicating analytics for various country contexts. Finally, the timing and sequencing of CCA investments is discussed.

KEY TAKEAWAYS

- **National Adaptation Plans can provide a practical starting point for further estimation of CCA needs.** Generally, NAPs put forth an extensive list of adaptation measures with actions that are feasible with current or slightly higher national budgets (often no-regret or low-regret measures), along with actions requiring more funding. Where NAPs can provide a basis for more detailed studies that consider updated climate risks, extreme scenarios, cascading or multi-hazard impacts, and cross-sectoral synergies, CCA studies provide a basis for more specific costing of CCA measures within broader programs or investment portfolios. This includes the identification of synergies and potential trade-offs and the feasibility of measures with current or increased budgets, thereby informing prioritization among measures and over time. For Bulgaria, the average costs of adaptation for a subset of sectors and hazards were estimated at €7.01 billion (undiscounted) for a five-year period, while Romania's soon-to-be-approved National Adaptation Plan includes measures whose costs to 2030 amount to €19 billion in total and around €15 billion for six key sectors.
- **Measures considered in a particular adaptation portfolio can target key performance indicators relevant to that thematic area.** As outlined in the Bulgaria case study, such portfolios could, for example, encompass investments related to heat and health, heat and comfort and productivity, wildfire and emergency management, and wildfire and forestry. Structuring CCA measures in portfolios also results in more holistic and outcome-oriented cost estimation. The breadth of the measures within a given portfolio often calls for appropriate budget considerations and multi-agency coordination structures.

- **Within a portfolio, short-term, low-cost adaptation measures can be considered alongside resource-intensive, long-term capital investments.** A mixture of measures, including no-regret and climate-smart adaptation as well as early adaptation for future options can constitute a portfolio. Developing such a portfolio helps to create adaptation pathways and ensures that benefits of adaptation are delivered early on, while still allowing to invest in longer-term systematic changes. The scale-up of plans and early steps for longer-term investment also provide opportunity for learning, monitoring, and evaluation. This can happen by scaling up adaptation over time as risks evolve or getting better information before tackling expensive options, such as retrofitting. This process can help to improve future decisions and enables to undertake ongoing multi-decade investments). These portfolios often work well when they include a mixture of technical and nontechnical (hard and soft) options and of green and grey measures.
- **The adaptation measures developed as part of national and sectoral studies can be used as inputs for macroeconomic studies but only in a limited way.** The Romania case study illustrates how disasters in key sectors pose risks to the macroeconomy, affecting GDP, fiscal revenues, and overall fiscal balance, and examines the costs of adaptation for extreme events like heat waves, wildfires, floods, and droughts. The findings, largely based on literature reviews and expert consultations, provide only a reference range for adaptation costs, underscoring the need for more comprehensive, tailored sectoral analytics. Macroeconomic impacts are also underestimated when only single hazards are considered and the economic representation of impact channels and estimates is limited. The study highlights the challenges of incorporating adaptation effectively into macro models. Overreliance on high-level, stylized benefit-cost ratios and the preliminary nature of the macroeconomic impact assessments indicate a need for more comprehensive, tailored sectoral analytics. Enhancing macro models to consider extreme events and developing in-depth adaptation studies across sectors are crucial for a more accurate representation of damage and adaptation pathways.
- **Replicability and scalability of analysis at the national level are improving.** Methodologies for undertaking the costing of CCA at the national level exist and have been applied in a variety of contexts (Austria, Bulgaria, France, Germany, and Romania, among others), although the level of complexity and comprehensiveness of the CCA measures considered have differed. Once a costing framework for a measure is established, the potential for replicability and scalability is good, recognizing that each costing process will need to be adjusted for differences in climate, demographics, geography, prices, and other aspects of the country context.
- **Countries can balance both immediate and long-term adaptation strategies to tackle hazards and encourage more research on the costs and scalability of resilient forestry measures.** As the case studies for Bulgaria and Sweden show, CCA measures can reduce wildfire losses and yield substantial co-benefits, such as mitigation of greenhouse gas emissions, reduced loss to timber production, and enhanced ecological value. These measures can include capacity building and awareness campaigns, improved monitoring and surveillance, adaptive management, and climate-smart forestry. Involving all stakeholders, including private forest landowners, will be important to help increase community understanding and acceptance of these measures, especially as the measures may require trade-offs. More early preparation needs to be encouraged for new climate risks that a country may not yet have experienced. The Sweden case study identifies issues concerning new types of wildfire risks (for example, from peatlands) or compound risks to forests from multiple hazards, where early planning would be beneficial. For Sweden, the analysis focused on prioritizing and costing a set of early actions to address the rising risk of wildfires for the forestry sector, including potential no-regret options, interventions to address lock-in risk, and early adaptation pathway actions, all of which could be justified based on their net economic benefits. Importantly, opportunities are present for Member States to learn from each other's experiences.

- **CCA measures in the transportation sector can be designed to address systemic vulnerabilities in assets, networks, institutions, and planning.** As shown by the Romania case study, strengthening climate resilience in the transportation sector requires a concerted package of measures going beyond standard engineering upgrades. Governments, in partnership with key stakeholders, can define and implement a consistent strategy to overcome the many obstacles to more resilient transportation systems. A focus on the early stages of infrastructure system development—the design of regulations, the production of hazard data and master plans, and the initial stages of new infrastructure asset design—is particularly important. These investments can significantly improve the overall resilience of infrastructure systems and generate large benefits. As they generally help enhance governance and efficiency, these solutions are no-regret options regardless of climate change. For Romania, the estimated cost of climate-proofing the transportation sector for resilience to floods is between €123 million and €491 million.
- **Even if climate-proofing is not the main objective of a retrofitting program of a portfolio of buildings, simple CCA measures can support it without imposing additional major costs.** When planning for the prioritized upgrading of a portfolio of assets of which CCA is not necessarily the main or single objective, CCA costing analysis can be useful to gain a better understanding of possible no- or low-regret options for the design or retrofit, as showcased in the case studies for Croatia and (fictional) Aurelia. These measures can help infrastructure withstand average climate change impacts (for example, through increased energy efficiency and insulation or measures for indoor temperature regulation related to temperature increase) and support risk reduction (through fire safety standards or the allocation of equipment, electricity networks, and functions across buildings to mitigate flood risk). This kind of costing can inform smart prioritization and decision-making and help with the practical integration of the disaster and climate change agendas.

Overview of case studies

The purpose of this chapter is to present analyses of selected case studies to illustrate "use cases" for costing CCA from the perspective of policy- and decision-makers. The concept of use cases was developed in a DG CLIMA study from 2020 on adaptation modeling[247] and refers to a generalized application of adaptation in particular decision-making contexts. This report presents three use cases—national planning, sectoral planning, and programmatic planning—which were determined based on reviews of the literature and of methodology and on consultations. They are complemented by case studies to provide specific examples of the use of adaptation models to support decision-making that can serve as partial or full illustrations of the use cases. The use cases focus on the policy-first and hybrid approaches set out in the previous chapter, while the country case studies were selected based on six criteria:[248] (i) additionality and complementarity to existing and ongoing analytics; (ii) available data and information at national level; (iii) relevance to allow the application of methods in various contexts; (iv) relevance of climate-related hazards of focus in terms of expected risk and potential economic impacts (wildfires, heat, floods etc.); (v) level of interest in expected results and ability to collaborate in the study from relevant national stakeholders; and (vi) feedback from European Commission (EC) stakeholders (see also Annex 3).

The use cases for this report can be outlined in detail as follows:

247 EC. 2020. Study on Adaptation Modelling. Report on Use Cases and Rapid Analysis.

248 Only EU countries are considered in the process of case study selection, although examples from countries outside of the EU are included in the report as well as a part of literature review, including the United Kingdom and the United States, among others).

- *National planning* refers to CCA costing undertaken from a high-level perspective, generally oriented mostly toward national governments and particularly line ministries tasked with coordinating CCA efforts and ministries of finance. The process may begin from a public financial management or macroeconomic perspective and/or that of a National Adaptation Plan (NAP) or program. It is undertaken for key climate risks and at aggregated levels across sectors in a cross-cutting manner. This type of analysis is useful for estimating CCA costs at a national level and allows for a broad tracking of implementation and dedicated lines in national budgets. The results can also be used to inform green budgeting and achieve the EU's Green Deal objectives or national development priorities, including climate actions. The case studies that illustrate national planning in this report are of Bulgaria and Romania (new quantitative analysis) and Austria, France, Germany, and the United Kingdom (presentation of external results).

- *Sectoral planning* refers to CCA costing undertaken from a sectoral perspective, generally oriented mostly toward line ministries. Costing includes the analysis of certain climate risks using detailed biophysical models, looks at impacts of hazards, or takes "lighter-touch" approaches that compile existing information and work up adaptation costs. This type of analysis is useful for estimating how much the implementation of policies will cost and for investment planning by line ministries (such as health and transportation) and to inform implementation of CCA generally in detail. Line ministries can also use it in advocacy for allocation of national budget lines to their sectors. The case studies that illustrate sectoral planning in this report are of Romania and Sweden (new quantitative analysis) and Austria, Spain, and the United Kingdom (existing studies).

- *Programmatic planning* (also referred to as investment portfolio planning) refers to CCA costing undertaken from a programmatic perspective, generally oriented most toward implementing agencies. The process generally begins with hazard analytics applied to climate risks to specific assets and associated analysis of response measures, whether infrastructure measures (for example, flood protection) or soft measures (such as early warning systems). Detailed vulnerability analytics are usually considered. This type of costing analysis is generally useful for prioritizing measures and investments within programs, whether for a portfolio of investments or single investments, and can also be used to track costs of CCA programs. It is also useful for evaluating cost-effectiveness and for the cost-benefit analysis of programs ex ante and ex post. Civil protection agencies, for instance, can apply it to plan their budgets, produce detailed adaptation investment plans, and inform sectoral adaptation planning by line ministries (see above). This type of costing is also often used by implementing agencies at local or regional levels of government. The case studies that illustrate programmatic planning in this report are of Croatia, Romania, and the fictional Aurelia (new quantitative analysis) and Italy and the Netherlands (existing studies).

Based on a detailed review, various methodologies and approaches were selected for the analysis of the three use cases to identify options and provide different perspectives. To compare results and approaches within certain use cases, two countries or more were analyzed per use case, including the presentation of at least one new quantitative analysis conducted for this study. An overview of the methodologies and approaches used in this chapter is provided in Figure 7 in Annex 2. The methodologies used called for different levels of data and information (see Table 8 in Annex 2), with granular data and information required for climate risk analytics on the effects of extreme heat, wildfires, or floods to inform and prioritize adaptation measures.[249] Disaster losses under future climate were based on robust climate projections considering one or more global warming

249 Historical data on disaster occurrence and impacts were usually obtained from national institutes and/or the EU database or analytics, such as the PESETA study, EFFIS, JRC hazard risk assessments, and the Copernicus Climate Change Service, and from the existing literature.

scenarios. Results from risk assessments,[250] previous World Bank analytics, such as Country Climate and Development Reports (CCDRs), and modeling conducted by the CIMA Foundation were used, as well. All the data on historical and future hazard risks and impacts provided a solid basis for the CCA costing analysis in this report, which took various forms, including sector, program, project, and activity-based costing; investment and financial flow (IFF) analysis; decision support tools; and sector-integrated assessment and damage costs.

In terms of parameters used for economic analysis, the analysis generally followed EC guidelines. The social discount rate considered, for example, was usually 5 percent based on the guidelines,[251] and sensitivity analysis was performed for various rates. This sensitivity included other key parameters—for instance, whether to use shadow carbon prices from the Commission, or national carbon valuation prices or carbon taxes, or alternative valuation methods for key parameters, such as the value of a statistical life or the value of life lost with respect to changes in the risk of fatalities. The value of a statistical life (VSL) is a concept often used in benefit-cost analysis to estimate the monetary value of preventing the loss of a single human life. It represents the amount of money society is willing to spend to reduce the risk of fatality in various activities or situations. In the studies presented, a VSL of €6 million was used, based on a study by Viscusi and Masterson.[252] Lower-bound estimates for sensitivity analysis used a VSL of €2.24 million, based on a study by Banzhaf.[253] National carbon valuation prices or carbon taxes were used to assess the costs of carbon emission. Analyses for which the national prices were not applicable—such as the Sweden case study—used the shadow carbon price from the EC, which suggests a current price of €131/t CO2e and a 2045 price of 660/t CO2e, based on an EC technical guidance.[254]

National planning assessment of CCA costs

ADDED VALUE AND COMPARISON TO EXTERNAL NATIONAL ASSESSMENTS

The purpose of the national planning use case is to demonstrate a generalized application of costing methods for short-term policy-first adaptation assessments. The objective is to inform budgetary planning and prioritize national CCA needs. For this use case analysis, two new case studies were developed for Bulgaria and Romania and supplemented by lessons learned from existing external case studies on Austria, France, Germany, and the United Kingdom. CCA measures were costed with a focus on specific hazards and portfolios of adaptation measures in selected sectors. The new case studies provide a more and comprehensive estimate of the costs of adaptation in specific sectors and considering specific hazards and reveals that the CCA costs in some existing high-level assessments may have been underestimated.

250 WB and EC. 2024. *From Data to Decisions: Tools for Making Smart Investments in Prevention and Preparedness*.
251 EC. 2014. Guide to Cost-Benefit Analysis of Investment Projects for Cohesion Policy 2014-2020. ISBN 978-92-79- 34796-2. Link. "Reference is made to the Commission Guide, which explains the social discount rate. The guide recommends that for the social discount rate 5 percent is used for major projects in Cohesion countries and 3 percent for the other Member States. Whereas the guide refers to the period 2014-2020, it remains a useful reference for the period 2021-2027." EC. 2021. Commission Notice — Technical guidance on the climate proofing of infrastructure in the period 2021-2027. Link.
252 Viscusi and Masterman. 2017. *Income Elasticities and Global Values of Statistical Life.*
253 Banzhaf, S. 2022. *The Value of Statistical Life: A meta-Analysis of Meta Analyses*. Link.
254 European Commission. 2021. Technical guidance on the climate proofing of infrastructure in the period 2021-2027, 2021/C 373/01. Official Journal of the European Union. Link.

The use case analysis was built on a mixture of new and existing data and information. CCA measures to be analyzed were extracted from NAPs, as well as designed based on new climate risk and economic analysis undertaken here. For both Bulgaria and Romania, the disaster and climate risk information used was on wildfires and extreme heat. In Romania's case, additional analysis considered flood risk, with sectoral outcomes then examined to determine potential macroeconomic impacts with and without adaptation. The analysis used newly developed approaches and adapted methodologies already in use in other countries, such as Austria, France, Germany, Türkiye, and the United Kingdom.

Building upon previous studies, the two new case studies were developed in five steps:

- **Step 1:** Identifying adaptation objectives and options and categorizing adaptation measures (for example, no- and/or low-regret actions or actions for climate-smart or early adaptation) in a sectoral context, considering short- and medium-term horizons and including a review of the state of the art and state of practice of the considered measures with reference to their relevance, applicability, and ease of implementation
- **Step 2:** Baselining the "current" situation in terms of KPIs,[255] deriving the baseline situation from available data sources and additional analytics
- **Step 3:** Bundling the measures into thematic portfolios according to their effects on specific KPIs to improve their overall effectiveness
- **Step 4:** Demonstrating simple procedures to evaluate the benefit to the KPIs of the considered adaptation measures with respect to the baseline and, thereby, identify strategies for investing in adaptation
- **Step 5:** Developing a systematic process for costing adaptation measures, including benefit-cost analysis (BCA), with an approach to costing aims that was consistent, transparent, and repeatable to ensure the comparability of CCA measures to each other and across different time scales

NEW ASSESSMENTS AND LESSONS LEARNED

Bulgaria: Informing NAP updates with costs of measures for adapting to wildfires and extreme heat

Bulgaria is prone to multiple climate-related risks, many of which are projected to worsen with climate change. Bulgaria presently faces an increasingly disrupted future because of projected climate change, with its induced temperature increase and associated risks of wildfires, droughts, and heat waves.[256] The National Disaster Risk Profile adopted in 2023 provides a detailed assessment of 14 major disaster risks faced by the country. Analysis building on the risk profile predicts an increase of 50 percent in the number of heat-related deaths and hospitalizations over the next three decades. The National CCA Strategy 2019–2030 includes a very comprehensive analysis on the impact of climate change on nine essential economic sectors in Bulgaria. To complement this existing national material, further work was undertaken to provide further insights into the possible changes in climate risks related to heat and wildfires, based on EC studies, such as COACCH, and the new quantitative analytics performed under this project (see below for details).

Bulgaria has enhanced its strategic planning and related legislation in recent years. Based on its National Risk Assessment (NRA), the National DRM Plan outlines a set of policy measures for each hazard. The government of Bulgaria also developed a framework for CCA action as part of its National CCA

255 KPIs with respect to extreme heat, for example, could include vulnerability to heat exposure, heat-related mortality and morbidity, loss in productivity, energy consumption, water usage, and so on.

256 Council of Ministers. 2022. *National Disaster Risk Profile of Bulgaria: Technical Annex 7: Assessment of Extreme Heat Risk in Bulgaria*. Link.

Strategy and Action Plan for 2019–30.[257] The strategy provides and proposes a series of adaptation options for each sector, with a particular focus on no-regret and non-capital-intensive measures. The Action Plan provides an estimate of the expected cost of each measure; these estimates are, however, designed to serve as general guidelines and are mostly represented by a broad budget cost categorization of low (up to €1 million), medium (€1 million–€100 million), or high (€100 million or more).

Bulgaria has also accessed portions of the available funding opportunities under the EU 2021–27 funding cycle for climate adaptation and disaster risk management. The government has accessed funding through the Cohesion Policy's "greener, low carbon transition"[258] objective, amounting to €2.4 billion overall, with €225.6 million dedicated to CCA.[259] Under the Operational program (OP) Environment, aligned with its National Disaster Risk Management Plan, Bulgaria aims to improve prevention of extreme events, modernize DRM practices (floods, droughts, forest fires) and implement green measures and ecosystem-based solutions for flood prevention and protection.[260] Additionally, Bulgaria has the potential to utilize a portion of its allocated €7.7 billion for overall Common Agricultural Policy (CAP) funds to address climate-related challenges and has allocated a percentage of its National Recovery and Resilience Plan to climate objectives for 2022–25, focusing on agricultural and water management sectors.[261] Notable national investment programs include the €1 billion Energy Efficiency of Multi-Family Residential Buildings National Program 2015–24 and various isolated initiatives, such as the climate-proof retrofitting of health and public facilities.

The analysis undertaken in this study can inform the development of adaptation programs aligned with Bulgaria's current NAP as well as updates of the NAP in the medium term. The objective was to develop and cost a set of adaptation portfolios for a number of key risks to help inform the government in its steps toward the development and implementation of specific National Adaptation Plans and investments.

This analysis built on existing work undertaken at country level and on best practices from other countries. It considered CCA measures identified under Bulgaria's CCA Strategy and National DRM Plan, as well as other key strategic documents. As measures in these documents were broadly defined, this analysis derived more specific measures and identified additional measures to be considered based on the results from climate risk analytics (see Box 6). It also considered local and international best practice, as demonstrated for instance by the Sofia Municipality Sustainable Energy and Climate Action Plan 2021–30; the CCA and DRM action plans of other EU Member States; the extreme heat adaptation strategies for cities in Europe and worldwide; the academic literature; and other sources. The overall methodological approach was also inspired by analytics undertaken in Austria, France, the United Kingdom, and other countries, as well as the academic literature (more than 200 reports and papers were reviewed - see Annex 3 and technical unpublished background note available upon request).

257 Republic of Bulgaria. 2019. National Climate Change Adaptation Strategy and Action Plan. Link.

258 Intervention areas under this policy area include CCA measures for the prevention and management of climate-related risks: fires, storms, droughts, floods, landslides (including awareness raising, civil protection and DRM systems, infrastructure and ecosystem-based approaches) Also included are risk prevention and management of non-climate-related national risks, such as earthquakes, and risks from human activities, such as technological accidents. Overall, for CCA measures, €13.9 billion has been spent by the EU under these funds and €18.8 billion in total. EC. 2023a. Cohesion Data.Link.

259 EU. 2023a. Link.

260 EC. 2022. Partnership Agreement with Bulgaria – 2021-2027. Link.

261 Government of Bulgaria. 2020b. Recovery and Resilience Mechanism *[Механизъм за възстановяване и устойчивос]*. Link. *See* Government of Bulgaria. 2020a. NRRP for Bulgaria. Link.

BOX 6. DEEP DIVES INTO PROJECTED CLIMATE RISK FOR WILDFIRES AND EXTREME HEAT

The analysis for Bulgaria built on new analytics undertaken under this project for wildfire and heat risks and impacts. These complemented results from the NRA[262] by considering the influence of climate change on environmental variables and wildfire hazard, quantifying social vulnerability and coping capacity,[263] and evaluating the average annual losses from wildfires. Future wildfire risk and impacts were projected for various climate scenarios,[264] considering multiple climate models, for 2030s and 2050s horizons. On extreme heat, results from the academic literature and previous analytical efforts, such as the COACCH project,[265] heat wave data from the Copernicus Climate Change Service,[266] and new analytics that built on the National Disaster Risk Profile, were used to gain an understanding of the current and future effects of heat on human health and productivity. More generally, the analytics were used to ascertain the scale of investment needed to undertake selected relevant CCA measures. The analysis is relevant to EUCRA's "Prolonged Heat and Drought" storyline, as it shows the serious consequences of the urban heat island (UHI) effect and extreme heat waves and assesses the costs of selected CCA measures that can reduce heat-related health impacts, such as heat health action plans, heat early warning system (HEWSs), and urban greening.

Several findings on wildfire provide new and interesting insights into the changing risks Bulgaria will face with climate change. The assessment found wildfire susceptibility, as well as the overall wildfire hazard, generally expected to increase in the coming decades, with changes that will vary in different parts of the country in the types of fires expected. In numerous lowland locations, the risk is expected to rise (that is, the likelihood of occurrence of low-intensity surface fires could increase from low to medium). Regions with higher elevation and predominantly coniferous forests are also likely to see more fires. This is especially alarming in areas with large coniferous forests, where fires tend to spread rapidly, posing greater threats to human life, property, and the environment. Bulgaria's ratings on the Wildfire Social Risk Index which, apart from wildfire hazard, considers social factors and coping capacity, are given as high and extreme for numerous Bulgarian municipalities, predominantly in the mountainous regions in southern and southwestern Bulgaria and in the foothills of the Stara Planina mountain range in central Bulgaria. In terms of annual losses to assets and critical infrastructure as a result of wildfire, an overall increasing trend was projected for the next 25 years. The assessment of risk to roads also yielded increase in losses with large variability under different climate scenarios. Finally, while wildfire hazard is generally increasing, the number of potentially affected people is expected to remain constant or have small decreases, due to the projected reduction of the population.

The process sought to be consistent, transparent, and replicable and to serve as a blueprint for other national assessments. Both the impacts of selected adaptation measures on a set of KPIs and their costs were analyzed; Box 7 provides an example of the costing for a specific measure addressing heat (HEWS). In brief, the analysis followed a four-step approach:

262 More details can be found in the Annex.
263 Commercial, residential, industrial, health care, and education facility exposure data were shared by the Global Earthquake Model (GEM) Foundation. Publicly available regional data were ground-truthed and complemented by national datasets covering fire and police stations. The key vulnerability factors considered were age, gender, income level, and education and income levels at local level. They were determined were based on data from GEM, Global Human Settlement (GHS), the literature (Fekete, A. and Nehren, U. 2023. Assessment of social vulnerability to forest fire and hazardous facilities in Germany. Link.), the European Forest Fire Information System (EFFIS) dataset, Corinne Land Cover, Copernicus Climate Data Store climate data, and national datasets. The coping capacity indicators considered were derived from data on firefighting facilities, number of employees, accessibility, and prevention and preparedness activities based on national datasets.
264 RCPs 2.6 / SSP1, RCP 4.5 /SSP2 and RCP8.5 / SSP5.
265 COACCH. 2022. CO-designing the Assessment of Climate Change Costs. (including data repository). Link.
266 Hooyberghs, H., et al. 2019. Heat waves and cold spells in Europe derived from climate projections.

- **Step 1:** Selecting and screening CCA measures. Based upon specified parameters, a range of possible adaptation measures—which could be applied in isolation or as part of a suite—were considered, focusing on those related to extreme heat (specifically, related to human health, productivity, and comfort) and wildfire risks. These measures were defined by drawing upon existing national plans in the case study country—in this case, Bulgaria—and a review of global best-practice examples.

- **Step 2:** Creating portfolios of CCA measures, considering their impacts and benefits. A set of key performance indicators (KPIs) relevant to some of the considered risks (specifically, those addressing extreme heat) was defined to gain an understanding of the impact of the selected adaptation measures. Selection was based on indicators commonly used in the literature for the specific hazards, including indicators related to environmental, economic, policy, energy, and social impacts. These KPIs included, for example, heat-related mortality and morbidity and changes in labor productivity resulting from extreme heat. The CCA measures were then bundled into portfolios according to their effects on the selected KPIs. In the context of heat adaptation, for example, portfolios of measures were created that affected KPIs in two thematic areas: health; productivity and comfort. Each of the portfolios considered a mixture of adaptation types, including no-regret, climate-smart adaptation and early adaptation for future options, which together create different adaptation pathways.

- **Step 3:** Assessing the costs of the selected CCA measures. The measures were costed based on information determined from national reports and other literature sources. The costs were benchmarked and price-adjusted using comparable investments in EU countries and existing projects and programs in Bulgaria. Given the breadth of the CCA measures, the costing of each CCA measure had to follow a tailored cost estimation approach. Generally, three types of costs were considered, although not all were applicable to every measure: implementation costs, also known as development or set-up costs; annual operating or fixed costs; and annual costs related to extreme heat events. The last two considered future climate and demographic projections. Where appropriate—for example, in the context of adaptation measures for new and/or existing health care facilities—the marginal costs associated with specific adaptation strategies were considered. Two types of costs were included: a five-year outlook cost that was undiscounted and was intended for short-term budget planning; and a net present cost (NPC) for the period 2023–50, which used a 5 percent discount rate and was intended to gain an understanding of the overall scale on investment required in the medium term. It needs to be highlighted that this case study provided indicative, high-level national cost estimates predominantly based on the academic literature and previous project costs, adjusted to the Bulgarian context and prices. Where possible, data were gathered from Bulgarian institutions, but, in many cases, costs were taken from similar EU or global initiatives and from the literature.

- **Step 4:** Assessing the benefit of CCA measures. The impacts of the identified CCA measures and pathways could be evaluated—in isolation or in combination—through, for example, cost-benefit analysis or by computing the levels of risk reduction associated with the CCA measures. From the perspective of the risk analysis, it was necessary to attempt to quantify the spectrum of projected risk reduction impacts to gain a better understanding of the range of possible outcomes. For the Bulgaria case study, the particular CCA measures whose benefits were investigated included the impacts of the heat early warning system and national heat health action plan on mortality and morbidity.

Based on the research conducted, the average costs of adaptation for a subset of sectors and hazards in Bulgaria were estimated at €7.01 billion for a five-year period (undiscounted), with a net present cost for 2023–50 of €22.9 billion. The breakdown of costs for the various measures and their associated potential benefits are summarized in Annex 3, Tables 10-13.

BOX 7. COSTING OF A HEAT EARLY WARNING SYSTEM FOR BULGARIA

Estimation of the cost of a heat early warning system (HEWS) in Bulgaria took into account implementation costs, fixed operating costs, and additional costs associated with triggering the system during a heat wave. The costs were developed for 2023–50 (considering a 5 percent discount rate) and benchmarked using similar systems in other countries, including Belgium, France, Spain, and the United Kingdom. All prices were adjusted to 2022 Bulgarian prices (in euros) using Organisation for Economic Co-operation and Development (OECD) purchasing power parities and the OECD's harmonized index of consumer prices. The net present costs (NPCs) for implementation and operation (considering 2023–50 operation) were estimated at €0.17 million and €3.01 million, respectively, based on the costs of France's heat wave and health alert system and other costs estimated in the literature.[267] These included initial investment in system setup, as well as ongoing human resource costs, annual contract fees, and so on. The costs associated with annual heat wave events were calculated using data on the annual number of projected heat wave days for the period (under RCP 8.5)[268] and the estimated cost per heat wave day, which include emergency services and the maintenance of a phone line, dissemination campaigns, media announcements, programs that would provide extra care to vulnerable groups, and the time contributed by health professionals primarily involved in the care of local residents in their homes. The average number of heat wave days across Bulgaria was projected to increase from 9 in 2023 to 22 in 2050, and the NPCs of lower- and upper-bound variables associated with the events were estimated at €2 million and €6.72 million (average €4.1 million). Finally, the total cost of implementing, maintaining, and triggering a HEWS in Bulgaria for 2023–50 was estimated at €5.18 million–€9.9 million (average €7.28 million in present value terms), where the five-year outlook cost was €1.63 million–€2.81 million (average €2.15 million, undiscounted).

Overall, the following cost ranges were estimated for the respective portfolios of CCA measures:

- **Heat/health:** The portfolio comprised seven sub-packages of measures, all costed separately considering implementation and operating costs: (i) national heat health action plan (NHHAP); (ii) heat early warning system (HEWS); (iii) data collection system for heat-related illness and mortality; (iv) establishment of cooling centers; (v) design of new health care facilities for heat resilience; (vi) heat resilience improvements to existing health care facilities; and (vii) information campaigns and awareness raising.
    - Total five-year outlook: **€1.67 billion–€2.79 billion (average €2.23 billion)**
    - Total net present cost, 2023–50: **€4.2 billion–€7.67 billion (average €5.93 billion)**
- **Heat/productivity and comfort:** The portfolio comprised six sub-packages of measures: (i) labor force heat protection strategy; (ii) improved access to cooled public transportation; (iii) building standards for new development; (iv) building improvements to existing buildings; (v) urban heat island (UHI) strategy at city level; and (vi) urban greening and blue solutions. It should be noted that two of these sub-packages were costed for Bulgaria only in a simple manner (UHI strategy) or not fully costed (blue/green solutions) ; the ranges of costs for them, based on the literature, are provided later in this section. The ranges below were estimated for the four measures that were costed specifically for Bulgaria.
    - Five-year outlook: **€3.12 billion–€5.82 billion (average €4.47 billion)**
    - Net present cost, 2023–50: **€10.86 billion–€22.46 billion (average €16.66 billion)**

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267 Hunt, A. et al. 2017.

268 Based on the health-related EU-wide definition, based in turn on results of the EUROheat project (Michelozzi et al. 2007; WHO 2009). For the summer period of June to August, heat waves were defined as days in which the maximal apparent temperature (Tappmax) exceeded its threshold (90th percentile of Tappmax for each month) and the minimum temperature (Tmin) exceeded its threshold (90th percentile of Tmin for each month) for at least two days.

- **Wildfires (emergency management):** The portfolio comprised five sub-packages of measures, all costed separately: (i) strengthening of fire responders' capacity to cope with wildfires; (ii) creation of a team for airborne firefighting and purchase of the necessary specialized aircraft and other equipment; (iii) building of a national system for rapid fire detection and for response to fire and other natural calamities; (iv) education and public outreach activities; and (v) legal activities for improved fire risk management and responsibility.

- **Five-year outlook:** €247 million–€302 million (average €275 million)

- **Wildfires (forestry):** The portfolio comprised two sub-packages of measures: (i) improvement of the plans for protection of forest territories; and (ii) fire mitigation and risk reduction actions in forest and agricultural lands.

- **Five-year outlook:** €35.1 million–€42.9 million (average €39 million)

It should be noted that several CCA measures considered in the analysis are planned or ongoing. Large-scale investments in the climate-proofing of residential buildings, for example, are planned under Bulgaria's National Recovery and Resilience Plan. A wide range of ongoing investments includes the retrofitting of public buildings and the replacement of the public transportation fleet, as well as firefighting vehicles, as part of the EU's multi-annual financial framework.

Also of note is that, because of the scale of the required investment, nearly all of the costs (about 98 percent) for heat-related CCA measures would come from capital investments in infrastructure upgrade. Costs for extreme heat measures not related to infrastructure, such as HEWS, the NHHAP, information campaigns, the development of strategies, and so on, would amount to €34 million–€37.4 million (average €35.6 million) over the next five years, with net present costs for 2023–50 from €109.6 million to €121.1 million (average €115.1 million). While these costs would be an order of magnitude lower than capital investments, programs related to upgrade of infrastructure should begin as soon as possible because of their long implementation timelines and the large budget requirement. To optimize the investment process and minimize maladaptation, such programs should also have a level of built-in flexibility and opportunity for evaluation and adjustment.

The analysis also covered several no-regret options related to human health, including the implementation of heat early warning systems and strategies to protect the population, especially vulnerable people, against heat. One conclusion was that many of the early investments—for example, in HEWS and NHHAP—would have relatively low costs and deliver high benefits and, thus, would be no-regret. Such investments could build upon existing coordination mechanisms and existing infrastructure. In this and other cases, the importance of considering the marginal investment costs was highlighted from the perspective of development and the costing of CCA measures.

Climate-smart heat adaptation options with longer timeframes were mostly related to the upgrading of critical infrastructure and building stock by improving cooling systems. The largest costs associated with heat CCA adaptation were related to capital investments and upgrades to the built environment, including health care facilities, cooling centers, educational institutions, and the general building stock. Such investments require multi-decade planning with agreed-on targets for new building and retrofits, taking into account future changes in demographics and climate. Prioritization and planning are key, given the volume of the required work. The use of risk information and other prioritization factors, such as social vulnerability, becomes crucial in structuring these long-term programs. The long time frames and limiting factors around labor and resource availability and the limited capacity of the construction industry mean that investments in the built environment should begin in the short term. Furthermore, since the investment involved in infrastructure upgrade at a national level is continuous in nature, it is important that their progress be monitored, evaluated, and adjusted on an ongoing basis to avoid maladaptation. To maximize the co-benefits, the investments should be bundled to form part of a larger package for building upgrade and new build — for example, an energy efficiency or seismic retrofitting program.

In addition to maintaining emergency preparedness and well-equipped and highly trained firefighting crews, a variety of measures related to forestry and land use measures are necessary to mitigate wildfire risk. Appropriate planning at landscape level is essential and can be further enhanced by risk modeling. Such measures can help reduce the risk of fire initiation, growth, and spread. Communication of the wildfire risk, which is expected to continue increasing with climate change, is very important to promote fire-safe behavior among the general population.

In terms of labor force heat protection strategy, the productivity losses associated with limiting labor activity and having safety measures in place may be high, but they do not take into account the health benefits of having such a strategy in place. An important factor to consider is that most of the studies and literature on reduction of labor productivity do not quantify the associated health benefits and avoided health impacts. More research is needed to gain a better understanding not only of the costs but of the benefits of the labor strategy. Productivity losses can be mitigated by, for example, shifting labor hours, mechanizing outdoor labor, and/or upgrading cooling systems for indoor work.

With regard to green and blue solutions in urban areas to mitigate the UHI effect, the cost of adaptation has been explored, yet no quantitative estimates could be provided for Bulgaria at the current stage because of a lack of specific, quantitative information on UHI effects across Bulgarian municipalities and costs of implementing urban CCA measures. Based on existing studies,[269] the total cost of developing city-level UHI strategies and supporting documents for one hundred urban areas with populations greater than approximately 8,000 were estimated at €1.26 million. This amount did not include the cost of UHI strategy implementation, which varies depending on the specific urban landscape, environmental factors, and population, and more country-specific data are needed to provide a more robust cost estimate for the country. Ideally, UHI strategies and reports should include a proposed list of costed investments to mitigate UHI, including green, blue, and white measures. Below is a summary of cost ranges for selected greening and blue solutions in Europe from the literature:[270]

- **Green solutions (green roofs):** Implementation cost €40–€310 per square meter; annual maintenance cost €1.20–€7.80 per square meter
- **Green solutions (gardens and urban parks):** Implementation cost €135–€850 per square meter; annual maintenance cost €3.40–€21.30 per square meter
- **Green solutions (street trees):** Implementation cost €76.92–€125 per square meter; annual maintenance cost around €0.77–€3.10 per square meter
- **Blue solution (ponds and lakes):** Implementation cost €19.71–€554.73 per square meter; annual maintenance costs €277–€2,640 per basin
- **Blue solutions (rain gardens):** Implementation cost €49–€80 per square meter; annual maintenance costs €0.06–€2 per square meter

Note, however, that the literature suggests the implementation costs of urban greening and blue adaptation measures, such as installing green roofs, planting trees, and creating ponds and rain gardens, and the cost to maintain them are highly location-specific and differ greatly across cities. This means such costs cannot be easily extrapolated for Bulgaria

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269 Gkatzioura, P. and Perakis, K. 2022. Analysis of Urban Heat Island (UHI) Through Climate Engine and Arcgis Pro in Different Cities of Bulgaria. Link.; Dimitrov, S. et al. 2021. "An Application of the LCZ Approach in Surface Urban Heat Island Mapping in Sofia, Bulgaria" Link.; Arabadzhieva, G. Urban Climate Adaptation in Bulgaria. Wageningen University & Research Centre. Link.

270 The cost ranges in the summary showcase only the unit implementation and annual maintenance costs of common green and blue adaptation measures in Europe. They do not cover all the costs reviewed, as many of the estimates in the literature represent only the total cost and, thus, are not comparable to the unit costs. In addition, the cost ranges here only cover European countries, though global studies were reviewed as well.

from the existing literature on other European countries.

Consideration of a spectrum of projected climate impacts is central to understanding and gauging confidence in the outputs of the assessment. During the analysis, two main types of sources leading to a range of possible outcomes were determined: uncertainty related to costs, and the spectrum of projected climate impacts related to climate modeling and, thus, risks and benefits. In terms of benefit estimation, the ranges of outputs from climate modeling played a significant role and resulted in large variations. At the same time, in estimation of investment needs, the costs were less sensitive to the ranges of outputs estimated in the climate modeling and more sensitive to ranges of possible other factors affecting costs (including implementation and operating costs). In short, the ranges estimated for costs that depended on events occurring, such as the costs of measures incurred during a wildfire or a heat wave, represent only a fraction of the overall investment in CCA measures.

The methodology developed for the Bulgaria case study, centered on heat and wildfire risk, demonstrates a good potential for transferability to other contexts. Both the methodology and the analysis performed are scalable to other countries, although this will require the inclusion of site- and context-specific considerations. The analysis requires an audit of current and projected initiatives, agreement on infrastructure lifespan, and attrition/augmentation rates for capital stocks (that is, the percentage of facilities to be retired from use and/or upgraded over the considered time horizon). Critical to the analysis and the development of strategies are considerations around market and sector capacity, supply chain issues, and climate projections. Furthermore, governing bodies must provide appropriate design standards, guidance documents, and planning regulations that demonstrate cognizance of the needs associated with a changing climate. The transfer also requires skills, expertise, and resources to replicate the analysis, as well as access to sufficient relevant data (see below)—in other words, this is not a simple copy and paste to another context.

While this case study offers insights into several climate risks in Bulgaria and proposes several adaptation portfolios, the cost estimates are limited in some ways. The indicative, high-level national cost estimates it provides are predominantly based on the literature and on previous project costs, adjusted to the Bulgarian context and prices. Where possible, data on costs were gathered from Bulgarian institutions, but, in many cases, they had to come from similar EU or global initiatives or literature. An important finding of the analysis was that the costing exercise is extremely data intensive, particularly at a local level, and that much of the required data are missing or fragmented. When undertaking such an assessment, therefore, it is recommended to consider available data sources and data collection strategies at the outset.

To summarize, this study presents the costs of adaptation measures needed at the national level in Bulgaria for selected hazards and sectors based on a portfolio-oriented approach. The estimated cost of adaptation for wildfire and heat waves is €7.01 billion for a five-year period, with most coming from capital investment into the upgrading of critical infrastructure and the built environment. This equates to an annual CCA cost of €1.4 billion per year. The estimate is relatively high compared to those from short-term, policy-first national assessments from the literature,[271] especially given that the case study considered only two types of hazards and four portfolio themes. If the cost were expressed in per capita terms, the annual investment needs for adaptation would amount to €205 per capita,[272] which is greater than the estimates from all existing studies. The higher costs reflect capital-intensive projects, such as the climate proofing of residential buildings. The analysis of CCA measures has only considered costs (for some options); it has not undertaken a cost-benefit analysis or a full options appraisal—and it may be that such options are not economically efficient. Some CCA

271 See "*Current evidence at EU level on CCA costs ranges*" in Chapter 1.
272 Based on 2022 Bulgaria population obtained from Eurostat database.

costs for the built environment may be underestimated and suggests the importance of countries' carrying out comprehensive national assessments in a contextualized manner, based on hazard-specific risk assessments and careful selection of adaptation portfolios.

Moving forward, countries could conduct portfolio-oriented analysis of national adaptation planning for heat and wildfire. Measures considered for a particular adaptation portfolio should be oriented to a set of KPIs of relevance to the thematic area, which might include heat and health, heat and comfort and productivity, wildfire and emergency management, or wildfire and forestry. Structuring CCA measures in portfolios also results in more holistic and outcome-oriented cost estimation. Given the breadth of the measures within a given portfolio, appropriate budget considerations and multiagency coordination structures could be put into place.

Within a portfolio, short-term, low-cost adaptation measures can be considered alongside resource-intensive, long-term capital investments. Such a mixture of measures, which include no-regret and climate-smart adaptation and early adaptation for future options, creates adaptation pathways and ensures that some benefits of adaptation are captured early on, while still investing in longer-term systematic changes to the built and natural environments. Early planning and the start of large capital investment also provides the opportunity for monitoring, evaluation, and optimization of ongoing multi-decade investments, such as improvement of heat resilience in existing health care facilities and the general building stock.

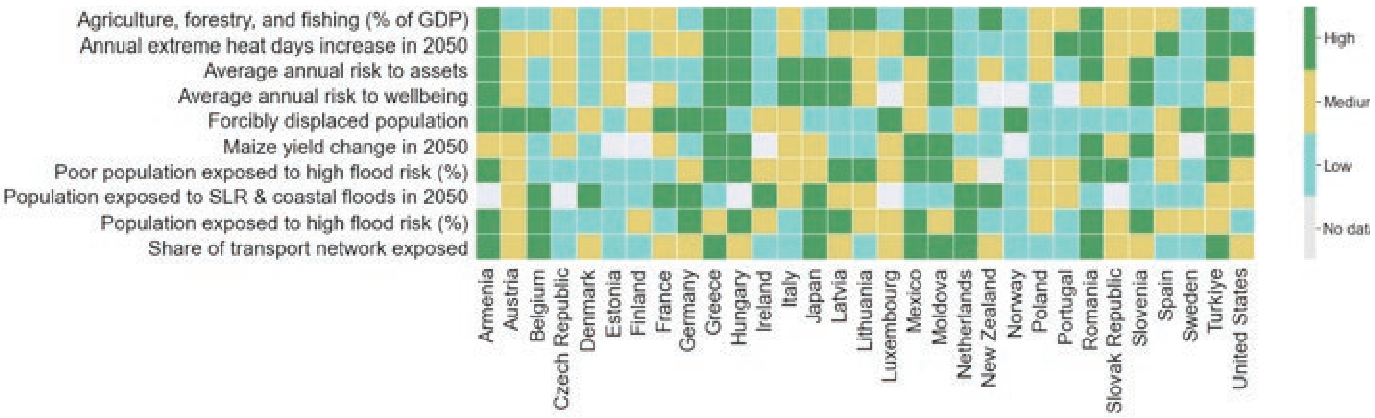
Romania: Improving the evidence base for macroeconomic analytics and NAP measures

Romania confronts significant vulnerabilities to climatic threats, including floods, droughts, and extreme heat events. These challenges have historically caused extensive socioeconomic damage: since the 1980s, climatological and hydro-meteorological events have caused economic loss amounting to €12 billion and almost 1,322 fatalities; river floods alone have affected more than 368,000 people.[273] Romania has high vulnerability in at least 7 out of 10 climate vulnerability dimensions relative to other EU and OECD countries, for which the median values are, respectively, 2 out of 10 and 4 out of 10 (see figure 19).[274] The recent wildfire crisis also highlighted the nation's susceptibility, both by its estimated €1.5 billion in financial costs and by the CO_2 emissions produced. The 2022 event was ten times as destructive as the average of the previous 15 years.[275]

Projections suggest impacts will intensify as a result of climate change. By the 2080s, Romania could witness a significant escalation in damage from extreme climatic events, potentially increasing sixfold,[276] along with substantial macroeconomic impacts from the combined effects of multiple hazards in multiple sectors (see Figure 19 and Figure 20, and for more details Figure 25 in Annex 3). Particularly concerning is an anticipated surge in the frequency and intensity of heat waves, exacerbated by urban heat island effects.[277] These climatic hazards are compounded by others, including earthquakes; Romania is one of the three EU countries with the highest seismic risk.[278]

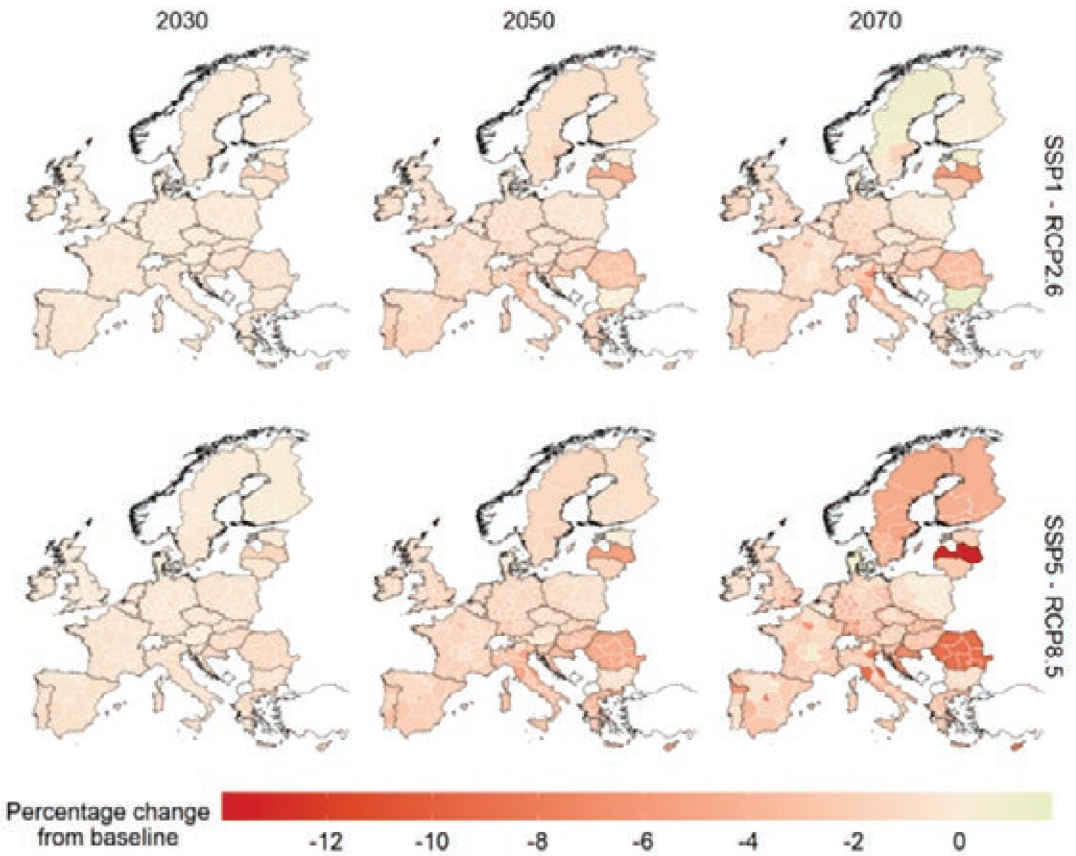
273 MunichRe. 2023. Data on natural disasters since 1980. MunichRe NatCat database. Link.
274 Due to lack of data, these figures are preliminary and not meant to provide a full overview of economic impacts.
275 City Monitor. 2022. The cost of Europe's summer of wildfires. Link.; based on EFFIS data.
276 IPCC. 2021. Link.; Climatic events included floods, droughts, fires, landslides, epidemics, and zoonoses (infectious diseases that are transmissible between humans and animals).
277 WB. 2023. Romania CCDR. Link.
278 WB and EC. 2021a.

Figure 19. Climate risk and vulnerability in Romania compared to EU and OECD countries



Source: World Bank staff calculations, based on data from Climate Impact Explorer; Kulp and Strauss 2019; Rentschler et al 2022; UNISDR 2015; World Development Indicators; and the World Bank Climate Change Knowledge Portal. The presented indicators are a selection of drivers of risk in OECD countries. Countries are rated using a benchmark approach: those rated at high risk (red) are in the top third, medium risk (yellow) are in the middle third, and low risk (blue) are in the lowest third.

Figure 20. Projected compounded macroeconomic impact of climate change in Romania



Compounded climate change impact on EU GDP impacts by region in years 2030, 2050 and 2070. Medim impact case. SSP1-RCP2.6 scenario combination upper panel and SSP5-RCP8.5 scenario combination lower panel. Values in percentage change from the baseline.

Source: COACCH. 2020. Bosello et al. 2020. D2.7. Macroeconomic, spatially-resolved impact assessment. Deliverable of the H2020 COACCH project. Link.

Recognizing these challenges, Romania has fortified its strategic planning and legislation with regard to climate change. Following robust awareness campaigns on the EU Mission on Adaptation to Climate Change, ten Romanian Administrative-Territorial Units (ATUs) have championed local adaptation projects, underlining the importance of grassroots resilience planning. Alongside these efforts are Romania's National Strategy for Climate Change Adaptation (2023–30) and linked action plan[279] , which promise synergy with EU climate objectives and significant financial commitments.

Implementation-wise, Romania is demonstrating fiscal dedication to climate resilience. The NAP estimates that approximately €19 billion would be expected to be allocated to 13 key sectors, with €15 billion earmarked for CCA initiatives across a total of six key sectors[280] for 2023–30. Additionally, the government approved Flood Risk Management Plans for 2023–27, with an estimated cost of €2.4 billion,[281] to be funded primarily by European funds (76.8 percent), national government funds (12.5 percent), and the national administration "Romanian Waters" (5.8 percent).[282] The Ministry of Finance incorporates climate risks into its financial planning, drafting annual priority investment lists and developing a green budgeting framework. Challenges remain, however, such as inconsistent disaster risk reporting and fragmented data management. Local governments often depend on intergovernmental transfers for disaster response, potentially incurring budget adjustments for unexpected disasters.[283]

For 2021–27, Romania has been utilizing EU funding for climate adaptation. The EU contribution to Romania under Policy Objective 2 (PO2)—"greener, low carbon transitioning towards a net zero carbon economy"—of the Cohesion Policy amounts to €7.9 billion of an overall €10.1 billion. Total CCA-specific funding from the EU under PO2 amounts to €557.1 million, with an overall amount of €665.5 million.[284] Romania has devoted 41 percent of its NRRP to climate objectives, allocating €1.4 billion to projects dedicated to climate adaptation for the period 2021–26.[285] The NRRP also includes the rehabilitation of existing defense lines, in accordance with the EU Floods Directive and the National Strategy for Flood Risk Management.[286]

This analysis can serve as inspiration for further adaptation studies and the development of adaptation programs aligned with the current NAP, as well as for updates of the NAP in the medium term. The objective in conducting it was to inform the costing of selected adaptation measures to feed into macroeconomic analytics, sectoral strategies, and national plans.

The analysis built on existing work undertaken at country level, complementing it with targeted analytics. A review of CCA measures identified under Romania's NAP and Country Climate and Development Report (CCDR)[287] was based on updated risk analytics (see Box 8) and examples from

279 Awaiting Government approval as of February 2024.

280 As per the draft National Action Plan for the implementation of the National Strategy on Adaptation to Climate Change for the period 2023-2030 – version as of August 2023. The strategy has been revised based on public consultation and it is expected to be approved in April-May 2024. These are estimates based on the CCA measures in 6 selected sectors in Romania (water resources, forestry, localities/urban systems, agriculture, energy and transport). In addition, the NAP also covers 7 other sectors: (1) biodiversity and ecosystem services, (2) population, public health and air quality, (3) education, awareness, research, innovation and digitalization, (4) cultural heritage, (5) tourism and leisure, (6) industry, and (7) insurance as a CCA instrument, which have not been covered in these preliminary calculations.

281 Excluding operation-maintenance costs.

282 Based on the Supporting note for the Government Decision on the updating the Flood risk management plans related to the 11 River Basin Administrations and the Danube River in Romania, approved by Government Decision nr. 972/2016. Link.

283 WB and EC. Forthcoming. *EDPP2 - Component 3 - Bringing National and Regional Finance to Scale*.

284 EU. 2023a. Link.

285 WB. 2023. Romania CCDR.

286 EC. NRRP for Romania. Link. Government of Romania. Green light from the EC for the NRRP (PNRR). Link.

287 The strategy has been revised based on public consultation and it is expected to be approved in April-May 2024.; WB. 2023. Country Climate and Development Report (CCDR) for Romania. Link.

other countries. The overall methodological approach was inspired by analytics undertaken in Austria,[288] Germany,[289] and Spain[290] under World Bank CCDRs such as the Türkiye,[291] the academic literature,[292] and other case studies in this report, such as those for Bulgaria and Sweden.

BOX 8. DEEP DIVES INTO CLIMATE RISK PROJECTIONS FOR WILDFIRE AND EXTREME HEAT

The analysis for Romania built on the new risk and impact analytics developed for this project for wildfire and heat. The methodology and approach utilized were the same as for the Bulgaria case study. For extreme heat, however, only the impacts on productivity (as reported by the COACCH project) were considered, not the impacts on human health. Information was obtained from external studies on floods[293] (for national cross-infrastructure impacts), the National Risk Assessment (RO-RISK) from 2018, and COACCH and from new analytics on droughts[294] and the impacts of floods on transportation infrastructure. Additional new information on heat waves and drought was produced after the NAP draft was finalized. The risk analytics helped illuminate the scale of investment and inform some potential follow-on CCA measures, building on the NAP priorities. The methodological approach aligned with EUCRA's "prolonged heat and drought" storyline by showcasing the compounding effects of wildfire and extreme heat that cascade across sectors, including both the direct losses inflicted during a disaster and the longer-term impacts, such as effects on productivity. The approach was also in line with EUCRA's message to enhance adaptation and resilience to heat waves, wildfires, and droughts in key sectors, such as the urban, water, and agricultural sectors, by focusing on the costs of adaptation measures in them.

Romania's National Strategy for CCA and corresponding Action Plan were developed through RO-ADAPT, the country's climate change adaptation platform. An innovative tool that supports the updating of the regulatory framework relevant to CCA based on the latest available information, RO-ADAPT made possible the development of forecasts and scenarios concerning the impacts of and adaptation to climate change, as well as the setting of medium- and long-term adaptation objectives for the strategy. The RO-ADAPT platform[295] was developed as part of an EU-funded project and implemented by several ministries and agencies to improve climate change policies and CCA by consolidating institutional capacity.[296] The project's objective was to contribute to knowledge on the impacts of climate change, accelerate CCA actions, and help enhance global resilience to climate change effects.

Several findings on wildfire provide new and interesting insights into the changing risks Romania will face with climate change.[297] In the future, a hotter and drier climate will lead to increased wildfire susceptibility and risks, especially in the southern, southeastern, and western parts of the country. The average annual loss (AAL) from wildfire in Romania in the 2030s and 2050s under different climate scenarios (SSP1 RCP2.6, SSP2 RCP4.5, and SSP5 RCP8.5) will rise significantly, from around €1.37 million currently to around €15 million in 2050 under all three climate scenarios. In addition, assessment of the impact of wildfires on different types of buildings revealed the greatest AAL for residential structures, estimated at €7.59 million in 2050 under the SSP5 RCP8.5 scenario, followed by education and health care facilities, at €2.8 million and €2.1 million, respectively. Under the same climate scenario, a general decreasing trend was found in the numbers of people exposed to and affected by wildfire risk, considering future population density. For roads and transportation networks, the losses were characterized by oscillating trends for both SSP1 RCP2.6 and SSP5 RCP8.5 scenarios.

288 Knittel, N. et al. 2017. The Costs of Climate Change Adaptation for the Austrian Federal Budget. PACINAS Working Paper #04. Link.; Van der Wijst, K. et al. 2021. Link.
289 Tröltzsch, J. et al. 2012. Link; IÖW. 2021. Link.
290 Scussolini, P. et al. 2013. Link.
291 The strategy has been revised based on public consultation and it is expected to be approved in April-May 2024.; WB. 2022c. Türkiye Country Climate and Development Report. Link.
292 COACCH. 2021.; EC. 2018. Climate change adaptation of major infrastructure projects. Link.
293 Underlying data on flood impacts that informed WB and EC. 2021b. Financial risk and opportunities to build resilience in Europe.
294 IIASA. 2024 (upcoming). Romania drought impact assessment – deep dive report.
295 Government of Romania. 2023. RO-ADAPT. Romanian National Meteorological Administration.
296 The Ministry of Environment, Water and Forests (MEWF) in partnership with the Environmental Protection Agency, the National Environmental Guard, the National Agency for Protected Natural Areas and the University of Bucharest (UB) and a consortium led by the National Meteorological Administration.
297 The CIMA Foundation. 2023. Wildfire risk analytics for European Countries.

With regard to drought, a comprehensive analysis of risk across various systems and regions accounted for the complex interplay among hazard, exposure, and vulnerability factors.[298] It found agriculture to be the sector most affected, with 18 different crops significantly affected and the AAL of crop yield projected to increase two- to fourfold in the future, reaching up to 18 percent. For energy production, the projected AAL from drought varied from 2 to 10 percent (average 6.3 percent), with the energy production potential of the Romanian local rivers worse affected than the Danube. In the water sector, Romania's water supply at present was found to be only mildly affected by drought, but the country's inland water transportation losses were projected to increase from 1.4 percent to 3.25 percent by the 2100s. Droughts also will have varying impacts on Romania's terrestrial and freshwater ecosystems, with increase in AAL mainly in the southern and southeastern river basins for wetlands and the eastern basins for forests.

The analysis also helps fill crucial gaps in information about adaptation in Romania that have been identified in strategic documents and dialogues. In the NAP, many CCA measures relate to improving information on climate risks and to the development of plans, actions, and measures to support the creation of effective risk reduction investment programs and policies. These measures could be considered as the fixed or initiation costs to select, define, and prioritize appropriate measures for reaching adaptation objectives. The costs of the prioritized measures will then have to be estimated. This study attempts to estimate or present some of these costs, focusing on measures related to extreme heat, wildfire, flood, and drought risks, based on recently completed external analysis, the analytics conducted under this project, and consultation with local experts and counterparts.

The results of sectoral and programmatic adaptation analytics are summarized in Table 13 and Table 14, Annex 3. The costs of CCA measures can serve as illustrative ranges of lower-bound costs to be confirmed and improved with further detailed assessments. The costs of CCA measures to enhance the resilience of transportation networks against flood risk, for instance, were estimated. Adaptation measures for the transportation sector were determined simply by transferring and adjusting investment needs and benefit-cost ratios from the literature and applying an adjustment factor based on reasonable assumptions and insights from plans and strategies for Romania, such as the Flood Reimbursable Advisory Services (RAS) [299] and the NAP (see case study below for more detail). Previous consultations have indicated that such information on sectoral impacts from climate extremes and natural hazards, as well as costed CCA measures related to DRM, would be useful to Romania's Ministry of Environment, Water, and Forests. A focused and selective overview of costs found in the literature could also be of interest to other countries considering similar CCA measures for their NAPs.

In addition, this analysis investigated indicative, high-level costs and benefits of adaptation measures to be considered for macroeconomic modeling. The main goal was to provide an overview of current methods and evidence complementary to other studies, previous or ongoing, from the European Commission[300] by looking at national studies. This investigation can be considered a starting point and inspiration for sectoral and macroeconomic analysis, as no single blueprint and methodology exists. It focuses on inputs on impacts and adaptation measures for the macroeconomic models most commonly used in the literature: the computable general equilibrium (CGE) model and macrostructural models (MFMod, Dobrescu). Major differences are outlined and more details on outcomes from previous assessments provided in Box 16 and Table 16 in Annex 3.

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298 World Bank. 2024 upcoming. Drought risk and resilience assessment in Romania; Note that the methodology is consistent with EDORA (European Drought Risk Assessment) and data shared by IIASA. The results are as of February 2024 as the final report has not yet been published.

299 WB. 2023. Report on advice provided to MEWF in the preparation of twelve (12) final draft Flood Risk Management Plans. Output 7 of the Floods RAS.

300 COACCH studies; EC DG CLIMA Ramboll. 2023. Macro-economic / top-down assessment of climate impacts on the EU economy. Interim draft report July 2023. When finalized, a summary of the findings will be included in the annex of this report.

The analysis for this case study applied the Cobb-Douglas model and included several steps. First, potential impacts of selected climate threats on yields and labor productivity were gathered from existing studies (World Bank/IIASA and COACCH). Their follow-on effects on growth, employment, fiscal indicators, and poverty were then assessed.[301] The impacts were estimated separately for heat (see Figure 21) and drought. For drought, the average impact for 2021–60 was estimated at 1.1–1.2 percent of GDP, depending on the Representative Concentration Pathway (RCP).[302] The macro model was "shocked" with extreme scenarios (extreme heat event, drought, and so on) to look in more detail at the spectrum of projected climate impacts. A thorough examination of the model's robustness was conducted by running a thousand simulations over a 50-year forecast period. This extensive simulation exercise was designed to test the resilience of the economic system against a variety of potential future climate conditions and events. The model was iterated so many times to capture a wide range of outcomes based on different sequences of projected climate impacts and extremes. The results from these simulations would provide a comprehensive perspective on how climate change could influence economic stability and growth over the next half-century.

Finally, the analysis presented high-level adjustment factors that could be considered for macroeconomic impacts with and without adaptation.[303] They could be considered specifically in the macroeconomic analysis by transferring values from the literature and adjusting them for the Romanian context and by validating and comparing these with adaptation costs from key national strategic documents. The results are summarized in Table 15 in Annex 3, which look at the four hazards for which the most evidence exists in the European context in terms of consideration for macroeconomic modeling (earthquakes are not climate related and therefore not included).

Adaptation measures against extreme heat were estimated to be effective in reducing substantial macroeconomic damage. In an RCP 4.5 climate change scenario, the reduction in labor productivity was estimated at 1 percent or less of GDP by 2050, depending on SSPs. This suggests the impacts from heat, while sizable, could be effectively managed through local interventions, such as shifting working hours to avoid the hottest periods of the day or installing shading and air circulation systems.[304] These relatively simple and cost-effective solutions are supported by the research literature (see technical unpublished background note available upon request) and, per this analysis, would cost an estimated €78 million annually in Romania's agricultural and industrial sectors. Such adaptation measures can be scaled up rapidly and flexibly, depending on needs and budgets. Unlike, for instance, the implementation of flood protection infrastructure—which requires long construction times and major upfront capital investments—basic heat adaptation measures can be adjusted from year to year by, for example, adjusting the number of days with shifted work hours. Such flexibility can help to increase the probability of these measures' being effective for a range of possible outcomes, given the breadth of climate impacts also projected to affect their costs. In the absence of such measures, extreme heat is expected to have a substantial impact on labor productivity, especially with respect to outdoor work,

301 Note that for drought, the following process had to be followed to obtain estimates usable in the macroeconomic model. First, the reduction value for yields was calculated for a maximum likelihood and for different scenarios, RCPs, periods, crops, and river basins. An average was calculated over river basins to get a national reduction value. Based then on the value of agricultural production by crops calculated by the UN's Food and Agricultural Organization (which covered only 13 crops out of 18 crops considered by IIASA but included main crops), the estimated reduction was computed in monetary terms by scenario, RCPs, and for the period 2021–60. A hard assumption had to be considered—namely, 2021 values for agricultural production were used, as no forecasts were available.

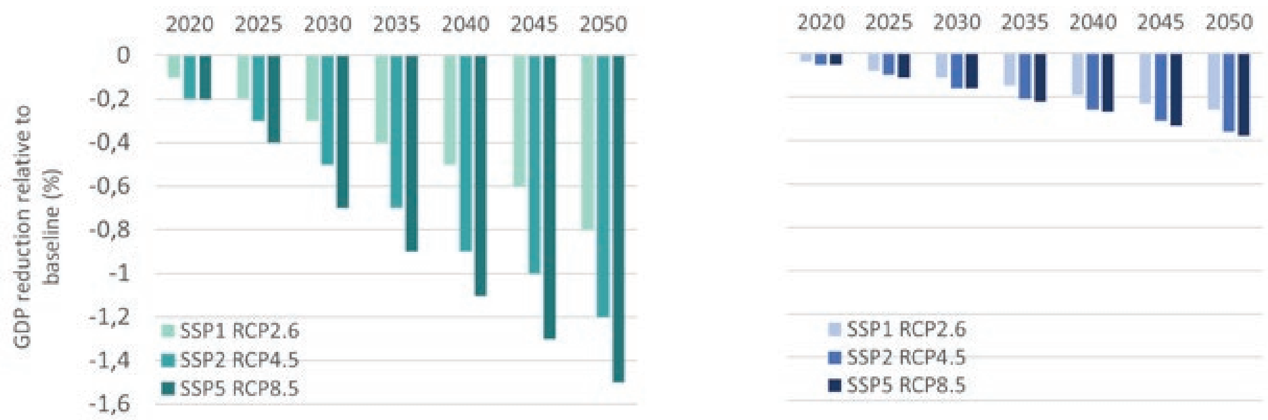
302 This finding is consistent depending on global climate models (GCMs) considered (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL) and on findings in the ongoing World Bank Western Balkans CCDR, but it is being discussed and remains to be determined.

303 Annex 3 presents an overview of costs and benefits considered at macroeconomic level in national studies and how they relate to modeling and methodological approaches.

304 In practice, adaptation measures to address extreme heat events would consist of a package of measures, some of them going beyond the measures reflected in the modeling exercise conducted for this analysis. Such additional measures could include heat early warning systems, awareness campaigns, health system adjustments, improvement of emergency services, hotlines, and community care protocols for vulnerable groups, including the elderly). This analysis focused on measures to reduce labor productivity impacts from heat and did not account for localized or sectoral impacts, such as urban heat island effects, loss of agricultural yields, or heat-related pressures on critical infrastructure systems.

which is common in the agricultural and industrial sectors. This, in turn, will affect output, resulting in GDP losses of about 0.2 percent in the current climate, rising to about 1.2 percent by 2050 (RCP 4.5; Figure 21, left panel). When accounting for the benefits of adaptation measures, our macroeconomic model estimated a substantial reduction in heat-related GDP losses (Figure 21, right panel).

Figure 21. Romania: Estimated macroeconomic impact of extreme heat as a percentage of GDP without adaptation measures (left), and with adaptation measures (right)



Source: World Bank.

Effective adaptation measures against rising flood hazards can require substantial capital investments in protective infrastructure, with benefits accruing in the long term. A World Bank analysis[305] highlighted the range of factors that drive investment needs for flood protection—socioeconomic growth scenarios drive the value of assets at risk, while climate change scenarios drive the probability of extreme flooding events. In addition, investment costs are influenced not only by local construction costs but by the level of risk tolerance of decision-makers (that is, by the safety standards to which protection measures are built). The last factor, especially, depends on local preferences and priorities, which can shift over time, implying there is no single "correct" standard. The World Bank's Reimbursable Advisory Services on flood risks in Romania examined these drivers and recommended a flood protection investment package costing €6.9 billion for the period 2022–28 and covering initial investment, replacement, and operation and maintenance. While these upfront investments are substantial, the macroeconomic benefits in terms of avoided flooded losses would continue to accrue over the long term.

In sum, this case study contributes to the understanding of the macroeconomic implications of climate change in Romania and addresses gaps in the information needed for national adaptation planning. It highlights how disasters in key sectors pose risks to the macroeconomy, affecting GDP, fiscal revenues, and overall fiscal balance. Through updated risk analytics and international examples, it provides insights into potential measures and cost ranges for sectoral and national planning for CCA. These can be further considered in building on the NAP and promoting agile adaptation planning, as aligned with EU objectives. Finally, the study's focus on the costs of adaptation for extreme events like heat waves, wildfires, floods, and droughts aligns with the European Union's objectives for agile adaptation planning.

The study does have limitations in that it relies on high-level, stylized benefit-cost ratios and preliminary macroeconomic impact assessments, underscoring the need for more comprehensive, tailored sectoral analytics. The findings, largely based on literature reviews and expert consultations, provide only a reference range for adaptation costs,

305 Rozenberg, Julie and Marianne Fay. 2019. Beyond the gap: how countries can afford the infrastructure they need while protecting the planet. Link.

underscoring a need for more comprehensive, tailored sectoral analytics. Macroeconomic impacts are also limited by the consideration of single hazards and the limited economic representation of impact channels and estimates. The study also highlights the challenges in incorporating adaptation effectively into macro models. Enhancing macro models to consider extreme events and developing in-depth adaptation studies across various sectors is crucial for a more accurate representation of damage and adaptation pathways.

Continued research and development are needed in macroeconomic modeling and sectoral studies to improve adaptation strategies. Future work should focus on multi-hazard analysis of impacts on infrastructure and assets and on detailed studies of drought, wildfire (with broader focus than presented here, examining not only impacts on forestry but on infrastructure and human health), and other climate-related hazards. Such a broadened focus will refine understanding of investment needs and benefit-cost ratios and improve the incorporation of extreme hazard events into macroeconomic projections. The study advocates using a variety of models for different purposes, such as macrostructural models for fiscal planning and CGE models with improved sectoral details, all while improving further the consideration of extreme hazard events. It also suggests a dynamic approach to adaptation, emphasizing regular improvements and transformative actions beyond traditional budget and planning constraints, and highlights methodologies that can be adapted to other European contexts.

Sectoral and programmatic planning assessments of CCA costs

ADDED VALUE AND COMPARISON TO EXTERNAL NATIONAL ASSESSMENTS

The sectoral and programmatic assessments of climate change adaptation costs are presented here together because, unlike with national planning, these two use cases overlap in many ways. The recommendations offered later also comprise one set for the national planning use case and a combined set for the sectoral and programmatic use cases.

For the use case from a sectoral perspective, CCA costs are linked to specific sectoral planning needs and the mainstreaming of adaptation across sectors for short- to medium-term horizons. A deep dive is taken into CCA costing for the forestry sector and wildfire risk reduction programs in Sweden, with the approach compared to analytics implemented for other countries (Norway and the United Kingdom) and purposes. In addition, a methodology for costing CCA measures considering wildfire risk analytics is outlined and applied in a more detailed sectoral manner.

For the use case from a programmatic perspective (also referred to as the investment portfolio planning use case), CCA costs are estimated to inform portfolio management for short- to medium-term horizons. The study includes three case studies. Results are presented from new quantitative analytics for Croatia, analyzing a portfolio of selected critical infrastructure investments; an analysis of the fictional Aurelia describes the cost investment mark-up required for climate change adaptation and compares the approach to analytics implemented for other countries (such as the Netherlands) and purposes; and CCA costing is presented for Romania for the transportation sector, considering flood risk and focused on road networks, with the approach compared to analytics implemented for other countries and purposes. The case study of Sweden was focused on forestry and wildfires and the economic analysis of adaptation. It demonstrated an approach that can be used to help prioritize and justify near-term national adaptation planning. Such approaches will be key to the scale-up of adaptation in countries' NAPs, providing an economic case for intervention through economic appraisal. The analysis first assessed the current and possible future costs of wildfires in terms of social and economic losses and investigated the potential of a set of adaptation options to reduce those costs, along with their economic costs and benefits. Importantly, the study concentrated on the economic analysis of near-term adaptation investments (in the next five years or so) that passed a cost-benefit test, including action to address current and longer-term future risks of climate change, given a spectrum of projected impacts.

In the scenario presented in its case study, the hypothetical country of Aurelia uses one of the many government planning options for climate-proofing its critical infrastructure and buildings. It engages in a process to evaluate the level of safety and adaptation required for climate-proofing based on multiple criteria, applying guidelines and lessons from other countries. The results of the analysis tend to show a positive correlation between the level of ambition in reducing residual damage and the cost of investments. Climate forecasting based on RCP 8.5 scenarios and analysis could be used to determine the appropriate design and retrofit specifications for critical infrastructure and buildings. Benefit-cost analysis and effectiveness analysis were used to ensure investments would make economic sense, and co-benefits of the functionality of assets were considered within 20- to 50-year time horizons. The case study assessed such strategies as passive survivability for buildings, multicriteria and criticality analyses for transportation and power networks, and multi-hazard climate-proofing for education, health, and civil protection infrastructure.

The case study of Croatia is complementary to the Aurelia case study, as it serves to provide example of how to address climate-proofing of critical infrastructure assets in the civil protection sector. In this case study, a portfolio assessment was conducted for Croatia's critical civil protection infrastructure served as a starting point for an analysis of CCA measures and the strengthening of critical infrastructure. The analysis identified climate-related risks and impacts to critical infrastructure, as well as determining CCA measures and cost ranges to prioritize risk reduction and preparedness investments at the sectoral level. The analysis also considered a single hazard approach, estimating the cost of improving the resilience to heat of existing buildings in Croatia, estimating the marginal costs. Croatia, like many countries in the EU, has an older building stock, therefore, the analysis considered this context when retrofitting older buildings with climate adaptive measures. This case study not only helps Croatia make informed decisions and prioritize actions, but it also demonstrates how to integrate disaster management and CCA in a practical manner. Furthermore, it can serve as a model for other countries facing similar challenges, facilitating the implementation of CCA strategies at the national and EU levels.

The case study of Romania, already discussed above with respect to wildfire and extreme heat from a national planning perspective, presented a strong economic case for integrating climate change adaptation measures into network infrastructure, where damage can quickly spread and multiply. To assess the flood exposure of Romania's transportation network, a spatial network criticality analysis was conducted, which demonstrated that even localized flood events can result in countrywide impacts on agricultural supply chain flows. Considering such indirect impact propagation is essential for evaluating the impacts of climate shocks on infrastructure networks and on the households and firms dependent on them. Accounting for them through criticality analyses can help determine the benefits of adaptation investments more comprehensively, yielding more meaningful investment appraisals. While the scope of this illustrative case study was limited in terms of sectors and hazards, it demonstrated the value of this approach. The findings also highlighted the need for adaptation measures to approach infrastructure systems as interconnected networks and require complementary actions to ensure adequate financing (including for infrastructure maintenance); standards for risk-informed planning; and well-defined roles, responsibilities, and institutions to ensure resilient infrastructure.

When costing CCA, it is crucial to consider the difference in methodologies for assessing current and future climate risks and impacts. Current impacts are often assessed based on historical data, producing risk and vulnerability maps and identifying high-risk areas or assets. A risk assessment project in the western Balkans, for instance, sought to identify the robustness of potential engineering and non-engineering interventions by analyzing multi-hazard risks for the current climate and the resilience of the trade and transportation networks.[306] The interventions were then organized into portfolios to reduce disaster risks, with estimated costs ranging from US$15 million to $60 million (€14.20 million–€151.46 million).

Also essential to any assessment regarding future climate is to take into account the spectrum of projected impacts and consider multiple possible scenarios under different temperature and meteorological projections. When assessing future flood risks, for instance, return periods have to be aligned with precipitation projections under different climate change scenarios to determine potential impacts. An assessment of global road and railway infrastructure considering flood and multi-hazard risks, for example, reveals that enhancing flood protection and adaptation would yield positive returns on 60 percent of the roads exposed to a 100-year return period flood event.[307] Consideration of the range of projected climate impacts is especially important when assessing long-term impacts and the benefits of adaptation. Additional factors that need to be considered include the presence of multiple hazards and potential compounding effects, changes in socioeconomic conditions, and the interdependency of critical infrastructure networks.

NEW ASSESSMENTS AND LESSONS LEARNED

Sweden: Example of adaptation costing and economic analysis for wildfire in the forestry sector

While a strong scientific case can be made for early adaptation, justifying adaptation from an economic perspective is often more difficult, and this will be a priority for allocating resources in national plans and programs. From a scientific perspective, the need for adaptation to reduce the risks of future climate change is clear. From an economic perspective, however, justifying such investment now, especially in proactive adaptation, is often difficult for several reasons. First, the impacts of climate change, and thus the benefits of adaptation, primarily arise in the future, which makes it difficult to justify in economic terms the upfront costs today. Second, uncertainty about future climate change is high, which makes it difficult to make optimal decisions. To address these barriers to investing in early adaptation, this scoping study of Sweden demonstrates a framework that is already being applied in economic analysis of adaptation in Europe.[308]

The study investigates how to advance the costing of adaptation investments and the use of economic analysis to prioritize adaptation options, presenting the example of wildfire adaptation. The analysis first assesses the current and future costs of wildfires in terms of overall economic costs in Sweden, including social and environmental impacts. It then demonstrates how to sequence and prioritize adaptation options, providing an economic rationale. The objective is to show how line ministries (of sectors) and civil protection agencies can use economic analysis to support early adaptation planning and decisions.

Current and future wildfire risks in Sweden

Wildfires are uncontrolled vegetation fires. While they require an ignition source, and most arise from some form of human activity, they also depend on land use and the presence of combustible material. Temperature and other climate variables are factors in wildfire incidence and extent, both in terms of the average climate and of climate variability and weather and climate extremes. A wide range of indicators used in fire danger or weather indices for early warning for wildfire usually involve consideration of temperature,

306 Green, M. et al. 2020. Diagnosing Vulnerability and Economic Resilience of transport Systems, Infrastructure and Operations in the Western Balkans (DIVERSION). Wood Environment & Infrastructure Solutions UK Limited for the WB.
307 Koks, E.E. et al. 2019. A global multi-hazard risk analysis of road and railway infrastructure assets. Link.
308 Watkiss, P. and Betts, R. A. 2021. Link.

relative humidity, windspeed, rainfall, and potential evaporation, as well as drought indices.[309] Studies that have assessed the spatial and temporal patterns of forest fire activity in Sweden and their association with climatic indices find dry conditions and droughts are the most important factors, although the patterns vary across the country.[310]

The current economic costs of forest wildfires in Sweden are significant. Although the wildfire impacts Sweden has experienced have not been high compared to other European countries, the associated economic losses are still important. From 2000 to 2021, Sweden had more than 105,000 wildfires, leading to a burnt area of a reported 74,148 hectares (ha) of land.[311] To date, most analysis has focused on the direct costs of these events, including the costs of suppression as well as the damage and loss incurred. These events also impose social and environmental costs, however, such as those from carbon and air pollution. This study valued the overall economic costs of wildfires in Sweden and estimated them, on average, at €66.7 million per year. These are much higher in major wildfire years, such as 2014 and, especially, 2018, when more than 8,000 fires were recorded, affecting more than 20,000 ha of productive forest area, and international support was provided.[312] This study estimated the costs of wildfires in 2018 at €512 million, incurred from firefighting and suppression, the loss of timber, and added air pollution and carbon emissions. These economic costs could be used to assess the economic case for early adaptation.

Climate change has the potential to increase wildfire risks, although uncertainty over the projections is high.[313] Northern Europe and, especially, the Arctic are already warming at a much faster rate than the global average, a trend projected to continue.[314] The picture for Sweden is more complex than in many other parts of Europe, however, particularly in terms of precipitation. While rainfall in Sweden may increase on average, the increase is primarily driven by more rain in the north and during the winter. Year to year variability and the frequency and intensity of dry spells and droughts may also change.[315] Most studies project an increase for the country in average wildfire risk from climate change,[316] as well as increased risk of major wildfire extreme seasons, as in 2018.[317] Analysis of projected modeled changes indicate the average annual risk could be one and a half to two times higher by mid-century, and that the frequency of extreme seasons could double in likelihood—(with a range of one and a half to three times more) by mid-

309 Arnell, N.W., Freeman, A. and Gazzard, R., 2021. The effect of climate change on indicators of fire danger in the UK. Environmental Research Letters, 16(4), p.044027. Link.

310 Igor Drobyshev, Mats Niklasson, Hans W. Linderholm. 2012. Forest fire activity in Sweden: Climatic controls and geographical patterns in 20th century, Agricultural and Forest Meteorology, Volumes 154–155, 2012. Link.; Droughts and wildfires in Sweden past variation and future projection (2017). Research project funded by the Swedish Civil Contingencies Agency (Myndigheten för samhällsskydd och beredskap: MSB).

311 EFFIS. Annual Fire Reports. Link. Note that EFFIS reports only on wildfires of a certain size and relies on nationally reported results, which vary by country. According to the MSB, the number includes 14,200 fires in productive forest (with 51,200 ha land burned), 38,700 fires in other tree covered area (with 9600 ha land burnt). And 53,500 fires in land without trees (with 13,000 ha land burnt). Fires smaller than 1m2 are not included and in some fire events, more than one type of land was affected. Therefore, there are more total number of fires than for the land type affected by the individual fires.

312 San-Miguel-Ayanz, J. et al. 2019. Forest Fires in Europe, Middle East and North Africa 2018. Publications Office of the European Union, Luxembourg. doi:10.2760/1128, JRC117883. Link.

313 Note that this report mostly focuses on wildfire hazard with factors linked to climate change and weather rather than other important factors affecting wildfire risk such as vegetation, changes in forestry practices, and human influences affecting ignition.

314 Rantanen et al. 2022. The Arctic has warmed nearly four times faster than the globe since 1979. Commun Earth Environ 3, 168. Link. Lee et al. 2021: Future Global Climate: Scenario-Based Projections and NearTerm Information. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553–672.Link. Eklund, A. et al. 2015. Sweden's future climate. Link.

315 Eklund et al (2015). Sweden's future climate. Link.; Skogsstyrelsen. 2020. Klimatanpassning av skogen och skogsbruket – mål och förslag på åtgärder. RAPPORT 2019/23. Link.; SMHI (2023). Future climate. Link.

316 Igor Drobyshev, Mats Niklasson, Hans W. Linderholm. 2012. Forest fire activity in Sweden: Climatic controls and geographical patterns in 20th century, Agricultural and Forest Meteorology, Volumes 154–155, 2012. Link.; San-Miguel-Ayanz, J. et al. 2022. Forest Fires in Europe, Middle East and North Africa 2021. Publications Office of the EU, JRC130846. Link.; Swedish Civil Contingencies Agency. 2017. Droughts and wildfires in Sweden. Link.; Fabbro et al. 2020. Future projections of forest fires in Sweden. Department of Earth Sciences NG0220 Climate Change and Society Report. Link.; Hurst. 2021. The Susceptibility of the Circumpolar North to Zombie Wildfire: An Exploratory Case Study of Sweden. Link.

317 Krikken, F. et al. 2019. Attribution of the role of climate change in the forest fires in Sweden 2018. Link.

century. While these projections support a strong case for scaling up adaptation to wildfire, it must take uncertainty into account.

Because forestry has long lifetimes and involves lock-in, decisions made for the sector in the next decade will influence the risk from climate change for decades to come. While practices vary in Sweden, the use of a long forest management cycle is widespread. This is important because forestry investments made in the next ten years will be exposed to the changes in climate over the next fifty or more, resulting in a degree of lock-in and path dependency for immediate and near-term decisions that highlights the need to mainstream climate adaptation in near-term investment and planning, although this involves decisions under uncertainty. It is also noted that achieving the Swedish net zero goal (to achieve zero net emissions of greenhouse gases into the atmosphere by 2045) will mean that GHG emissions should be at least 85% lower than in 1990, with the remaining 15% reduction achieved through supplementary measures (for emissions that are very difficult to reduce). The Swedish policy statement for net zero[318] sets out that these supplementary measures include increased carbon sequestration in forest and land, carbon capture and storage technologies (CCS) and emission reduction efforts outside of Sweden. This means that new forest or woodland areas might be part of the mix to support net zero goals and any new areas would need to be designed with the future climate in mind.

Additional wildfire-related risks from climate change could be significant in coming decades. Climate change could produce major risks for Sweden that have not been experienced to date. These include new risks associated with peatland wildfires, as well as indirect changes to wildfire risk following pest and disease outbreaks in forests. While these are not considered serious problems in Sweden today, they are already significant in other European countries, and they may become important in Sweden by mid-century, especially under higher warming scenarios. Starting to prepare for these risks as an initial adaptation step and identifying early actions that could improve future decisions is therefore valuable. To explore their potential importance, this study developed storylines for these two new climate risks, including indicative analysis of economic costs. The analysis highlighted early research and planning as part of an adaptation pathway approach to preparing for risks proactively.

Building blocks and analytics for adaptation economics

Sweden is developing adaptation plans for forestry but lacks costed estimates and economic analysis. Sweden recently refined its fire risk model based on the Canadian Fire Weather Index System,[319] and the Swedish Forest Agency has published an adaptation plan designed specifically for the forestry sector, covering all risks, including wildfires.[320] While the plan identifies the importance of estimating the costs and benefits of climate adaptation and selecting adaptation measures that are cost-effective, it also acknowledges that existing assessments and cost estimates are limited and need to be improved. This case study addresses this gap, focusing on an approach to prioritizing and sequencing early adaptation. It illustrates how analysis could be undertaken to support national strategies and NAP investments for near-term plans.

Given the increasing risks and impacts of wildfire, three types of early adaptation investments—referred to here as building blocks—are proposed that can be justified in economic terms, with the objective of enhancing climate and wildfire resilience. Other national assessments in Europe have used an economic rationale to build up the case for early adaptation.[321] This analysis looks at these three areas of investment in the forestry sector to address the current and future climate risks identified above:

318 Government of Sweden. 2022. Sweden's climate policy framework. Link.
319 San-Miguel-Ayanz, J. et al. 2022. Forest Fires in Europe, Middle East and North Africa 2021.
320 Skogsstyrelsen. 2020. Klimatanpassning av skogen och skogsbruket – mål och förslag på åtgärder. RAPPORT 2019/23. Link.
321 Watkiss, P. and Betts, R. A. 2021. Link.

- *The first building block involves no-regret* options that can reduce current economic costs of wildfires today and can be justified in cost-benefit terms and implemented immediately, reducing current losses and building resilience for future and rising risks.

- *The second building block looks at the opportunity to integrate adaptation into early investment decisions that will be made anyway over the next five to ten years to reduce lock-in risks.* This recognizes that if irreversible investments are going to happen in the short term, it makes sense to ensure they are climate-resilient.

- *The final building block identifies early low-cost actions that could be implemented today to start preparing for longer-term risks* and can be justified based on the future option value and improved future decisions. This provides an example of sequencing and prioritizing adaptation based on the urgency of decisions and the economic benefits delivered.

These three types of investments are not mutually exclusive, and a combination of all three is often needed as part of a portfolio at the national level. The process conducted here demonstrates a replicable approach for building a portfolio of early adaptation options that can serve as a blueprint for other national assessments. The analysis of the options and its results are summarized below.

For early no-regret adaptation, the study analyzed the option of wildfire prevention training and an awareness-raising program:

- *The study purposed a set of "no-regret" adaptation options may be good to introduce now,* based on their potential to reduce the current economic costs of forest wildfires. They tend to be low-cost nontechnical options, such as wildfire early warning systems, awareness raising, and training programs, among others.

- *To explore this set of options, the study considered a forest wildfire capacity-building, awareness-raising, and training program,* building on a recommendation in Sweden's sectoral adaptation plan for forestry[322] that targets Swedish fire-fighters, incident commanders, and private forest owners, especially those in the southern part of the country. The costs of such a program, based on a 10-year period, were estimated at €70 million, or €6.9 million per year.

- *An analysis of the economic benefits of this program* in terms of reducing the number of wildfires and burnt area estimated the cost at €129 million per year over the next 15 years, even for the current climate.

- *A cost-benefit analysis found this option could have a positive benefit-cost ratio of 2 to 1*—that is, the benefits would outweigh the costs even today. The ratio would increase with the changing climate to 3 to 1, assuming increased wildfire risk with early climate change. The large nonmarket benefits determined would justify public sector investment.

- *This approach could be used to assess a wider set of no-regret options,* both those proposed in the recent Swedish sectoral adaptation plan for forestry and others included in a more detailed appraisal. For example, this could include programmes to raise awareness and support prevention among the public, or it could target specific actors, such as forest entrepreneurs. To support this kind of action, further , it would be useful to further investigate the effectiveness of potential non-technical options, through a combination of detailed review, feasibility studies and expert consultation.

For integrating adaptation in near-term investment decisions for forestry, the study analyzed the options of climate-proofing forests and creating woodlands to support the net-zero target:

322 After the 2014 wildfire seasons, a few training programs and prevention measures have been in place by the MSB and the Swedish Forest Agency to enhance wildfire prevention and response, such as web-based training module for firefighters and voluntary forest fire forces. After the 2018 wildfire season, investigations were carried out that led to the establishment of new laws for the municipal rescue service to enhance wildfire response and collaboration. Nevertheless, currently there is still a lack of a more qualified combined training/practice to manage extensive and complex forest fires and to also use special analysis teams for forest fires.

- *Given their very long lifetimes, reducing the lock-in risk associated with new investments in Sweden's forestry sector could be beneficial today.* These options can ensure that new planting (whether as part of ongoing silviculture management cycles and replanting or for carbon sequestration for net-zero) takes account of future wildfire risks.

- *These decisions are complex because of future uncertainty.* The options, costs, and benefits of climate-proofing new forests or replanting can vary not only with a 2˚C, 3˚C, or warmer future world but with whether the future climate is wetter or drier. Decisions, therefore, must be made under uncertainty. They can take account of future uncertainty, by, for example, considering options that are more robust to alternative futures or that introduce flexibility or allow scaling up later as evidence emerges.

- *To explore this, the study investigated options to introduce adaptive management planning in new forest or woodland creation,* using the example of new forest or woodland areas. Among options that could be introduced in these new areas are wildfire risk management plans, wildfire prevention, reduced tree density, and mixed species for wildfire reduction.

- *The analysis suggests that for new investments this decade, low-cost wildfire management plans and some early prevention measures might already make economic sense.* Based on the central projections of the future climate, they could reduce future lock-in risk to climate change with a benefit-cost ratio of 1.2 to 1 even today. More extensive actions for wildfire management, however, including extensive firebreaks, lower-density spacing, and mixed species, had a benefit-cost ratio below 1 in this decade.[323] Additional beneficial early actions could come from flexible, early measures that allow future scale-up—for example, designing new plantations to make it easier to introduce firebreaks later. Furthermore, the analysis highlighted the need for an iterative cycle of wildfire management planning to put a process in place to address the change in risk over time and to allow for scale-up as evidence of wildfire risks improves.

- *While the case study focused initially on new areas for carbon sequestration, similar actions could also be considered in terms of the general replanting and regeneration cycle for Swedish forests.* Tackling all forest replanting would represent a much greater scale-up. Pilot studies on climate-proofing new forest investment would be advisable to obtain real-world information on options, costs and benefits, while taking the first steps toward integrating climate-proofing requirements into national policy and processes.

For early preparation to address future major risks, the study analyzed bark beetle surveillance and peatland wildfire prevention programmes:

- *The final area of analysis was future uncertain but potentially large climate risks and what early actions might be beneficial today* to address risks that might emerge in coming decades.

- *Early adaptation can be justified for addressing even long-term (and uncertain) risks,* as part of iterative adaptative management approaches, or adaptation pathways. Early actions can be worthwhile to invest in today, in terms of the option value they provide and their ability to improve future decisions, resulting in improved future benefits and reduced future costs.

- *To explore this, the study considered two potential major new risks for wildfire in Sweden, using story-lines.* The first looked at the northward climatic suitability for bark beetle infestations and the higher wildfire risks that might follow major outbreaks due to. The second investigated peatland wildfires and the very large carbon emissions these could emit. In both cases, early actions would involve taking the first steps in preparing for adaptation.

323 Note that this calculation is with respect to wildfire benefits only. These options do have additional climate and other ecosystem service benefits. They might also be valid for new planting in future decades if, for example, stronger wildfire risks emerge.

- *The analysis of bark beetle surveillance assessed the economic costs of increased pest and disease outbreaks, with a focus on the bark beetle* and the indirect impact these outbreaks might have on wildfire risk (due to changes in leaf cover, fuel load, and from tree mortality, though the changes on overall wildfire risk are uncertain[324]). The study looked in particular at the value of information that would be provided by enhanced monitoring in terms, first, of the potential for improved information to reduce current and near future losses by improving decisions to tackle outbreaks and, second, the potential to use this information in decisions on new investments in the forestry sector, such as whether to invest now or later. Low investment in monitoring was found to provide a positive economic return. The analysis also highlighted the potential benefits of a research program in bark beetle and wildfire linkages, again based on the value of the information this would provide for future policy.

- *The analysis of peatland wildfire prevention looked at the potential economic costs of peatland wildfires,* using analogues from other northern European countries. It found that these risk could be important for Sweden, and that an early programme of investigation would be justified. The analysis also identified the costs of early activities that could be implemented as part of adaptive management to support future adaptation decisions.

- *Both of these examples showed how, even for more uncertain future risks, early, low-cost steps of adaptation could make sense as* part of adaptative management strategies.

In sum, considered together, the three building blocks of investment can provide an adaptation portfolio that will deliver immediate economic returns, reduce risks in near-term investments with lock-in, and support some early actions to start the process of adapting to long-term major risks. The additional costs of this package of measures would be moderate (less than €10 million per year). They encompass actions, mostly in the next five years, that can be justified in economic terms, delivering immediate benefits several times the costs and future benefits. The analysis also provided useful insights into the timing and sequencing of adaptation options.

Takeaways from Sweden

The approach taken by the Sweden case study highlights the economic benefit that may derive from investing in various types of adaptation today, even in the face of uncertainties about future climate impacts. The study showed how countries can use economic analysis to help sequence and prioritize adaptation measures for sectoral or national planning. Key takeaway points are summarized below.

It is useful to start with the current, then look to the future, as part of an adaptive management framework. Countries like Sweden, once considered low-risk, now face increased wildfire threats because of climate change, at least in some areas of the country , but adaptation investments can be difficult to justify in these formerly low-risk areas. An important starting point is to establish current economic costs before considering future risks.

The analysis provided an economic case for some early adaptation actions, but not all were justified in the Swedish context. The analysis drew on international literature, looking at adaptation options in other countries with existing wildfire risks. While some interventions could be justified for early action in Sweden, this was not the case for all. This finding highlights the value of economic analysis in helping to prioritize and sequence adaptation actions. It also highlights the benefits of further research, especially on the likelihood of wildfire risks, and the transferability of adaptation options to the Swedish context, to help improve future decisions and actions.

324 Hicke, J. et al. 2012. Effects of bark beetle-caused tree mortality on wildfire. Forest Ecology and Management, Volume 271, 1 May 2012, Pages 81-90. Link.

By focusing on the three building blocks for early adaptation, a strong economic case for action could be constructed. The analysis showed it is possible to identify and justify immediate no-regret actions, like capacity-building and awareness campaigns, that also deliver benefits in the short term. Potential lock-in risks could also be identified and addressed through climate-smart thinking in near-term investments, while noting the need to consider uncertainty. Finally, the analysis showed the importance of identifying and taking the initial actions to address longer-term major risks, even if uncertain, generating information as part of an iterative approach that can be applied in subsequent decisions.

The use of the approach presented here to estimate the economic costs of adaptation for forest wildfire demonstrates its application. It is stressed, though, that comprehensive dialogues involving all stakeholders, including private forest landowners, are crucial for taking such approaches forward in practice.

The example of early economic analysis provided for Sweden could be relevant for other countries in Europe, as well. Few go further than to consider the costs of adaptation, look at the economic benefits, and assess them in benefit-cost analysis terms. In the specific area of wildfire, this approach could be translated to other countries. Box 9, for example, outlines how follow-up studies could apply this analysis to Portugal or Romania. It should be noted that while this type of analysis can serve as an initial scoping study, the making of a detailed investment plan (such as for a spending or budget submission) would benefit from a more detailed analysis requiring more information, data, and technical decision-making. For Sweden, more than 15 data sources (international, national, and regional) were available, as were more than 150 reports and various forms of grey literature that reviewed and modeled results with projections for future climate. For studies of climate change risks in other countries and sectors, such a knowledge base would have to be developed by the researcher.

BOX 9. PORTUGAL AND ROMANIA: HYPOTHETICAL APPLICATIONS OF THE METHODOLOGY USED FOR SWEDEN

The methodology used in the study of Sweden could be applied to other European countries, with the countries' specific climate and wildfire context considered.

Several considerations are important when undertaking this analysis for Portugal. Existing programs, such as Safe People and Safe Villages, and legislation for wildfire safety should be included in the assessment of current and future risks, as should the costs and benefits of immediate and longer-term interventions. Rural exodus, fuel management, and other social dynamics also need to be considered in allocating resources to wildfire emergency management. Since peatland is localized to limited areas in the mountains of northern Portugal and in the central region, risk reduction for future wildfires could be combined with cross-border collaboration for resilience measures. Forestry adaptation could also focus on areas of rural Portugal where, although the population is shrinking, forest and wildfire management are crucial to efforts to avoid catastrophic wildfires resulting from increasing climate change effects.

If applied to Romania, the analysis could consider the country's unique wildfire context. Wildfires in Romania have historically had lower impacts than other hazards but have been more likely to occur.[325] The analysis could make use of existing data, although they are less robust than for other countries. The development of scenarios and storylines for the future would benefit from detailed climate risk analytics using information on historical losses and climate projections. Romania's high proportion of Natura 2000 protected areas and diversity of forest types, among other sectoral characteristics, would have to be considered to assess losses and develop adaptation measures. Adaptation measures could also be selected based on Romania's current NAP and complementarity in terms of assessing benefits and costs and adjusted based on the current state of fire prevention and forest management.

325 EC. 2021e. JRC Technical Report on Forest Fires in Europe, Middle East and North Africa 2020. Link.

In general, countries could (and will probably need to) make more use of economic analysis to help them sequence and prioritize options in national adaptation planning. Pressure to demonstrate the value for money of adaptation will be greater than for other priorities, and economic analysis provides a way of doing this.

Finally, cross-sectoral and multi-stakeholder dialogues are key to this analysis. Given the complexity of the topic and associated decision-making, such dialogues are needed to inform comprehensive studies of climate change, particularly among relevant ministries, organizations, and civil protection agencies, as well as research institutes and private entities.

The fictional case study of "Aurelia": Climate-proofing selected critical infrastructure assets

In this hypothetical case study, the fictional country of Aurelia is interested in investigating and evaluating investments needed for climate proofing various types of critical infrastructure, including power and transportation networks, education and health infrastructure, and civil protection infrastructure. Critical infrastructure networks serve important functions in society but are vulnerable to climate hazards, such as floods and extreme heat waves etc. In the real world, the results from the COACCH assessment suggested that, under RCP 4.5 and 8.5 climate scenarios, the expected annual damage (EAD) to road infrastructure from river flooding would be an estimated €920 million for the EU-27 and €1.4 billion for the United Kingdom.[326] The EU-funded research project ToPDAd (Tool-supported policy development for regional adaptation) has shown the vulnerability and reduced generation capacities of European countries' energy systems as a result of temperature rise, increased rainfall and storms, and sea-level rise, especially in Central and Eastern Europe.[327] Such loss, however, can be greatly reduced with adaptation measures, such as implementing smart grids and upgrading the cooling system.

The analysis for Aurelia sought to evaluate the level of safety and adaptation required and/or desired for climate-proofing buildings based on multiple criteria, following best practices outlined in guidelines and the literature and from other countries.[328] It considered whether to protect the country's buildings to a constant relative risk level or to maintain a constant absolute risk level (see Chapter 1), a decision that depended on the assets at stake and information from historical disaster impacts, climate projections, existing exposure and vulnerability studies, criticality and redundancy criteria, stakeholder consultation, benefit-cost analysis, and concepts related to the passive survivability of buildings (see below). As the analysis included multiple hazards, the adaptation objectives for a given of type of asset depended not only on these factors but on the applicable legislation and standards in the country. Horizons of 20 to 50 years were considered for the infrastructure, depending on whether retrofitting or new construction were to be involved; hence, the study focused on climate projections for the 2050s and 2070s. The obsolescence rates of infrastructural assets and replacement versus repair strategies were taken into account, as were national strategies concerning the

326 Lincke, D. et al. 2018. Link.

327 Tool-supported policy development for regional adaptation (ToPDAd). 2015. Securing the EU's Energy Future - Adapting our energy system to climate change. Link.

328 Climate-ADAPT. 2023. EU-level technical guidance on adapting buildings to climate change. Link. Climate-ADAPT. 2023. Technical Report. Link.; Climate-ADAPT. 2023. Best Practice Guide Link.; EC. 2021. Commission Notice — Technical guidance on the climate proofing of infrastructure in the period 2021-2027. Link.; Institute for European Environmental Policy (IEEP). 2012. Methodologies For Climate Proofing Investments And Measures Under Cohesion And Regional Policy And The Common Agricultural Policy - Final Report. Link.; European Commission. 2018. Climate change adaptation of major infrastructure projects - A stock-taking of available resources to assist the development of climate resilient infrastructure. Link.; Hallegatte, S. 2019. Link.; Miyamoto International, Inc. 2021. Overview of Engineering Options for Increasing Infrastructure Resilience in the Caribbean: 360° Resilience Background Paper. Link.; World Bank. 2019. Overview of Engineering Options for Increasing Infrastructure Resilience - Final Report. Link.; UNDP. 2011. Paving the way for climate-resilient infrastructure: guidance for practitioners and planners. Link.; Asian Development Bank. 2011. Guidelines for Climate Proofing Investment in the Transport Sector Road Infrastructure Projects. Link.; OECD. 2023b. Taming wildfires in the context of climate change. Link.; OECD. 2023a. Adapting policies and practices to extreme wildfires: a cross-country review. Link.; Lynch et al. 2019. Fighting Wildfires with Innovation, Insurance Information Institute. Link.

percentage of stock retrofitted over a specified time horizon—for example, five to ten years—as well as assumptions around supply chain and labor availability. National initiatives around retrofitting were embedded in the analysis, and the costing exercise considered marginal costs in the provision of new or the rehabilitation of existing infrastructure (see case study on Bulgaria).

The adaptation ambitions and objectives considered for Aurelia depended on the hazard and type of asset examined. In general, a positive correlation tends to occur between the level of ambition in terms of reducing potential residual damage—that is, the effectiveness of the investments—and their cost (see Chapter 1). Climate forecasting and analysis, as well as information from engineers about building vulnerability and adaptation options, can be used to determine effectiveness to produce specifications for retrofitting or design. Furthermore, this information can support the prioritization of investment.[329] The benefits of climate-proofing might be considered in terms of damage to property avoided (for example, destruction of buildings), economic activity not forgone as a result of damage (electrical outages, failed bridges), avoided effects on health and human life or impacts on environmental services (erosion, loss of natural capital for climate resilience), and so on. These impacts can be more or less straightforward to monetize, and nonmarket valuation may be required for benefits not observable through market transactions and pricing. Generally, the aim for Aurelia was to achieve a constant relative risk level or maintain a constant absolute risk level. This meant concretely that, terms of flood risk, the analysis would consider the protection of buildings against a specified return-period event as a building standard in the country but in terms of heat would consider rising average temperature, according to RCP 8.5 scenarios, and robustness against some extreme heat wave events. It was also necessary to consider the variation in return-period levels as a function of climate change effects. In terms of wildfire, some measures were considered, but information was supposed to be insufficient on building vulnerability and effective measures particular to Aurelia, so this would be subject to an additional one-year research program, building on recent outputs from wildfire risk analytics for current and future climate, to be supported by the Ministry of Environment, overseeing the implementation of the NAP. For other hazards, such as landslides, storms, and sea-level rise, vulnerability was considered on a case-by-case basis, as exposure analytics showed only a small proportion of buildings in areas with medium to high hazard, subject to further refinement of the data. For all major investments, a benefit-cost analysis was undertaken to determine whether they made economic sense. Some nonmarket valuation needed to be improved, however, so the research project covered this, as well. For all analytics, the spectrum of projected climate impacts and other estimates were transparently outlined, and sensitivity analysis was conducted with different key parameters.

"Passive survivability" is defined as maintaining livable conditions in the event of extended loss of power or shortage of heating fuel. When a power outage or interruption in fuel supply occurs, most mechanical heating and cooling can no longer operate. The aim of passive survivability is to be prepared in any such an event to maintain safe indoor temperatures and, where possible, potable water. Examples from the use case considered in the analysis included options and paths to be followed to achieve passive survivability for newly constructed buildings.[330]

For transportation and power networks, detailed vulnerability studies and multicriteria analysis were conducted to inform the selection of CCA measures to be costed. Experts in Aurelia undertook detailed criticality assessments and considered plausible future hazards with large cascading effects that could affect these assets. A risk analysis involving determination of network vulnerability, criticality, and risk assessment under current climate was done for transportation networks to identify high-risk locations and prioritize adaptation interventions. For power

329 WB and EC. 2024. *From Data to Decisions: Tools for Making Smart Investments in Prevention and Preparedness.*
330 United States Green Building Council. 2023. Passive survivability and back-up power during disruptions. Energy and Environmental Design credits. Link.

networks, an integrated approach included risk analytics and impact scenarios to examine current and future climate impacts, with the interdependent cascading effects between power infrastructures taken into account. A long list of climate adaptation measures was considered, based on local and international experience (see also Table 5 in Annex 1 and Table 17 and Table 18 in Annex 3).[331]

The final selection and costing of measures are ongoing. In addition, the government of Aurelia is engaged in a multi-stakeholder dialogue with, first, industry stakeholders, as investment in power networks is often also led by the private sector, and there is potential during decarbonization to invest in both greener and resilient renewable energy;[332] and, second, the general public, as tools are now available to assess vulnerability at building level across Europe that could be used to provide better information.[333]

For education, health, and civil protection infrastructure, resilience against heat was prioritized, with proofing against other hazards to be done on a case-by-case basis. The assessment followed a portfolio-based prioritization of buildings requiring interventions based on risk analytics, socioeconomic considerations, and the functionality of buildings and their importance in the network (including acting as emergency hubs and shelters). As with transportation and power networks, a long list of climate adaptation measures was considered based on local and international experience (see also the Bulgaria case study in the previous section),[334] including measures for the passive survivability of buildings. Examples are outlined in Table 19 in Annex 3.

The measures mentioned above were then costed based on assessments by local engineers, considering national standards and international experience. Although these assessments are ongoing, an idea of the ranges of mark-up costs could be obtained from the literature and other country assessments (including Bulgaria; see previous section). Costs of selected measures to retrofit health buildings for heat protection can be found in Box 10 and potential costs of selected measures for fireproofing buildings in Box 11.

Other relevant examples of CCA costs from the literature include the following:

- *Residential building resilience against extreme heat (United States).* Implementation of cool roofs: US$0.75–$3 (€0.70–€2.79) per square foot[335]

- *Residential building resilience against wildfire (United States).* Fireproof retrofitting of roofs: US$22,010 (€20,574) per house[336]

- *Residential building resilience against wildfire (United States).* Fireproof retrofitting of external walls (including windows and doors): US$40,750 (€38,092) per house[337]

- *Education facility resilience against extreme heat (Italy).* Establishment of green schoolyards or gardens: €160–€300 per square meter[338]

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331 IEEP. 2012. Link.; World Bank. 2019. Overview of Engineering Options for Increasing Infrastructure Resilience - Final Report. Link; Interreg Adriadapt. 2022. Adaptation of transport infrastructure and services. Link.; Climate-ADAPT. 2023a. Adaptation options for hydropower plants. Link; European Commission. 2018. Climate change adaptation of major infrastructure projects - A stock-taking of available resources to assist the development of climate resilient infrastructure. Link.;

332 World Bank. 2019. Overview of Engineering Options for Increasing Infrastructure Resilience - Final Report. Link.; Deloitte Insights. 2022. Carbon-proofing the grid: increasing renewables and resilience. Link.

333 R4RE. Resilience for real estate. Link. - only for heat outside of France.

334 USHHS 2014. Primary protection: enhancing health care resilience for a changing climate. Link.; Boston Planning and Development Agency. 2005. Link.; Wisconsin. 2023. Flood prevention: steps that can save your life and property. Link.; C40. 2016. C40 Good practice guide: climate change adaptation in Delta cities. Rotterdam climate change adaptation strategy. Link. and blog; Stanford. 2023. Climate resilient California schools. Link; Miyamoto International, Inc. 2021. Overview of Engineering Options for Increasing Infrastructure Resilience in the Caribbean: 360° Resilience Background Paper. Link.; Miyamoto International. 2019. Link. Background Paper for this report, WB, Washington, DC; Miyamoto International. 2019. Link. Technical annex to background paper; Report for the Caribbean: ; ClimateAdapt. 2023. EU-level technical guidance on adapting buildings to climate change. Link. Technical report Link. and best practice guide Link.; Asian Infrastructure Investment Bank. 2022. Investing in Climate-Resilient Roads for a Better Tomorrow. Link.

335 US Environmental Protection Agency. 2022. Using Cool Roofs to Reduce Heat Islands. Link.

336 Headwaters Economics. 2018. Building a Wildfire-Resistant Home: Codes and Costs. Link.

337 Headwaters Economics. 2018. Link.

338 Di Pirro, Elena, Peter Roebeling, Lorenzo Sallustio, Marco Marchetti, and Bruno Lasserre. 2023. "Cost-Effectiveness of Nature-Based Solutions under Different Implementation Scenarios: A National Perspective for Italian Urban Areas" Land 12, no. 3: 603. Link.

- *Transportation network resilience against extreme temperature and weather events (EU Member States).* Adaptation of roads and tracks to higher temperatures or increased precipitation: €30 million–€8.9 billion per year[339]

- *Power network resilience against multiple hazards (EU Member States).* Adaptation of electricity grids: €640 million–€650 million per year[340]

- *Power network resilience against floods (six EU Member States).* Increase in dam height of hydropower stations: €16 billion per year[341]

- *Power network resilience against extreme heat (EU Member States).* Additional cooling of thermal power plants: €640 million per year[342]

BOX 10. HEAT RESILIENCE IMPROVEMENTS TO EXISTING HEALTH CARE FACILITIES IN AURELIA

Estimation of the cost of heat resilience improvements to existing health care facilities in the fictional country of Aurelia, considering marginal costs, was based on the literature. The comprehensive study, "Risks to Productivity in Hospital Settings from Heat-Induced Health and Well-Being Impacts," published by Frontier Economics in 2022,[343] analyzed the costs associated with climate change adaptation measures in 248 National Health Service hospitals in England. The four retrofitting measures considered for an existing medium-rise courtyard-type facility, with their estimated unit costs, were as follows:

- *Option 1:* Sealed mechanical ventilation heating and cooling; all glazing sealed; airtightness improved as far as practicable; mechanical ventilation installed—£953/m2

- *Option 2:* Natural cross-ventilation; perimeter heating retained; greater opening of glazed areas; shading provided—£1,152/m2

- *Option 3:* Advanced natural cooling summer ventilation; supply of winter gardens; liberal opening areas above the glazed areas to dissipate solar gains in addition to the natural ventilation provided in option 2—£1,568/m2

- *Option 4:* Natural ventilation provided, incorporating passive down-draught cooling and perimeter heating; development of a low-energy cooling strategy using passive down-draught cooling—£1,776/m2

A conversion factor of 0.5 was applied to these UK unit prices to adjust them to Aurelian prices in euros, which were then used to estimate the size of investment required to upgrade health facilities in Aurelia. For the purpose of the case study, the average size of a health care facility in Aurelia was assumed as 5,000 square meters. The costs per facility of the four adaptation options were as follows:

- *Option 1:* €2.38 million
- *Option 2:* €2.88 million
- *Option 3:* €3.92 million
- *Option 4:* €4.44 million

Considering an ensemble of three hundred facilities with an aggregate area of approximately 1.5 million square meters provided the total costs in 2022 prices of the four options:

- *Option 1:* €714 million
- *Option 2:* €864 million
- *Option 3:* €1.18 billion
- *Option 4:* €1.33 billion

The benefits of the alternative adaptation measures were accrued in terms of reduction in heat-related mortality and enhanced labor productivity of staff in the facilities. In the UK study, for example, labor productivity benefits for the four considered adaptation options ranged from 2 to 6 percent in 2030. For 2050, they were determined by retrofitting option as follows:

- Option 1: 6–34 percent
- Option 2: 1–3 percent
- Option 3: 5–27 percent
- Option 4: 5–30 percent

339 IEEP. 2012. Link.
340 IEEP. 2012. Link.
341 IEEP. 2012. Link.
342 IEEP. 2012. Link.
343 Frontier Economics. 2022. Risks to productivity in hospital settings from heat-induced health and wellbeing impacts. Internal report for the UKCCC (unpublished).

BOX 11. FIRE-RESISTANT BUILDING STANDARDS FOR FIRE SERVICE INFRASTRUCTURE IN AURELIA

The country of Aurelia conducted an evaluation of its building regulations for fireproofing design after determining that more than 10 percent of its current development is within the wildland-urban interface (WUI) – a transition zone where wildlands interact with humans and their activities.[344] Aurelia expects additional development in intermix regions as the economy grows, city centers become increasingly unaffordable, and sprawl begins to occur near forested areas. Additionally, the evaluation found that 80 percent of fire stations and fire service buildings are located in areas at high to very high risk for wildfire. Considering current vulnerability and future development realities, Aurelia intends to take a climate-oriented review of existing building codes so it can upgrade for fire safety today with consideration of future climate realities (see more details in Box 17 in Annex 3). Review of the current legislation shows two weak points in current design guidance. First, the guidance does not mention specifically how civil protection and fire service buildings should be designed to enhance fire safety codes nor how operations can be affected and risk can be reduced through adaptation measures. Second, while the guidance mentions hospitals, it provides no specific design requirements for fire safety or civil protection buildings. On the other hand, a strong point in the guidance is the mention of openings and glazing systems, as well as their materiality in terms of specifications to reduce fire spread. The current regulations also fail to mention microscale features,[345] of design that could help prevent fire from crossing over from one building to the next. These include, at minimum, roof and gutter characteristics, including roofing angle and material composition; geometry of gutters and eaves and the distance between them to prevent fire from spreading to the roof; and decks and verandas from which flammable materials or fuels can cause ignition.

Because country and regional data on the cost of implementing fireproofing for buildings in the WUI are lacking, data from different states in the United States were used to produce a baseline estimate for a two-story residential building in Aurelia.[346] Typically, the highest class of ignition resistance for a building focuses on roof design (which is also the component of the building most susceptible to fire ignition and/or damage). Buildings that are resistant to severe fire exposure have roof coverings made of asphalt fiberglass–composition shingles or of concrete or flat or barrel-shaped tiles.[347] Such wildfire-resistant construction can add approximately 2–13 percent to the entire cost of a new home, with baseline and enhanced building materials adding 2–8 percent and optimum building materials 4–13 percent.[348] The analysis for Aurelia found that the low-end cost of improvements to a WUI design for a new building would add approximately €5,150 to average building costs; the high-end cost would add approximately €48,800. It should be noted that these values represent floor estimates that will likely be higher for fire service and civil protection buildings, as they do not account for specific measures they must consider, such as flammable materials onsite that call for additional fireproofing design considerations. Finally, the transportation networks within the community must also be evaluated for the fire service to be operational during a fire event.

Aurelia's building regulation development committee, along with its fire protection services, agreed to include the above provisions in the next cycle of code development. They also provided low- and high-end cost estimates to discuss with contractors and owners. As part of its future agenda, Aurelia has decided, as well, to conduct research on the susceptibility to fire of its fire station and operation network and on design considerations. This would include transportation routes, especially routes to current and future high-density areas requiring services. In addition, the cost of fuel breaks and fire breaks in Aurelia will be considered and included in any masterplans for development in the WUI. Last, it will be prudent to update codes and regulations in future cycles for a 30- to 50-year policy and development plan to consider other areas of high wildfire risk resulting from climate change.

344 Stein, S. M. et al. 2018. Wildffre, Wildlands, and People: Understanding and Preparing for Wildffre in the Wildland-Urban Interface. USDA Forest Service.

345 Vacca et al. 2020. WUI fire risk mitigation in Europe: A performance-based design approach at home-owner level. Journal of safety science and resilience, 1(2), pp.97-105. Link.

346 Home Innovation Research Labs. 2020. Cost Impact of Building a House in Compliance with IWUIC. National Association of Home Buildings. Link. Note that the values from tables in this report are averaged and converted to 2023 Euros for purposes of this study. The three cities in three states referenced in the report provide estimates from areas of differing densities and construction costs.

347 National Fire Protection Agency, Class A roof covering description. Source: Link.

348 Headwaters Economics. 2022. Construction costs for a wildfire-resistant home: California edition. Link.

A few key elements could be considered by the country of Aurelia to ensure the successful implementation of climate-proofing and retrofitting. For climate-proofed infrastructure, the development of guidelines and building standards for both new designs and retrofitting of existing assets could provide detailed information and examples of good practice and offer a performance-based design approach. Such guidelines could also include code-based and above-code guidance for future proofing, especially prior to the implementation of large-scale climate-proofing retrofits that may face significant resistance from utilities to locating cogeneration and major electrical switchgear above the ground floor. Moreover, planners must ensure that enhancing resilience to one type of hazard does not lead to maladaptation or other unintended consequences. If not properly retrofitted, for instance, buildings affected by a seismic event could be further damaged by high precipitation or increased temperatures under a future climate. Moreover, ensuring adequate financial funding and resources for climate-proofing of infrastructure is crucial, as is using a sustainable financial model for adaptation investments in the long term. Finally, the implementation and maintenance of climate-proofed infrastructure requires cohesion between national and subnational regulation and collaboration between central and local authorities, as well as effective monitoring and evaluation mechanisms that can ensure high-quality review and constant upgrading of the adaptation measure.

Croatia: Climate-proofing selected civil protection assets

Croatia grapples with threats of climate change. In recent years, the country has encountered climatic extremes, notably the excessive heat of its most intense summer of 2017, a 74 percent surge in forest fires in 2022, and devastating cascading events in 2023.[349] Croatia is among the countries most affected economically by climatic events;[350] the cost of floods damage to infrastructure alone has been estimated at 0.4 percent of GDP annually.[351] Looming climate threats suggest more frequent and intense disasters ahead, threatening multiple critical sectors.[352]

Croatia has taken steps to implement climate adaptation. Adopted in 2020, Croatia's National Adaptation Strategy provides an assessment for the period up to 2040 with a view to 2070.[353] According to 2019 estimates, the total investment needed to implement the strategy will be around €3.6 billion for the period up to 2040, with the average annual cost amounting to around €183 million; such estimates provided useful information for planning projects for EU funding (for example, Cohesion Policy funds). More than half of the estimated amount refers to the implementation of "structural" measures, particularly in the sectors of agriculture, forestry, and water management (with respect to water resources) and, to a lesser extent, to energy and tourism. Investments in the first two sectors can be considered "no-regret measures"; as mentioned earlier, these are measures whose implementation is already planned that will also be helpful in terms of climate change adaptation. National authorities in Croatia have also developed legislation relevant to the enhancement of the climate resilience of infrastructure; this includes the Long-Term Renovation Strategy and the National Program for Green Urban Infrastructure.

349 *See DW*. 2022. Record high temperatures, and it has only just begun [Rekordno visoke temperature, a tek je počelo]. Link. *See* Global Forest Watch. 2023. Croatia. Link.
350 Climate-ADAPT. 2022. Croatia. Link.
351 Dottori et al. 2020. Adapting to rising river flood risk in the EU under climate change. Link.
352 State Hydrometeorological Institute (DHMZ). 2023. Climatological overview of the extreme weather in Croatia. July 2023 [Državni hidrometeorološki zavod in Croatian]. Link.
353 Government of Croatia. 2020. Climate change adaptation strategy in the Republic of Croatia for the period up to 2040 with a view to 2070 [Strategija prilagodbe klimatskim promjenama u Republici Hrvatskoj za razdoblje do 2040. godine s pogledom na 2070. Godinu] (Official Gazette 46/2020). Link. See Government of Croatia. 2023. Adaptation to Climate Change [Prilagodba Klimatskim Promjenama]. Link.

Croatia has taken advantage of opportunities within the EU's 2021–27 funding cycle to invest in strengthening climate adaptation measures. The total EU contribution to Croatia under Policy Objective 2 (PO2)— "greener, low carbon transitioning towards a net zero carbon economy"—of the Cohesion Policy amounts to €2.4 billion of an overall €2.9 billion. For CCA-specific investments under PO2, the EU total contribution amounts to €421.2 million, with an overall amount of €495.6 million.[354] Using the European Regional Development Fund (ERDF), Croatia renovated 250,000 square meters and 69 public buildings (hospitals and schools) with an expected annual savings of 70 GWh in energy consumption.[355]

The results of this CCA costing analysis can complement studies for prioritizing the upgrading of critical infrastructure that may ultimately feed into updated CCA and DRM plans. The adaptation objective of the analysis was to inform potential CCA measures for a portfolio of assets based on climate risk analytics.

The analysis considered climate risks that could be relevant to the upgrading of a broad set of critical infrastructure types and, more generally, to the portfolio management of assets (see Box 12). The analysis also assessed whether additional retrofitting measures should be considered to enhance resilience and what design features should be considered for new buildings, and it sought to inform policy dialogue on the management of a critical infrastructure portfolio.

Finally, this analysis complements a report that is a companion to this one. That study included the collection and analysis of data on more than 60 buildings used for emergency response services to assess their vulnerability[356] and the benefits and costs of providing them with seismic upgrading and energy efficiency interventions.[357]

BOX 12. PROJECTED CLIMATE-RELATED RISKS AND IMPACTS ON CRITICAL INFRASTRUCTURE

The analysis for Croatia built on quantitative and qualitative information on the risks of multiple hazards and impact analytics gathered for this project and from external sources. Information on exposure of infrastructure stocks was extracted from the GEM database,[358] while general information on extreme temperatures and floods, with future projections of heat impacts as per the COACCH scenario explorer, came from the 2019 NRA.[359]. This analysis was also conducted in line with EUCRA's "Critical infrastructure failure" storyline. It adopted a rapid risk assessment approach, viewing the vulnerability of critical infrastructure from the standpoint of a portfolio of climate and natural hazards—a perspective that can help inform more-detailed assessments in the future.

The study produced new and interesting findings on future wildfire risks and exposures resulting from climate change.[360] As a result of drier and windier conditions, wildfire hazard is expected to increase in the north and northeastern parts of the country, where the wildfire susceptibility currently is low. The places at high risk are mainly grassland and broadleaves areas, portending losses in the agricultural and forestry sectors. A trend of increasing annual losses overall in assets and critical infrastructure from wildfire is expected in the next 25 years. The losses for commercial and residential buildings, for instance, are estimated at €8 million and €25 million per year, respectively. In addition, more roads will be exposed to risks in the future under the SSP1 RCP2.6 climate scenario, with the exposure even worse if the SSP5 RCP8.5 scenario is adopted.

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354 EU. 2023a. Link.
355 EC. 2020. Link.
356 WB and EC. 2024 forthcoming. From Data to Decisions. The vulnerability analysis investigated seismic risk and estimated replacement costs and annual average losses, using probabilistic scenarios for 95-, 225-, and 475-year return periods, as well as a deterministic scenario event based on the 1880 earthquake in the city of Zagreb. To the extent possible, indirect impacts on the economy were estimated, including broad socioeconomic impacts and disruptions, including in GDP.
357 The analysis considered estimates of global and regional costs related to upgrading for seismic and climate protection. Among these were estimates for energy efficiency and levels of upgrading, including to meet EU-wide standards, building codes, and renovation strategy. The benefits considered were those related to risk reduction, taking into account their temporal and spatial contexts and current as well as future climate projections, along with the co-benefits generated.
358 Global Earthquake Model. Croatia. Link.
359 COACCH. Climate Change Impact Scenario Explorer. Link.
360 The CIMA Foundation. 2023. Wildfire risk analytics for European Countries.

This analysis was to be consistent with approaches taken in other countries and provide inspiration for further research. The case study followed climate-proofing of investment principles,[361] considering climate change mitigation and adaptation, particularly measures to enhance energy efficiency and flood resilience; wind- and heat-proofing considerations from the literature; and country best practices.[362] The analysis undertaken for Croatia used a portfolio-level rapid identification of climate risks and identification of CCA measures and cost ranges to support initial prioritization of risk reduction and preparedness investments at sectoral level, building on previous initiatives and providing a basis for future updates and refinements.

Potential risk-proofing and adaptation measures were outlined for selected infrastructure assets. The long list of CCA measures from the literature used for the Aurelia case study was considered for Croatia, with some selected for further consideration. The costs for these selected measures could be adapted for the Croatian context and for additional hazards with further studies, based on local market price information, expert consultations, and more in-depth vulnerability assessments on the portfolio of assets.

For Croatia, the decision was to undertake first an analysis considering the selected measures and one hazard. The analysis focused on the additional costs of proofing buildings against heat, considering guidelines such as those put forth by the EU in 2023;[363] follow-up studies might consider wildfire or flood risk. The results of the heat analysis are summarized in Box 13.

BOX 13. HEAT RESILIENCE IMPROVEMENTS TO EXISTING BUILDINGS IN CROATIA

The analysis sought to estimate the cost of improvements to increase the resilience to heat of existing buildings in Croatia, considering marginal costs. Retrofitting older buildings with climate-adaptive measures, such as improved insulation, energy efficient HVAC systems, and weather-resistant roofing materials, helps reduce energy consumption and carbon emissions, while the incorporation of features like stormwater management, green infrastructure, and enhanced ventilation systems will help the buildings withstand the extreme weather events that are increasing in frequency and severity. These improvements not only contribute to the longevity and safety of existing structures; they make them more adaptable to the changing climate and create a more sustainable and resilient built environment.

The four retrofit measures considered by the analysis were as follows:

Option 1: Sealed mechanical ventilation heating and cooling; all glazing sealed; airtightness improved as far as practicable and mechanical ventilation installed

- *Option 2:* Natural cross-ventilation, retaining perimeter heating; greater opening of glazed areas; shading provided

- *Option 3:* Advanced natural cooling summer ventilation; supply of winter gardens; liberal opening areas above the glazed areas to dissipate solar gains in addition to the natural ventilation provided in option 2

- *Option 4:* Natural ventilation provided, incorporating passive down-draught cooling and perimeter heating; development of a low-energy cooling strategy using passive down-draught cooling

Estimation of the costs of these options required taking into account the types and geographical distribution of buildings in Croatia, with asset valuations at the national level provided by the GEM database. While the analysis would be heavily skewed by the age distribution of the buildings, this information was not readily available, so assumptions had to be made concerning asset condition, valuation, and so on. As elsewhere, marginal costs were based on building size and type (that is, use category). A short-term outlook

361 In line with EC. 2021. Technical guidance on the climate proofing of infrastructure in the period 2021-2027. Link.
362 OECD. 2023b. Link; Lynch et al. 2019. Fighting Wildfires With Innovation, Insurance Information Institute. Link.; Interreg. 2022. Climate proofing of building codes. Link.; Miyamoto. 2019. Overview of engineering options for increasing infrastructure resilience and Increasing infrastructure resilience technical annex. Background papers for WB report that was published Link.; WB. 2019. Overview of Engineering Options for Increasing Infrastructure Resilience: Final Report. Link.; Hallegatte et al. 2019. Link.; UN. 2021. Climate Proofing Toolkit: For Basic Urban Infrastructure with a Focus on Water and Sanitation. Link.; EC. 2018. Climate change adaptation of major infrastructure projects. Link.;
363 EC. 2023. Technical guidance on adapting buildings to climate change. Link.

was considered for two heat resilience design scenarios: a lower estimate for cost allowing for, for example, the installation and maintenance of sealed mechanical ventilation plus sealed glazing; and an upper estimate allowing for, for example, an advanced natural ventilation system and energy efficient cooling system, provision of heat-resistant materials, external and internal shading, and high-performance glazing, plus green, blue, and hybrid solutions. To facilitate the analysis, an obsolescence rate had to be assumed for existing facilities and an assumed retrofit rate of 10 percent of necessary facilities replaced per five-year period over the considered time horizon (that is, 60 percent of stock retrofitted by 2050).

The marginal costs over the next five years for provision of the considered interventions in existing buildings ranged from €1.32 billion to €2.84 billion, with a net present cost (NPC) for interventions in the period up to 2050 ranging from €6.19 billion to €13.28 billion. Note that these cumulative totals may be further subdivided by building category for further analysis, with prioritization strategies for retrofit developed per category. Necessary underlying assumptions concerning labor availability and supply chain capacity can be nuanced in the analysis. Furthermore, the retrofit rate, assumed here at 10 percent of the stock per five-year period, can become a variable in a multicriteria optimization. Finally, the analysis can incorporate national strategies concerning targets and/or incentives for the retrofitting of, for example, residential stock.

The results from this case study can inform smart prioritization and decision-making and improve integration of the disaster and CCA agendas in a practical manner. This study provides only a starting point, as the analysis considered a single hazard for one type of asset. Moreover, the case study costed measures for resilience to heat that go beyond typical energy efficiency measures. While initial analysis can focus on one hazard, it is crucial to consider a holistic approach that incorporates multiple risks to maximize co-benefits.[364] By understanding the broader costs and benefits of implementing holistic improvement measures rather than partial solutions, decision-makers can weigh various criteria (economic, time and resources, political, operational) and the benefits of different interventions, including preventing maladaptation, avoiding future retrofits, and ensuring cost-effective CCA.

The overall purpose of this case study was linked to a policy objective of prioritizing the "smart" rehabilitation or reconstruction of critical infrastructure buildings. This type of analysis can inform measures aligned with the EU Renovation Strategy[365] and integrated renovation approaches.[366] Testing transformative solutions is also important in the context of implementing the EU Adaptation to Climate Change Mission.[367] The references and links to the literature and best practices from other countries on measures for climate-proofing included in the study can be integrated into the enhancement of resilience to wildfires, floods, and extreme heat risks. Finally, this study can be expanded to consider more hazards for climate-proofing, in terms of both CCA and DRM.

Romania: Flood-proofing and upgrading transportation networks

Romania is highly exposed to flood risk, but evidence on the impacts of flooding on critical infrastructure systems is too limited to allow for the effective prioritization and design of interventions. In line with Romania's NAP, a high priority for climate change adaptation until 2030 is to conduct a vulnerability assessment of the transportation sector and integrate climate change considerations into planning and decision-making. The Flood Reimbursable Advisory Services (RAS)[368] emphasizes the importance of adapting infrastructure to intensifying risks of flooding by updating technical regulations, improving infrastructure inventory, and prioritizing at-risk assets.

364 WB, EC. 2021.Investment in Disaster Risk Management in Europe Makes Economic Sense. Link.
365 EC. 2020. A Renovation Wave for Europe - Greening Our Buildings, Creating Jobs, Improving Lives. Link.
366 Butenweg, C. et al. 2022. Policy measures for seismic and energy upgrading of buildings in EU Member States. Link.
367 Government of France. 2023. Testing and demonstrating transformative solutions to protect critical infrastructure from climate change, mainstreaming nature-based solutions. Link.
368 WB. 2019. Technical Support for the Preparation of Flood Risk Management Plans for Romania (P170989).

This case study was conducted to demonstrate how to assess systemwide flood vulnerabilities and prioritize investments in resilient transportation networks, as planned in the NAP. The objective was to develop and cost adaptation measures in line with vulnerability analytics of the transportation network to support decision-making at sectoral and national levels. The analysis built on the transportation network vulnerability assessment undertaken for the Country Climate and Development Report (CCDR) for Romania,[369] which focused on current climate hazards. This new case study expanded that analysis to flood risks under future climate change scenarios and how they would alter the identification, prioritization, and costing of resilience investment. Several inputs to the analysis were based on the outputs of previous analytics,[370] and the overall methodological approach was based on analytics previously applied and validated in Albania,[371] Serbia,[372] Türkiye,[373] and other countries, as well as recent scientific literature.[374]

The main criteria for this analysis were to ensure analytical rigor, practicality, and replicability. It allowed for estimation of the order of magnitude of impacts on the transportation sector, as well as subsequent updates and extensions as improved data become available. The analysis consisted of a network-based economic analysis of resilience investments, following three analytical steps:

- **Step 1:** Estimating potential impacts of floods on transportation networks. The case study estimated two types of damage under current and future climate conditions: direct damage to transportation infrastructure and indirect damage in terms of disruptions to transportation and wider macroeconomic impacts. The probability of flood events under future climate scenarios was estimated by recasting the probability of current flood hazards in line with precipitation projections under different climate change scenarios in established climate models.[375] Applying vulnerability curves from previous assessments, the analysis translated kilometers of flood-exposed roads into average annual losses in euros.

- **Step 2:** *Determining potential adaptation needs and costs.* The case study then gauged the costs and benefits of integrating climate change adaptation into flood risk management in the transportation sector's investment portfolio. High-level technical costing of resilience measures for transportation networks was based on insights from Romania's strategic documents (NAP) and in line with World Bank estimates of public investment needs in the sector and additional costs for incorporating resilience into transportation.[376] Combined with total road exposure data (Step 1), this process provided insights into future road budget requirements and adaptation costs resulting from impending flood risks due to climate change.

- **Step 3:** *Estimating the potential benefits of CCA measures in terms of reduced expected losses.* The benefit-cost ratio of transportation resilience investments can vary widely, depending on the assumptions and scenarios considered. This analysis established a benefit-cost ratio by comparing the adaptation investment needs (Step

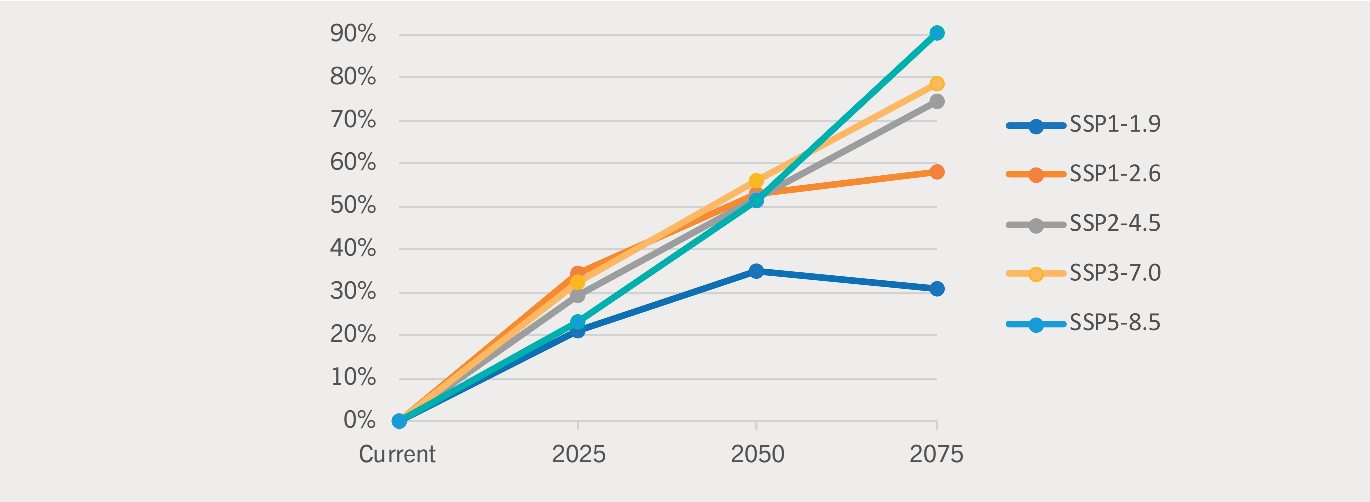
369 WB. 2023. Romania CCDR. Link. WB and EC. 2024. *From Data to Decisions: Tools for Making Smart Investments in Prevention and Preparedness.*
370 For the second implementation cycle of the EU Floods Directive (FD), Romania crafted flood risk management plans for its 12 units of management. During the 2019 Preliminary Flood Risk Assessment, 526 areas of potential significant flood risks were identified, leading to the development of new hazard and risk maps and programs of measures, which emphasize sustainable, climate-resilient interventions, prioritizing nonstructural measures, green infrastructure, and nature-based solutions; these were integrated into the draft flood risk management plans (FRMPs). WB. 2023. Report on advice provided to MEWF in the preparation of twelve (12) final draft Flood Risk Management Plans".
371 Xiong, J. & Alegre, E. X., 2019. Climate Resilient Road Assets in Albania, Washington, DC.: WB. Lin.k
372 Vukanovic, 2018. *Climate and disaster resilient Transport Infrastructure*. Washington DC: WB; *Rozenberg* et al, 2019. F*rom A Rocky Road to Smooth Sailing: Building Transport Resilience to Natural Disasters.* Washington DC: WB.
373 WB. 2022c. Link.
374 He et al. 2022. Mobility and resilience: A global assessment of flood impacts on urban road networks. Link; "Hallegatte, S. et al. 2019. Link; Rozenberg, Julie; Fay, Marianne. 2019. Beyond the Gap: How Countries Can Afford the Infrastructure They Need while Protecting the Planet. WB. Link; van Ginkel, K. C. H., Dottori, F., Alfieri, L., Feyen, L., and Koks, E. E. 2021. Flood risk assessment of the European road network, Nat. Hazards Earth Syst. Sci., 21, 1011–1027, Link; EC. 2018.
375 Based on the CMIP6 model ensemble, or by use downscaled rainfall projections from EURO-CORDEX for 2050, 2075, etc.
376 Rozenberg; Fay. 2019. Link; Hallegatte, Stephane et al. Link.

2) to the direct and indirect losses that could be mitigated by such investments (Step 1) and then comparing the result to existing estimates from the literature and country case studies.

The analysis yielded several key insights into the vulnerability of Romania's transportation network, the impacts of floods, and the costs of CCA measures and their potential BCRs.

Under current climate conditions, flooding is expected to increase nationwide annual road transportation costs by around 6 percent and passenger railway costs by around 25 percent compared to a baseline scenario with no flooding. For 10-, 100-, and 500-year return-period flood events, the costs will be 26 percent, 52 percent, and 65 percent higher, respectively. For the railway network, even a small-scale flood event can cause significant disruption: a 5-year flood event almost doubles the nationwide cost of passenger railways, increasing to around 180 percent for a 200-year event.[377] Under future climate by 2050, economic impacts from flooding are expected to be even greater. Taking the example of agricultural losses related to flood-induced transportation disruptions, annual nationwide losses are projected to increase by an average of around 35 percent for SSP1 RCP1.9 and around 51 percent for SSP5 RCP8.5 by 2050 compared to the baseline average annual loss (AAL). By 2075, the losses could increase by between 30.7 percent (SSP1 RCP1.9 scenario) and 90.3 percent (SSP5 RCP 8.5 scenario, see Figure 22).

Figure 22. Increases in agricultural losses from flood-related transportation disruptions

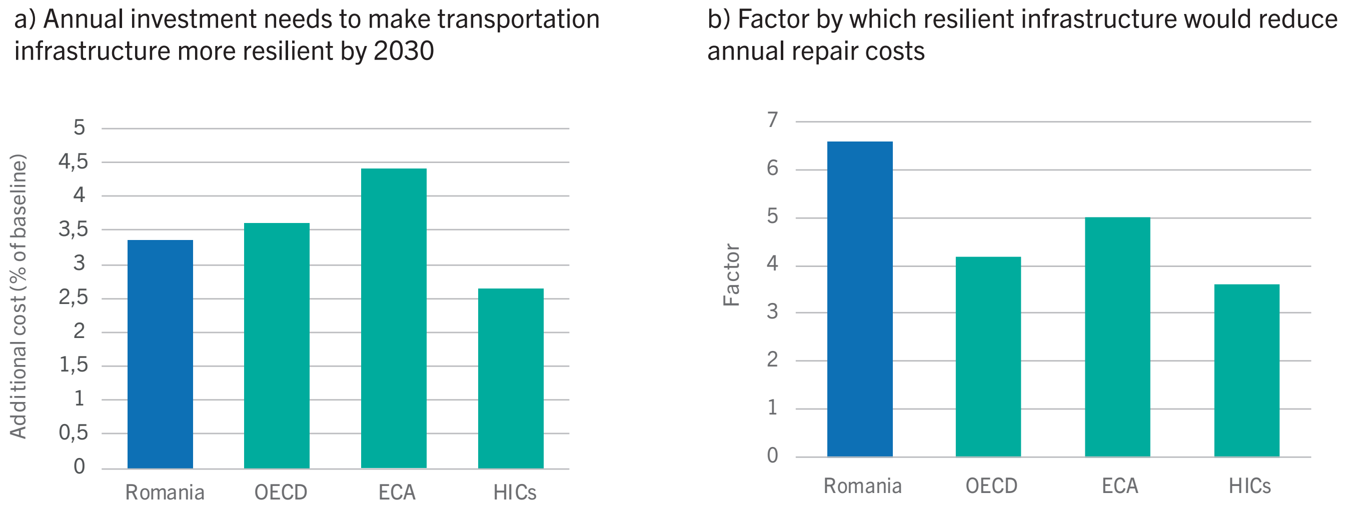


Source: World Bank.

The analysis estimated that resilience measures in the transportation sector would increase public transportation investments by only 3.4 percent but yield substantial benefits. Romania's infrastructure resilience investment needs are similar to those of countries in the OECD and the Europe and Central Asia region. Because most of Romania's transportation system is exposed to various hazards, building all new transportation infrastructure assets to higher resilience standards could reduce average annual repair costs by a factor of 6.6—significantly more than in the other countries (Figure 23).

377 Although these large numbers are partly artifacts of modeling (the railway network is less disaggregated than the road network), the findings have some ground truth for two reasons. First, inundation of a small segment of a very long road will cause only local disruption on the inundated segment. In contrast, localized inundation of a railway segment, especially a high-intensity inundation, can substantially disrupt the whole route or even render it impassable. Second, while the presence of smaller local roads can sometimes provide alternate routes when main roads are flooded, such alternate local routes are not available for railway networks.

Figure 23. Investment needs and cost efficiency of resilient transportation infrastructure



Source: Hallegatte, Rentschler, and Rozenberg. 2019.
Note: ECA = Europe and Central Asia; HICs = high-income countries.

Overall, while resilience measures are case- and location-specific, the nationwide assessment suggests a strong economic case for resilience measures, including nature-based and engineering solutions. The case study specifically estimated cost and benefit of measures over the implementation period until 2080for reducing the impacts of increasingly likely and severe flood events across Romania's road network. Implementation costs for nature-based solutions, such as incorporating swales, ponds, and geotextiles, were estimated at €123 million, yielding benefits with a net present value of about €1.34 billion (lower bound). Similarly, traditional engineering measures, such as installing filters and drains, were estimated to cost €491 million and yield benefits with a net present value of €5.38 billion (upper bound).

In short, the economic case for resilience measures reflects not only the wide range of impacts associated with floods but the opportunities presented by different types of solutions. CCA measures would avert direct damage of flooding to road networks (and hence mounting repair and maintenance costs), as well as the wider economic impacts associated with transportation and supply chain disruptions propagating through economic systems. While policy-makers have traditionally been more likely to consider engineering measures, such as filter drains in national adaptation investments, nature-based solutions have relatively low implementation costs and wider co-benefits and should also be promoted. The earlier such resilience measures are implemented, the larger the losses avoided (and the greater the benefits) will be.

This analysis demonstrated how a comprehensive benefit-cost assessment of sectoral CCA measures can be conducted in a way that accounts for indirect effects across systems, regions, and networks. It remained limited, however, in sectoral scope and granularity, as it was applied to a single hazard (flood) with limited sectoral coverage (transportation, agriculture). As part of a dedicated risk assessment and investment appraisal, further consideration of exposure, vulnerability, and potential impacts of multiple hazards across sectors would be preferable. In addition, the impact of additional shocks and stressors could be assessed and the benefits of adaptation evaluated through complementary scenario-based analyses. Benefits of resilience investments that may be difficult to monetize but strengthen the business case could be illuminated by broadening how they are defined, in line with the

Triple Dividend framework.[378] Finally, accounting for the spectrum of estimates associated with the different data sources, especially in the case of long-term projections, is crucial for robust decision-making. Although such comprehensive assessments have substantial requirements in terms of data and resources, yet they could better identify the benefits of adaptation under compounding shocks.

This case study provides an example for other countries in Europe, many of which have transportation networks and infrastructure systems exposed to high flood risks. A COACCH flood risk assessment identified three flood hotspots in the EU road network, including the Netherlands; the western Alps in France, Italy, and Switzerland; and Croatia and Serbia in the northwestern Balkans.[379] Assessments like COACCH, however, tend to focus on direct exposure and damage while overlooking broader macroeconomic impacts. Replicating this case study would help countries understand how localized flood impacts can propagate across infrastructure and supply chain networks, thus leading to significant losses in other vulnerable sectors (such as agriculture) and regions. By identifying the most critical chokepoints in road and rail networks, this analysis can assist policy-makers in prioritizing CCA investments cost-effectively.

The network effects captured in this case study highlight the need to design CCA measures in the transportation sector to tackle systemic vulnerabilities in assets, networks, institutions, and planning. Strengthening climate resilience requires going beyond standard engineering upgrades to implementing a concerted package of measures in five areas, as summarized in Table 4. Getting the basics right—including through operations and maintenance—is crucial to improving baseline service quality as well as resilience. Ensuring institutional roles are well-defined is key to enabling smooth collaboration, including between central and local authorities, as well as among different line ministries and transportation agencies. Regulation and legal standards can be essential to ensure infrastructure developers and operators (public and private) take climate risk into account, especially during planning and design phases. Investments in data systems and decision-making capacity can support the continuous monitoring of infrastructure performance, thus enabling more rapid and spatially targeted response to shocks, as well as smarter use of limited funds. Finally, it is important to note that ensuring adequate financing arrangements for resilience measure is easier said than done; financing needs to be earmarked early in project cycles to conduct risk assessments, and contingency financing strategies are key for authorities to achieve quick recovery of transportation assets damaged by climatic shocks.

Experience shows that no single measure can make infrastructure systems resilient. Instead, governments—in partnership with all stakeholders, including transportation agencies, investors, business associations, and citizen organizations—need to define and implement a consistent strategy to tackle the many obstacles to making transportation systems more resilient. Of particular importance is an emphasis on the early stages of infrastructure system development—the design of regulations, the production of hazard data and master plans, and the initial stages of new infrastructure asset design. In these early stages, small investments can significantly improve the overall resilience of infrastructure systems and generate large benefits. Implementing resilience measures early has been shown not only to increase the resilience of transportation systems but to improve their overall governance and efficiency, thus making them no-regret options regardless of climate change.

378 Tanner et al. 2015. The Triple Dividend of Resilience. GFDRR/World Bank/ODI Link.
379 Van Ginkel, K et al. 2021. Link.

Table 4. Five recommendations to strengthen the climate resilience of transportation systems

RECOMMENDATION	ACTIONS
1. Get the basics right	1.1. Introduce the enforce regulations, construction codes and procurement rules 1.2.Create systems for appropriate infrastructure operation, maintenance, and postincident response 1.3. Provide appropriate funding and financing for infrastructure planning, construction, and maintenance.
2. Build institutions for resilience	2.1. Implement a whole-of-government approach to resilient infrastructure, building on existing regulatory systems 2.2. Identify critical infrastructure and define acceptance and intolerable risk levels 2.3. Ensure equitable access to resilient infrastructure
3. Create regulations and incentives for resilience	3.1. Consider resilience objectives in master plans, standards, and regulations and adjust them regularly to account for climate change 3.2. Create economic incentives for service providers to offer resilient infrastructure assets and services 3.3 Ensure that infrastructure regulations are consistent with risk-informed land use plans and guide development toward safer areas
4. Improve decision making	4.1 Invest in freely accessible natural hazard and climate change data 4.2. make robust decisions and minimize the potential for regret and catastrophic failures 4.3 Build the skills needed to use data and models and mobilzie the know-how of the private sector
5. Provide financing	5.1 Provide adequate funding to include risk assessments in master plans and early project design 5.2 Develop a government-wide financial protection strategy and contingency plans 5.3. Promote transparency to better inform investors and decision makers

Source: Hallegatte, Rentschler, and Rozenberg. 2019.

Ways forward to enhance CCA costing evidence

The analysis of case studies to illustrate certain "use cases" had twin benefits. It allowed calculation of the costs of CCA measures that could feed into updates of NAPs, sectoral strategies, and risk reduction programs (as summarized in Figure 24). It also provided useful lessons learned for the application of various methodologies and the replication of these studies for other sectors and countries.

Although analytics are very specific for each use case, insights and results can support analyses in other countries. Costing for the forestry and emergency response sector considering wildfire risks in Bulgaria and Sweden, for instance, provided very useful information to update NAPs, civil protection programs, and forestry strategies across Europe. Analytics on wildfire that informed the Bulgaria case study were informed by new quantitative evidence that revealed many lessons learned and avenues for further research (see Box 14 below). Insights on CCA measures for the health sector derived from the case study for Bulgaria could be considered in broader and detailed assessments for the sector and, ultimately, feed into national programs and NAPs. Insights on urban heat CCA measures could be applied by local governments when formulating their own strategies. The analysis on climate-proofing infrastructure conducted for Croatia and Romania could inform early conceptual thinking around programs to upgrade public infrastructure elsewhere. Most generally, evidence gathered during these studies could be shared through knowledge networks, with broad focus (on NAP costing or macroeconomic analysis) or specific focus (on sectors such as forestry or health or hazards such as wildfires or heat). Further analysis would be needed to assess how transferable studies and methods are from one context to another.

BOX 14. LESSONS LEARNED FROM WILDFIRE RISK ANALYTICS CONSIDERING CLIMATE PROJECTIONS

The novel wildfire risk and loss modeling framework focused on incorporating the effects of climate parameters and using higher-resolution data. This approach allowed for deeper insights into the evolution of risk considering different climate change scenarios. The analysis revealed an increase in wildfire risk across the analyzed countries (Bulgaria, Croatia, Greece, and Romania) and showed the importance of considering different climate models and year-to-year variability in understanding the possible range of outcomes. The new framework leverages pan-European fire occurrence data, strengthening the reliability and comparability between regions. The developed model revealed future trends of changes in susceptibility and hazard to large fires in the four countries, which are expected to experience an increase in temperature and heat wave days leading to higher risk of extreme wildfires. The study also uses information on social vulnerability and coping capacity to enrich the understanding of wildfire risk, where a Wildfire Social Risk Index was developed to include data on fire-fighting capacity and provide insight into which regions are more vulnerable and require further investments.[380]

The studies developed for this report found high benefits from portfolios of CCA measures that consider multiple risks and objectives and soft and hard measures. Much of the adaptation cost literature focuses on a narrow set of technical options (for example, the cost of dikes for flood protection). The studies here revealed that low-cost and early no-regret actions based on nontechnical options are often available and, further, that portfolios of options are usually beneficial when they take into account the complex timing of climate change adaptation and the spectrum of projected climate impacts and, therefore, of appropriate CCA measures. More focus on softer measures, and on portfolio approaches, would be useful. As these can be more difficult to cost than technical measures, enhanced guidance on how to cost them would be useful.

A knowledge gap remains on the effectiveness and benefits of CCA measures. A common theme across

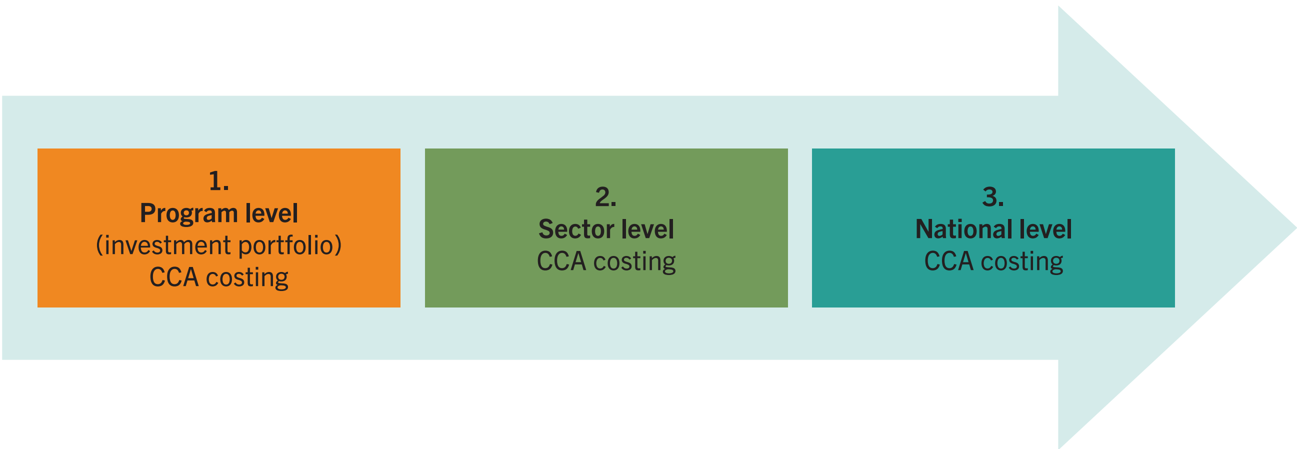
380 WB and EC. 2024 forthcoming. From data to decisions: tools for making smart investments in prevention and preparedness in Europe.

studies is that information is insufficient on the effectiveness of adaptation in general, and wide variations are also found in the effectiveness of the same options between locations and contexts. Further investigation of effectiveness (and benefits) is critical, including more ex post analysis on existing no-regret options and early examples of applied adaptation, as well as ex ante modeling that looks at the important issues related to the gauging of benefit ranges and what is important to consider.

Possibilities exist to scale up and replicate analytics, but certain limitations remain. The potential to apply the methods demonstrated in this report to other contexts is considerable, and doing so would be extremely useful in encouraging various countries, sectors, and other stakeholders to gain some experience in adaptation costing. Nonetheless, the approaches show that such studies often require considerable expert knowledge, as well as time and resources. Consideration has to be given to how to promote studies (and motivate actors to do costing) but at the same time provide the support needed to allow the actors to start testing and adopting approaches to costing.

Going forward, analytical gaps need to be filled to allow for more detailed and expanded adaptation studies. A final issue identified was the data gaps for more detailed analysis. While increasing amounts of data are available from Copernicus and ISIMIP, their extraction and use for context-specific risk analysis is complicated, and gaps often occur with regard to the specific variables of interest for adaptation (at least in terms of easy access). These data gaps are larger for adaptation costing, and while many inventories of options are available, translating them into applied adaptation analyses and assessing costs and effectiveness is subject to major data limitations. A continued focus on research and innovation (through Horizon Europe and others) is needed to provide more real-world adaptation information that can be used in planning ranging from national to local to support decision-making on adaptation over the next five years.

Figure 24. Analytics for use cases informing each other



Source: World Bank.

3. Conclusion and Policy Recommendations

Costing CCA: Orienting our compass ...

Scaling up investments in climate adaptation requires more and better information on their costs. A knowledge gap regarding the costs of CCA at national and EU levels inhibits countries from taking timely actions, making decisions about CCA investments, and scaling up finance (public and private) to address current insufficiencies in adaptation. In 2023 reporting from EU Member States to the European Environment Agency (EEA), the Member States noted substantial technical and resource constraints on developing comprehensive climate risk assessments and studies for CCA costing, as well as on the development of better expenditure tagging and reporting systems on climate adaptation expenditures. By enhancing the knowledge base of methodologies and evidence on CCA costing, this report can support the Member States in their process of CCA costing, identifying adaptation funding gaps, and implementing CCA expenditure tagging.

Adaptation costs for various objectives differ, based on economic efficiency, acceptable levels of risks, or risk minimization. Costs also differ with relation to the timing of adaptation and, especially, with the focus on near-term investment (to 2030) to scale up national adaptation planning and investment. Existing estimates from individual countries on CCA costs at the national level vary from €3.96 million to €11.6 billion per year, with large disparities in their coverage of risks and sectors. Of the more than 120 literature reports reviewed by this study, only 30 or so (covering 17 European countries) included CCA cost estimates. As an intellectual exercise, illustrative short-term annual adaptation costs can be derived based on extrapolation from national studies; the result indicates a level of €15 billion–€78 billion per year for EU-27 until 2030, with central and medium estimates of €21 billion and €64 billion per year, respectively.

Effective adaptation pathways can be developed by combining current and future climate risk information with multidisciplinary expertise. To prepare for compound, multi-hazard, and disruptive events, comprehensive investment packages need to be developed for CCA and DRM. Because climate change could lead to transformative and systemic changes in sectors that change the fundamental attributes of a social-ecological system, there is a need for more strategic analysis today and long lead times for planning. . The development of adaptation pathways starts with current risks and looks at future pathways, considering the diversity of projected scenarios for climate impacts. This approach encourages adaptive management and iterative learning and helps with navigation of the challenges posed by the spectrum of possible climate impacts, leading to numerous possible ways to adapt.

This report provided an overview for practitioners and policy-makers of methodologies, the literature, and country examples for costing CCA. There is no single blueprint or approach for costing CCA, and the appropriate method depends on the specific objectives and the level and type of CCA cost assessment. The report applied these insights for specific "use cases"—national, sectoral, and programmatic— presenting generalized applications of adaptation in particular decision-making contexts, as defined in a recent DG CLIMA study. Five new case studies, covering four countries and one fictional example, complemented these use cases, providing more practical applications to support decision-making. The study focused on the short-term timelines (2030s–50s) of the most relevance to policy decision-making to supplement existing research and studies, which often focus on medium- to long-term timelines (2050s–2100s). The costing of adaptation for national policy requires multiple evidence lines and studies and develops over time as more evidence emerges.

With rising adaptation costs, the demand to assess the economic benefits of adaptation and to compare alternative uses of resources will increase, requiring more concentration on economic appraisal. The European Commission (EC) and many Member States use economic appraisal to assess public policies, strategies, and investments as part of impact assessments. The analysis of the economic benefits and the social cost-benefit analysis of adaptation is of growing importance, especially given the likely demand for public financing of adaptation, but it is also challenging because of the range of projected climate impacts and the complexity of finding the right timing for adaptation (as adaptation requires upfront costs but often yields benefits in the long term). This study demonstrated how to extend costing analysis and begin to consider adaptation benefit-cost analysis with respect to short-term investments. The demand for such analysis will almost certainly grow, but such analysis is challenging.

... toward effective and resilient pathways

Adaptation costing studies spur important multi-stakeholder dialogues and inform policy discussion, planning, and budgeting for mainstreaming and scaling up CCA. Across the EU, such costing processes have helped raise awareness, initiate national discussion, support decisions, and improve systems to monitor and track progress on CCA. They have contributed to mainstreaming CCA into line ministries' plans, while the more complex assessments have sought to determine the effectiveness of measures to be selected, prioritized, and implemented. In Austria and Germany, decade-long adaptation studies with multiple building blocks revealed a need for better expenditure tracking at both national and local levels to improve financing for adaptation; these studies took note of the substantial costs and benefits that could also be expected at the macroeconomic level and highlighted possible synergies between CCM and CCA investments.[381] Studies in France, focusing on low-regret measures in the short term, have informed the next National Financial Budget Strategy and longer-term financial and fiscal planning based on various climate scenarios. France has also begun preparations for a 4°C world based on the national debates that informed the updating of the National Adaptation Plan in 2023. Such preparations represent a starting point for larger-scale systemic changes and the setting of pathways for more transformational adaptation.[382]

Lessons from EU countries provide invaluable insights for better planning and budgeting for CCA. National planning studies like those in France, which estimated early adaptation costs at around €2 billion

381 Tröltzsch, J., et al. 2012. Link.; IÖW. 2021. Link.; Knittel, N., et al. 2017.Link; Government of Austria. 2022.Spending Review im Rahmen des Aufbau- und Resilienzplans - Modul 1 „Analyse der klima- und energiepolitischen Förder- und Anreizlandschaft". Link.; Eichberger, S., et al. 2023. Budgeting for Climate Action: Lessons from Austria, France, and the European Union. Link.

382 Depoues et al. 2022.; Alexandre, S., et al. 2019. Link.; Eichberger, S., et al. 2023. *Budgeting for Climate Action: Lessons from Austria, France, and the European Union*. Link.; I4CE. 2023. Economic implications of adaptation pathways (upcoming). Link.

annually in this decade, have influenced short-term financial strategies as well as medium- and long-term planning. Austria's estimate of €421 million–€573 million and Germany's of €140 billion–€142 billion annually, were the conclusion of years of collaborative research. The studies highlighted the pressing need for improved expenditure tracking and a better understanding of broader macroeconomic implications to further improve such estimations. Bulgaria and Romania, with their research determining adaptation costs until 2030 of approximately €7 billion and more than €19 billion, respectively, have enriched national dialogues on multi-hazard investments and financial resilience. The new case studies undertaken in this report also provided new insights. Sweden's CCA costing analysis, focused on the forestry sector, helped identify the high returns of adaptive forest management and capacity-building measures. Croatia's findings on climate-proofing underscored the significance of infrastructure upgrades in future programs and the importance of a national dialogue on managing multi-hazard risks, while initial estimates of €123 million–€491 million for climate-proofing the transportation networks in Romania against flood risks enhanced the knowledge base for future in-depth multi-hazard assessments. Together, these studies offered a comprehensive roadmap, informing both sectoral strategies and National Adaptation Plans for countries embarking on climate change adaptation.

Building resilient futures in the face of evolving climate risks, including compound, multi-hazard, and disruptive events, requires developing comprehensive investment packages for CCA and DRM, with a mixture of options that evolve over time. Countries can balance both immediate and long-term adaptation strategies to tackle hazards and encourage more research on the costs and scalability of measures. Within a portfolio, short-term, low-cost adaptation measures can be considered alongside more resource-intensive, long-term capital investments. A suite of measures that include no-regret, climate-smart integration and early adaptation planning to support future scale-up creates adaptation pathways and ensures the benefits of adaptation are delivered early on, while taking the first steps toward longer-term systemic changes. The scale-up of plans and early steps for longer-term investment also provide opportunities for monitoring, evaluation, and learning to improve future decisions and for ongoing multi-decade investments (either scaling up adaptation over time as risks evolve or getting better information before tackling expensive options, such as retrofitting). These portfolios often work well when they include mixtures of technical and nontechnical options (hard and soft) and of green and grey (soft and hard) measures. Measures considered in a particular adaptation portfolio can geared to key performance indicators relevant to that thematic area, as exemplified in this report.

Further research and ways forward

This report was limited in its scope and needs to be considered in the context of broader CCA debates and studies. Adaptation is a complex topic, and decisions on investments need to be based on societal debates, cross-sectoral studies, cross-hazard risk analytics, economic studies, and adaptation studies. Costs of adaptation are difficult to identify precisely because of the wide range of future climate impacts and the many levels of adaptation they require. Evidence is also limited on the costs of CCA measures in terms of sectors and hazards, often because reports are internal, unpublished, or available only in local languages; and the types of measures covered (hard structural versus soft behavioral or policy measures) call for more complex approaches than has been the case for mitigation. This report focused on a selection of use cases and referenced the literature for further insights. The key issue on who should bear the investment costs for CCA and investments, which was only touched upon, will be crucial for future adaptation. To date, adaptation has been largely undertaken by the public sector, but given the adaptation finance gap, the private sector and households clearly will need to contribute. Beyond methodological concerns, the public/private split of investments will require national legislation and much more detailed adaptation studies.

National Adaptation Plans and supporting institutional processes can take into account adaptive management and iterative knowledge development. Generally, NAPs provide an extensive list of broad adaptation measures with actions that are feasible with current or slightly higher national budgets (that is, early actions, including no-regret or low-regret measures, among them soft options), as well as actions that require more funding. NAPs can provide a basis for more detailed studies that take into account updated climate risks, extreme scenarios, cascading impacts or multi-hazard impacts, and cross-sectoral synergies. CCA studies allow for more specific costing of CCA measures within broader programs or investment portfolios, identifying synergies and potential trade-offs and assessing the feasibility of measures with current or increased budgets, therefore informing the prioritization of measures and their timing. This study showed how continually developed risk analytics and adaptation studies can help inform NAPs and implied that it can be useful to include soft and research CCA measures in NAPs so that they are embedded with a process of regular improvement of the evidence.

Both existing and new institutional actors can be involved in shifting thinking on adaptation from its being an environmental issue to a finance and planning one, with responsibilities assigned across all ministries. More broadly, such dialogue requires coordination across ministries, agencies, and institutes and for policies influencing resilience such as spatial planning to be considered at national and cross-border level. The 2023 EEA report on adaptation progress has identified national adaptation networks, panels, and committees as key to helping MS with horizontal policy integration, multi-level coordination, scaling of adaptation actions, progress evaluation, and coordination through knowledge networks.[383] These entities can review evidence regularly to inform updates of NAPs and review progress on adaptation investment and remaining gaps. They can also be responsible for member state reporting to the EC on adaptation progress, as required under the EU Climate Law. Finally, these national coordinating entities can be connected to European and cross-country expert networks to ensure they have access to the latest evidence from other countries on modeling, methodologies, climate risk analytics, and CCA costing.

The EU can enable the uptake of CCA costing assessments. The practice of costing studies to enhance the efficiency and effectiveness of CCA investments would confer broad benefits. Moreover, it would be valuable to have available databases of CCA options that can highlight potential no-regret actions and provide benchmark costs and methodologies and—whenever available—information on the potential benefits of CCA measures, taking into account that these tend to be very site- and context-specific. Such databases could support quicker and more robust assessments and, in turn, improve the value of adaptation expenditures. An information base of evidence on expected climate impacts, built from such sources as EUCRA, TRACE, PESETA IV, and rapid exposure and vulnerability assessments, and on extreme scenarios can also be useful to EU Member States. A menu of tools are already available for instance on managing climate risks.[384]

383 EEA. 2023c. Adaptation governance examples include: (i) reporting obligations or procedural rules; such as in Greece, Sweden (through the Swedish Meteorological and Hydrological Institute), Ireland, Romania (Inter-Ministerial Committee on Climate Change), Portugal (through the Climate Action Commission; (ii) technical or operational coordination; such as in Belgium, Croatia, France, Germany, Greece, Ireland, Slovenia and Spain (i.e., the Climate Change Office, with other national coordination and participation bodies tasked with adaptation issues); and (iii) NAS or NAP task force-like groups, such as in Estonia (national adaptation web portals), Denmark(thematic working groups), Czechia and Portugal (sector-related coordination).

384 EC. 2024. Managing climate risks - protecting people and prosperity. Section 3.2. Tools for empowering risk owners. Link.

Finally, these databases and knowledge products could support climate risk and adaptation assessments conducted to identify CCA measures to feed into NAPs, as well as inform CCA costing and budget planning at the national and local levels. They could be complemented by a network of experts who advise countries on the costing of CCA on a scase-by-case basis, in detail and considering climate risks. All these support mechanisms would aid implementation of the European Climate Law and the Green Deal, including the EU Adaptation Strategy. Further consideration of how to develop them, or provide support through existing or new mechanisms, would be useful.

The following is a summary of main challenges, limitations, and opportunities.

KEY CHALLENGES AND LIMITATIONS	WAYS TO MOVE FORWARD
• Lack of information on projected impacts of climate risks for the short to medium terms (2030s–50s), particularly to inform sectoral or investment portfolio assessments and including consideration of extremes (wildfires, heatwaves, etc.) • Lack of comprehensive evidence on CCA costs • Difficulties of comparing costs of climate adaptation measures across countries due to use of different methodologies • Lack of knowledge on the benefits of CCA measures needed to enable prioritization and timing, as well as assessment of trade-offs among various measures • Complicated contextualized costing of CCA measures due to lack of analysis at sectoral level or for investment portfolios, calling for creative solutions that have to be arrived at through a resource-intensive process based on a mixture of literature reviews, data, and information collected on national strategies • Lack of research on CCA measures supporting multi-hazard resilience	• Continue investing in data collection at the national level. • Provide incentive for adaptation studies at the national level. • Support capacity building on costing CCA across Europe. • Encourage the exchange of knowledge and lessons learned as well as the sharing of data and reports—even preliminary insights—on costing of CCA measures to enhance the evidence base. • Evaluate expenditures and budget plans to identify adaptation gaps and track progress. • Conduct further analytics on private versus public sector investment in CCA measures.

ANNEX 1. Background and Overview of Findings on Climate Change Adaptation Costs

BOX 15. CCA OBLIGATIONS UNDER EU CLIMATE LAW

Regulation 2021/1119/EU imposes various obligations on the EU institutions and the EU MSs, including CCA obligations. Pursuant to Article 5, EU MSs shall:

- Ensure continuous progress in enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change (Article 7 Paris Agreement[74])
- Ensure adaptation polices are coherent and, mutually supportive, provide co-benefits for sectoral policies, and work toward better integration of CCA in a consistent manner in all policy areas,
- Adopt and implement national adaptation strategies and plans, (a) considering the EU Adaptation Strategy;[75] (b) based on robust climate change and vulnerability analyses, progress assessments, and indicators; (c) guided by the best available and most recent scientific evidence; (d) taking into account the particular vulnerability of the relevant sectors; and (e) promoting nature-based solutions and ecosystem-based adaptation (MSs shall regularly update the strategies); and

EU MS reporting obligations, pursuant to Article 19(1) of Regulation 2018/1999/EU,[76] on the national CCA planning and strategies, outlining the implemented and planned actions to facilitate CCA, including reporting requirements agreed upon under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, as well as reporting on adaptation actions, including (a) the main goals, objectives, and institutional framework for adaptation; (b) climate change projections, including weather extremes, climate-change impacts, assessment of climate vulnerability and risks, and key climate hazards; (c) adaptive capacity; (d) adaptation plans and strategies; (e) monitoring and evaluation framework, comprising the state of play of the implementation of measures and reporting on funding, covering the spending earmarked for CCA, including DRM, and to the extent possible, the share of spending to support CCA in each sector; (f) progress made in implementation, including good practices and changes to governance.

Table 5 and Table 6 present the CCA costs found in the literature. Table 5 summarizes the results and methodologies of existing CCA cost assessments undertaken for different European countries, categorized by the three 'use cases': national planning, sectoral planning, and programmatic planning.

74 UNFCCC. 2015. Paris Agreement. Link.
75 EU. 2021c. Forging a Climate-Resilient Europe - the New EU Strategy on Adaptation to Climate Change. Link.
76 EU. 2023. Regulation 2018/1999/EU. Link.

Table 5. Overview of CCA costs at the national level found in the literature

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
NATIONAL PLANNING						
Short-term policy-first assessment						
Austria	Knittel et al. 2017	• Top-down approach: transport, innovation, and technology; agriculture, forestry, and water management; environment • Bottom-top approach: agriculture, forestry, biodiversity, water, disaster risk management, transportation infrastructure	All climate hazards	The adaptation-relevant expenditure for the annual federal budget ranges from €358 million (bottom-up approach based on the Austrian 2012 CCA strategy) to €488 million (top-down approach based on the federal government's 2016 budget plan)	Two types of assessment: a. A top-down approach based on the federal government's budget plan b. A bottom-up approach based on the Austrian national adaptation strategy	• CCA costs could vary greatly depending on the approach and methodology used even for the same country • The two approaches cover different aspects and types of adaptation and can be used in complement to one another. The top-down approach is limited to existing measures, while the bottom-up approach can also assess new measures; the top-down approach focuses on grey measures, while the bottom-up approach focuses on soft ones • A bias toward investment costs, costs for subcontracts, and cost of maintenance exists for the assessment
France	Depoues et al. 2022	8 sectors (health, civil security, urban, public infrastructure and networks, energy, transportation, forestry, water, and land resources)	All climate hazards	€2.3 billion per year from 2022 to 2027 for the implementation of 18 'no regret' measures	A two-stage analysis, which involves (a) a qualitative definition of adaptation needs and (b) a quantitative estimation of costs of actions	Social consensus and public discussion could play an important role in budgetary planning and decision-making in CCA.
	Alexandre et al. 2019	Overall economy	All climate hazards	€55 billion expenditure in total; at least €33.1–35.9 billion once favorable to the environment and at least €25 billion once unfavorable	CCA estimation based on research and tagging from the I4CE study for French national budgeting[77]	The study does not focus on CCA but green budgeting, yet it is a good demonstration of using CCA estimation from existing studies as a basis of green budgeting and policy making.

77 Depoues et al. 2022.

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
Sweden	Government of Sweden 2007	Across sectors	All climate hazards	€18.4 million (SEK 210 million) per year from 2007 to 2012 (€22.8 million or SEK 260 million if including a new subsidy for investments to protect against natural disasters); €3.6 million (SEK 155 million) per year after 2012	• Vulnerability and climate impact analysis based on two global climate models and two global emissions scenarios from the IPCC for three time frames (2020s, 2050s, and 2080s) • CCA cost estimation based on surveys and expert and institution consultation	The study provides insights on CCA policy making and financing. It proposes CCA measures, estimates the costs (total costs and detailed breakdowns), and provides four possible financing options (which is valuable, as the funding of CCA remains challenging).
Romania	Government of Romania 2023	13 sectors (water resources, forests, biodiversity and ecosystem services, population, public health and air quality, education and research, cultural heritage, urban systems, agriculture and rural development, energy, transport, tourism and recreational activities, industry, insurance)	All climate hazards	Overall, CCA measures are estimated at approximately €19 billion across 13 key sectors, with €15 billion estimated for CCA initiatives across a total of 6 selected key sectors from 2023 to 2030.	• The measures proposed in the draft NAP primarily took into account the allocations/financing available through European or international funding mechanisms, targeting both public funds and, where possible, private funds. • The amounts provided by the MEWF in the NAP were based on both an expert judgement and a summing of the values of the financing lines available (MEWF noting the list of financing lines covered is not exhaustive). Based on this, a value that was considered to be accessible and achievable for the authorities and the implementing stakeholders was proposed and included in the draft Action Plan.	The approach showcases a way to assess national-level adaptation costs through a combination of sectoral perspectives.
Bulgaria	Republic of Bulgaria 2019	9 sectors (agriculture, biodiversity and ecosystem, energy, forestry, human health, tourism, transport, urban environment, water)	All climate hazards	Budget for each adaptation option in the 9 sectors ranged from €0.003 million to €760 million and falls into one of the three cost categories: • Low (L) (up to €1 million) • Medium (M) (€1–100 million) • High (H) (€100 million and more)	Project and activity-based cost estimation for the various adaptation options purposed in the country's National Adaptation Strategy and Action Plan, with detailed BCA undertaken for some adaptation options	Scoring adaptation options according to different cost categories (low, medium, high) instead of proving specific numerical value as an alternative way to present costs of CCA

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
Spain	Government of Spain 2020[78]	6 sectors (climate and weather, water, nature and biodiversity, coastal and marine environment, urban planning, transportation)	All climate hazards	Overall, €1.5 billion from 2021 to 2025 in 18 sectors and across measurement; largest expenditure includes water (€525.6 million), environment and biodiversity (around €320 million), coast and marine environment (€277.7 million), urban planning and construction (€205.7 million), and transportation (€114.6 million)	Sector and project-based cost estimation for the various adaptation options purposed in the country's National Adaptation Strategy and Action Plan	The approach showcases a way to assess national-level adaptation costs through a combination of sectoral and investment portfolio perspectives.
Estonia	Republic of Estonia, Ministry of Environment, 2017[79]	8 sectors (health, land use and planning, natural environment, bioeconomy, economy, society and cooperation, infrastructure and buildings, energy, and security of supply)	All climate hazards	€43.7 million from 2017 to 2030	A top-down approach based on the federal government's budget plan for the implementation of the Development Plan for Climate Change Adaptation	The approach showcases a way to assess national adaptation costs through budget forecasts by sectors and by administrative areas.
Slovakia	Republic of Slovakia 2018[80]	Across sectors	All climate hazards	Around €3 billion (2,958,319,881) from 2014 to 2020, which covers budget for operation programs for national development and cross-border and transnational cooperation programs	Project and activity-based cost estimation for the various adaptation options purposed in the country's National Adaptation Strategy	The cost estimate considers adaptation actions taken both at the national and international (cross-border) levels.
Croatia	Government of Croatia 2020[81]	11 sectors (general, water, agriculture, forestry, fishing, biodiversity, energy, tourism, health, spatial planning, and risk management)	All climate hazards	Around €3.6 billion (HRK 27 billion) for the period up to 2040, with more than half of the amount allocated to the implementation of structural measures, especially in the agriculture, forestry, and water management sectors	Sector and project-based cost estimation for the various adaptation options purposed in the country's National Adaptation Strategy	The National Adaptation Strategy only provides a rough estimation; more precise cost of measures and activities can only be calculated in action plans and implementation documents of the Adaptation Strategy.

78 Government of Spain. 2020. Programa De Trabajo 2021 - 2025: Plan Nacional de Adaptación al Cambio Climático. Link.
79 Government of Estonia. 2017. Climate Change Adaptation Development Plan until 2030. Link.
80 Government of Slovakia 2018.
81 Government of Croatia 2020.

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
UK	Watkiss 2023[82]	Across Sectors	All climate hazards	€5.3–11.6 billion (£4.5–10 billion) per year for this decade	Rapid review of the potential adaptation costs of Third UK Climate Change Risk Assessment (CCRA3) risks	No single, definitive cost of adaptation for a country as it depends greatly on the choice of methods and key assumptions.
Medium and long-term science-first assessment						
Germany	IÖW 2021; Tröltzsch et al. 2012	2012 analysis: 13 sectors (transport, urban environment, finance, water and oceans, building sector, industry, health, soils, biodiversity, agriculture, energy, tourism, DRM)	2012 analysis: 3 (extreme heat, droughts, and floods)	2012 analysis: Overall ~ €140–142 billion per year CCA costs until 2100 (+ €260 per ha sustainable agriculture practices); specific costing for each of the 13 sectors and BCRs calculated • Implement now (2012): ~ €135–136 billion per year (+€260/ha sustainable agriculture practices) • Implement until 2050: + €2.6–3.3 billion per year • Implement until 2085/2100: + €1.6–2.2 billion per year • 2021/2022 studies: No CCA costs published	An integrated framework with three different economic approaches: econometric modelling (with the simulation and forecasting model PANTA RHEI), cost-benefit analysis (with innovative valuation approaches), and institutional analysis of climate adaptation policy	• Policy-oriented research aiming at assessing the economic consequences of climate change and adaptation to assist policy maker with the further development of the German Strategy for Adaptation to Climate Change • Need to adopt different approaches when assessing CCA costs at different scales (regional/national) • The modelling and approach show a way to endogenize the expected changes between the different actors of CCA by modelling relevant industries and economic sectors explicitly.

82 Watkiss 2023.

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
Greece	Bank of Greece 2011[83]	Across sectors	All climate hazards	€28 or €67 billion (in 2008 GDP values) cumulative from 2011 to 2100 (based on 0% and 2% discount rate)	• Quantitative assessment of the effect of adaptation on Greek economy under high-intensity climate scenario, with the use of the general equilibrium model GEM-E3[84] and BCA CCA cost estimated as direct expenditure for adaptation works and interventions, with data from sectoral analyses or international literature	• Difficulty to purpose optimal adaptation policy and assess its costs due to a range of projected climate impacts. • Only planned, public adaptation measures are taken into account; adaptation by the private sector is not represented as exogenous changes in the economic model.
	Government of Greece 2016	7 sectors (transportation, costal system, ocean, forests, tourism, agriculture and fishing, buildings and infrastructure)	All climate hazards	€123 billion cumulative until 2100 Costs for the various adaptation options in the seven sectors between the two adaptation phases (2025–2050 and 2050–2070) are estimated in one of the following three ways: • Cumulative cost between the two adaptation phases: €600 million–20 billion (2010 value) • Annual cost: €30–276 million (2010 value) per year • Cost as percentage increase (for the tourism sector): 10% increase	Sector-based cost estimation for the various adaptation options purposed in the country's National Adaptation Strategy and Action Plan	The approach showcases different ways to provide cost estimates (for example, as cumulative costs, annual costs, or as percentage increase) depending on the types of adaptation measures

83 Bank of Greece 2011.

84 According to EC, GEM-E3 is "an applied general equilibrium model that covers the interactions between the Economy, the Energy system and the Environment. It is well suited to evaluate climate and energy policies, as well as fiscal issues". See EC. 2023. GEM-E3. Link.

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
SECTORAL PLANNING						
Spain	Van der Wijst 2021[85]	Across sectors	Riverine flood, changes in agriculture and forestry caused by climate changes	CCA expenditure is around 0.02% of Spanish GDP, or 0.09% of overall government expenditures in 2019; €0.33 billion as additional public adaptation expenditure in 2050	Projection of future adaptation expenditure (to 2050) based on an aggregated list on past, current, and planned adaptation actions in Spain provided by the Basque Centre for Climate Change and existing assessments taken by national experts in adaptation	Challenges to estimate CCA cost due to data availability: Not all information on the costs and types of past, current, and near-future adaptation investments is available.
	Watkiss and Preinfalk 2022	Agriculture	All climate hazards	Specific value for public adaptation expenditure (investment, maintenance, and operating costs) not mentioned	Current and future projection (until 2050) of public adaptation expenditures (investment, maintenance, and operating costs) based on COACCH results	• The study presents new findings based on existing estimates of public adaptation expenditures to inform decision-making. • The cost-effectiveness of adaptation measures is highly site and context specific and depends greatly on the future projected climate change impacts.
Austria	Van der Wijst et al. 2021	3 sectors (flood risk management, forestry, and agriculture)	Riverine flood, changes in agriculture and forestry caused by climate change	€550 million in 2017 (latest year available for the Austrian budget report at the time of analysis); €0.24 billion as additional public adaptation expenditure in 2050	A top-down approach based on the federal government's budget plan, combined with the consultation of experts in the relevant ministries	Challenges to estimate CCA cost due to data availability: public adaptation costs for Austria can only be deduced from medium-term forecast for the federal budget.

85 Van der Wijst et al. 2021.

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
Austria	Bachner et al. 2019; Watkiss and Preinfalk 2022	forestry	All climate hazards	Cost pathways for adaptation estimated. In 2050, climate change-induced annual GDP losses in the impact scenario for Austria are 0.15% from climate change and these losses can be reduced by public adaptation to only 0.06%.	Current and future projection (until 2050) of public adaptation expenditures (investment, maintenance and operating costs) based on COACCH results	• The study presents new findings based on existing estimates of public adaptation expenditures to inform decision-making. • The cost-effectiveness of adaptation measures is highly site and context specific and depends greatly on the future projected climate change impacts. • The importance to consider all types of adaptation interventions (structural, ecosystem based, informational).
Netherlands	Van der Wijst et al. 2021	Across sectors	Extreme riverine (100-year flood) flood, coastal flood risk	€1.2 billion as additional public adaptation expenditure in 2050	Project and investment-based modelling for the estimation of flood-related expenses based on consultation	Trade-off between the expansion of green adaptation and the agriculture and livestock sector (negatively impacted) may be a consideration when the government is choosing adaptation options.
	Watkiss and Preinfalk 2022	Disaster risk management	All climate hazards	Specific value for public adaptation expenditure (investment, maintenance, and operating costs) not mentioned	Current and future projection (until 2050) of public adaptation expenditures (investment, maintenance, and operating costs) based on COACCH results	• The study presents new findings based on existing estimates of public adaptation expenditures to inform decision-making. • The cost-effectiveness of adaptation measures is highly site and context specific and depends greatly on the future projected climate change impacts.

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
UK	Watkiss 2022	Agriculture, forestry, water, land management	Wildfire	• Climate adaptation costs estimated for a range of peatland adaptation options, which vary across measures: • National training and capacity building program: around €1.59–7.6 million [£1.4–6.7 million] • Wildfire management plan: average implementation costs of €200 (£175) per ha of land, with a maintenance cost of €70 (£61) per ha and an update cost of €40 (£35) per ha every five years	BCA for different purposed adaptation measures, with cost estimation based on literature review and expenditure of existing measures	• Effective preventive actions can take various forms; there is potential to explore climate-smart designs and 'soft' prevention measures such as early warning system and training programs. • Private and other co-benefits of adaptation may be underestimated in the case study, as the benefit is mainly measured in terms of reduced carbon and air pollution emission.
PROGRAMMATIC PLANNING						
Netherlands	Jonkman et al. 2013[86]	Land management	Flood and sea level rise	€4.5–22.4 million per km per m for defense (dike raising), €2.3–7.5 per m3 material for nourishment, €0.1 million per km per year for maintenance	Review of current quantitative cost assessment of existing adaptive coastal defenses measures (project-based assessment)	Aspects (for example, rural versus urban environment, adaptation of other [water] infrastructures, and future changes in materials and labor costs) that contribute to a nonlinear increase in the cost must be taken into account.
	Rijkswaterstaat (Dutch Ministry of Infrastructure and Water Management) 2022[87]	Transportation	Flood	€1.2 million	Flood risk exposure analysis based on the assessment tools by the Climate Atlas and the 'climate in the development of the plan' framework with the KNMI climate scenarios[88] taken into account	The methodology is easy to replicate and can be applied to other road development projects.

86 Jonkman et al. 2013. *Costs of Adapting Coastal Defenses to Sea-Level Rise: New Estimates and Their Implications*. Link.
87 Rijkswaterstaat (Dutch Ministry of Infrastructure and Water Management). 2022. A27/A12: *Adjustment Ring Utrecht*. Link.
88 The Royal Netherlands Meteorological Institute (KNMI) is the Dutch national weather service and data and knowledge institution for climate science. The KNMI climate scenarios provides the likely changes in the future climate of the Netherlands. Each scenario provides a consistent picture of the changes in 12 climate variables, such as temperature, precipitation, sea level, and wind. See KNMI. 2015. Climate scenarios – pictures of the future. Link.

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
Spain	Meyer et al. 2015[89]	Water, agriculture	Drought	€200 million adaptation cost, which includes implementation costs, market value of land, loss of economic activity, conflict with other users of the water district, and environmental losses	Quantitative, scenario-based (RCP4.5 and RCP8.5 climate change scenarios) BCA and multi criteria analysis (MCA) analysis based on the Water Availability and Adaptation Policy Assessment (WAAPA) model	Underestimated benefits (20% of projected avoided damage on the environment were not estimated)
		Water, agriculture, health, biodiversity and ecosystem	Heatwave	• Green roof: the initial cost ranged from €279 million to €1.5 million and the maintenance cost over 2020–2100 ranged from €98 million to €2,029 million, under different discount rate and climate scenarios. • Heat-health warning system: the initial cost ranged from €0.4 million to €21.3 million and the additional cost ranged from €7.1 million to €12 million under different discount rate and climate scenarios.	Quantitative, scenario-based (RCP4.5 and RCP8.5 climate change scenarios) BCA for two adaptation options: a green roof and a heat-health warning system	• BCA is sensitive to the choice of discount rate and socio-climatic scenario. • Challenging to evaluate costs and benefits of adaptation measures in monetary terms when the service is intangible and when data availability is limited.
	Scussolini et al. 2013[90]	Urban space and land management	Flood	€210 million for grey measures and €0.03–10 million for soft measures	Project-based cost estimation for different types of grey and soft infrastructures purposed in the regional Flood Risk Management Plan (PGRI) 2015–2021, based on a 500-year flood return period	The study shows that the implementation costs of soft measures are much lower than traditional grey measures, which means soft measures should be considered as a potential option in Flood Management Plans at the local or national level.

89 Meyer et al. 2015.
90 Scussolini et al. 2013.

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
Czech Republic		Water, land management	Flood	Depending on the adaptation option, the CCA costs vary from €0.21 million to €44.4 million (CZK 5–1,043 million).	BCA of selected adaptation measures under current and future flood risks (10-, 100- , and 1000-year return periods)	• The study aims at conducting 'real-world' economic appraisals of investments in climate change adaptation and generalizing guidelines in assessing CCA costs and benefits for the EU context. • The assessment only considers hard adaptation measures due to the limitations of BCA .
	Climate-ADAPT 2016[91]	Water, disaster risk management	Flood	• €145.9 million (2013 value) for the implementation of grey infrastructure, which includes • The implementation cost of the flood control system: €144.4 million; • The installation costs per flood event: €0.65 million; and • Annual maintenance and storage costs: €0.89 million	Project-based BCA analysis, with costs of the grey infrastructures calculated for flood events with 20-, 50-, 100-, and 500-year return periods	The study proves that grey measures are cost-effective to provide city-wide protection from floods. Yet it also suggests that there is still potential to adopt green and blue measures on small streams.
Denmark	EEA 2023a	Urban and land management	Flood	€2.68 billion (DKK 20 billion) for the conventional solution (increasing the dimensions of the sewerage system) and €1.74 billion (DKK 13 billion) for the alternative solution (green infrastructure)	Ex ante project-based BCA that compares the cost-effectiveness of conventional and alternative adaptation measures to inform investment decision	The study shows the relatively low cost of green infrastructures in comparison to conventional solutions. Despite the result of the BCA, a hybrid solution was selected in the end.

91 Climate-ADAPT 2016b.

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNED
Poland	Climate-ADAPT 2018[92]	Water, disaster risk management, biodiversity, and ecosystem	River flood	€217 million for the implementation of a hybrid adaptation measure (green and grey infrastructure)	Project-based BCA for the implementation of the hybrid adaptation measure	The project yields a BCR of 2.05, with benefit calculated in terms of avoided flood damage to buildings. Nevertheless, the benefit is likely to be underestimated as the impact on people is not considered.
	European Commission 2018[93]	Transportation	Floods, droughts, and extreme weather events	€64–74.4 million	Vulnerability and risk assessment for different climate scenarios and weather conditions	The case study is a good demonstration of how to integrate CCA measures in early (planning and designing) stages of a road infrastructure
Croatia	DBV 2023[94]	Transportation	Extreme temperature and weather events	€225.3 million	Climate change impact study and risk and vulnerabilities assessments under different climate scenarios with three types of climate change effects considered	The project demonstrates CCA proposals and cost estimation for airports, which are rarely considered in existing adaptation planning case studies.
Latvia	EC 2018	Transportation	Extreme temperature and weather events	€519 million	Risk and vulnerability assessment for the transportation system under current and future climate scenarios, with the effect of different climate hazards modelled and corresponding adaptation measures purposed	The case study shows how climate change impacts and adaptation can be considered for existing infrastructure (for example, when investing in upgrading existing road network).
Romania		Transportation	Floods, storms, and meteorological events	€2 billion	Climate-induced risks and hazards identification and risk assessment, then purpose corresponding adaptation measures and make evaluations	The case study shows how to implement CCA measures during two phases of a project: (a) in the beginning phase where climate change effects need to be modelled and foreseen and (b) in the operation phase where adaptation options purposed are subject to operation costs.

Source: World Bank based on sources as noted in the table.

92 Climate-ADAPT 2018.
93 EC 2018.
94 DBV. 2023. *Project Dubrovnik Airport Development.* Link.

Table 6. Overview of CCA costs at the global, Europe, and regional level found in the literature

Table 6 summarizes estimates of CCA costs at the global, EU, and sub-national scales based on existing literature.

LEVEL	REFERENCE	SECTORS	CLIMATE HAZARDS	RANGE OF CCA COSTS	METHODOLOGY	OBJECTIVE AND LESSONS LEARNT
Europe	Jeuken et al. 2016	Agriculture, health	Floods	Overall cost of adaptation in the EU ranged from €26.89 billion to €47.06 billion [US$32–56 billion] (2005 values) in 2050	Cost estimation of adaptation measures in three sectors (floods, agriculture, health) represented by the AD-WITCH model[95], with the climate scenario set at the calibration point (+2.5°C, around 2050)	Adaptation cost estimates are greatly affected by a range of future socioeconomic scenarios (differences between scenarios and sensitivity to particular model assumptions).
Europe	Jeuken et al. 2016	Across sectors	River floods	€700 billion for the 2030s and €900–1,100 billion total costs for the 2080s (€13–15 billion per year for the 2030s and €9–11 billion per year for the 2080s)	Cost estimation for river flood adaptation measures in EU countries, with the use of a flood risk model that assesses the changes in river flood risks in two future periods (2030s and 2080s), compared to the baseline (1980s)	When the total costs were translated into annual costs, a lower cost was found for the 2080s than the 2030s because the costs are spread over a shorter period and include the upgrading costs of many flood protection systems across Europe up to a level of 100 years.
Europe	Jeuken et al. 2016	Agriculture	All climate hazards	For RCP4 and RCP8 scenarios under SSP2, SSP3, and SSP5: Cost of improved management measures ranged from 0.002% to 0.016% GDP for short-term (2040) time horizon and from 0.001% to 0.023% GDP for long-term (2070) time horizon Cost of irrigation measures ranged from 0.003% to 0.08% GDP for short-term (2040) time horizon and from 0.004% to 0.01% GDP for long-term (2070) time horizon	Cost estimation of two types of adaptation measures (water management and irrigation) under two emission scenarios (RCP4 and RCP8) and in two time horizons (short term and long term), with the use of LAND USE and e CROP SHARE model	The result shows that water management is a more effective adaptation strategy than irrigation, as the effectiveness of irrigation is contingent on favorable climatic conditions and water availability.

95 The AD-WITCH model is an energy-economy-climate model that aims at explicitly dealing with the main features of climate change, with a long term horizon covering all century until 2100. See Bosello, F., Carraro, C., & De Cian, E. 2018. APPENDIX I : THE AD-WITCH MODEL. In An Analysis of Adaptation as a Response to Climate Change (pp. 56–64). Copenhagen Consensus Center. Link.

Europe	Jeuken et al. 2016	Health	Extreme heat	Costs of heat-health warning systems from 2015 to 2099 (under RCP8.5 and SSP5 scenario) is €323.7 million with 3% discount rate and €163.9 million with 5% discount rate (2013 value)	Cost estimation based on the expected costs per day of the alert system under different climate scenarios, which include basic interventions (for example, risk communication to the public and basic emergency services) and extensive actions (for example, extra care to vulnerable people)	The estimation of heat-health warning system costs is subject to many uncertainties.
Europe	Rojas, Feyen, and Watkiss 2013[96]	Whole economy	Flood	• For EU: €7882.1 million per year for flood protection upgrade from current to future 100-year flood event and an average BCR of 4 • For countries: Adaptation costs vary greatly across countries, with high costs found in United Kingdom, France, Italy, Romania, Hungary, and Czech Republic	Ensemble-based pan-European flood hazard assessment for present and future conditions with the use of hydrological model LISFLOOD[97]. The socioeconomic impacts are estimated by combining flood hazard maps with information on assets.	The project assesses the socioeconomic impacts of river flood in the EU in the context of both climate and socioeconomic change, and it reveals that future changes in the socioeconomic dimension can be as essential as future changes in climate-induced disaster risks and thus need to be considered in the assessment.
Europe	ClimateCost 2011[98]	Across sectors	All climate hazards	Wide range of CCA costs for different sectors and Europe as a whole based on different economic and climate scenario models	Literature review of 50+ existing global European, sectoral, regional, and national studies on the costs of adaptation in Europe	• CCA cost estimation could vary greatly depending on the methodological approaches, time frames, and climate scenarios used in the assessments. • Existing sectoral assessments on adaptation costs have a very uneven distribution.
	Skourtos, Kontogianni, and Tourkolias 2013[99]	Water	Flood	With cross-sectoral synergies taken into account: €1,383–3,847 billion Without cross-sectoral effects: €401–10,559 billion	Cost-effectiveness analysis (basic and under uncertainty) for different adaptation measures leading to water savings due to technological changes without including cross-sectoral effects	CCA costs could vary significantly for (a) basic and under uncertainty analysis and (b) with and without cross-sectoral effects.

96 Rojas, R., L. Feyen, and P. Watkiss. 2013. "Climate Change and River Floods in the European Union: Socio-Economic Consequences and the Costs and Benefits of Adaptation." *Global Environmental Change* 23: 1737–1751. Link.
97 LISFLOOD is a grid-based hydrological rainfall-runoff-routing model that simulates the hydrological processes that occur in a catchment. See JRC. 2022. LISFLOOD hydrological model Fact sheet. Link.
98 ClimateCost. 2011. *The Costs and Benefits of Adaptation in Europe: Review Summary and Synthesis.* ClimateCost Policy Brief. Link.
99 Skourtos, Kontogianni, and Tourkolias. 2013. *Report on the Estimated Cost of Adaptation Options Under Climate Uncertainty*. Link.

Europe	EC, DG-CLIMA, 2017[100]	Across sectors	All climate hazards	Adaptation investment needs in the EU estimates range from €35 billion to €500 billion annually	Literature review of estimates of adaptation investment needs in the EU and the landscapes of climate finance in individual EU countries	Under assumptions and methodological approaches, the estimation for CCA investment needs could vary significantly.
Western Europe	EU 2017[101] based on De Bruin, Dellink, and Agrawala 2009[102]	6 sectors (agriculture, other vulnerable markets, coastal, health, non-market time use, catastrophic events, and settlement)	All climate hazards	The estimated annual investment needs for CCA range from €158 billion to €518 billion (2015 value) for 2025–2185	Estimation of the cost of adaptation as a policy variable under two scenarios (base model and higher damage) with two IAM models: the global Dynamic Integrated model for Climate and the Economy (DICE) and its regional counterpart, the Regional Integrated model for Climate and the Economy (RICE)	• The study provides a solid framework for examining adaptation cost issues within more complex, modified IAMs. • The results of the study can be further improved by incorporating more detailed regional knowledge on the impacts of climate change and of adaptation options.
The Alpine Region	Müller, Vilà-Vilardell, and Vacik 2020[103]	Tourism, agriculture, forestry, land uses	Wildfire	The estimated adaptation cost for the integrated forest fire management measures is around €10 million per year.	A bottom-up estimation of CCA costs based on literature review, expert consultation, and current adaptation expenditure of 7 countries in the Alpine region	• The goal is to develop the first integrated fire management plan for the Alpine region, which combines fire prevention, fire suppression, and post-fire management. • It is crucial to consider both the costs of individual adaptation options and the total cost when developing integrated fire management plans.
Global	World Bank 2010	Across sectors	All climate hazards	• Estimated CCA costs global and for 7 case studies (developing countries) • Global adaptation costs range from US$70 billion to more than US$100 billion annually by 2050	Calculated existing and planned IFF and then estimated the additional investment required for adaptation as a premium on existing and planned investments, based on a climate change scenario of 2ºC above pre-industrial levels by 2050	

100 Forster et al. 2017. Link.
101 EU. 2017. Climate mainstreaming in the EU budget: Preparing for the next MFF - final report. Link.
102 De Bruin, Dellink, and Agrawala 2009. Link.
103 Müller, Vilà-Vilardell, and Vacik 2020. Link.

Europe and Global	ECONADAPT 2015[104]	Across sectors	All climate hazards	Wide range of CCA costs for OCED countries, developing countries, EU countries, and different sectors based on different economic and climate scenario models	Literature review of costs and benefits of adaptation at global, national, regional, and local scales and for different sectors	• CCA cost estimation has progressed in recent decades, covering a wide range of countries, sectors, and risks. • It is challenging to directly compare the results between studies (especially for aggregate estimates) due to the diversity of approaches, assumptions, choice of climate and socioeconomic scenarios, discount rates, and so on.

Source: World Bank based on sources as noted in the table.
Note: Additional studies have been reviewed as mentioned below, but these only focused on the quantification of potential impacts of climate change rather than on climate adaptation costs and are not at the national scale (Europe and beyond). They have therefore not been included in the above table. These studies are EC, DG CLIMA, 2021[105] (review of methodologies and limitations for costing CCA); ICLEI 2017[106] (definition of costing frameworks at the urban scale for adaptation measures focusing on typologies of buildings and infrastructure in terms of climate impacts); World Bank 2022[107] (climate impact assessment in Türkiye and adaptation action proposal); Botzen et al. 2010[108] (downscaled assessments of risks and costs of climate in Europe and for three case studies, literature and methodology review, CGE model described and then applied in Knittel et al. 2020[109] and Bachner et al. 2019[110]); UNECE 2020[111] (climate change impacts for transport networks and nodes in Europe and Canada); Impressions 2019[112] (impact assessment for 4°C and more and the options available for reducing the risks for various sectors; stress testing of policies and strategies); Forzieri et al. 2018[113] (analyze additional investments needed to climate-proof critical infrastructure such as transport against multiple hazards based on literature-based vulnerability assessments); TopDad 2016[114] (socioeconomic tool to develop sectoral CCA strategies considering regional climate scenarios and demonstrated for selected case studies); Impact2C 2015[115] (climate impact assessment under 2°C warming for Europe for several sectors); Krausmann et al. 2019[116] (climate impact assessment of a power grid considering flood risk; scenario-based approach).

104 ECONADAPT. 2015. *The Costs and Benefits of Adaptation: Results from the ECONADAPT Project*. Link.
105 Ebrey et al. 2021.
106 ICLEI. 2017. *RAMSES - Science for Cities in Transition.* Link.
107 World Bank. 2022c.
108 Botzen, W., et al. 2020. *D3.4 Socio-Economic Tipping Point Analysis. Deliverable of the H2020 COACCH Project, Research consortium*. Link.
109 Knittel et al. 2020. “A Global Analysis of Heat-Related Labour Productivity Losses under Climate Change—Implications for Germany’s Foreign Trade.” Climatic Change 160 (2): 251–269.
110 Bachner et al. 2019. “How Does Climate Change Adaptation Affect Public Budgets? Development of an Assessment Framework and a Demonstration for Austria.” Mitigation and Adaptation Strategies for Global Change 24 (7): 1325–1341.
111 UNECE. 2020. Climate Change Impacts and Adaptation for Transport Networks and Nodes. Link.
112 Impressions. 2019. Impressions: Impacts and Risks from High-End Scenarios: Strategies for Innovative Solutions. Link.
113 Forzieri et al. 2018. “Escalating Impacts of Climate Extremes on Critical Infrastructures in Europe.” Global Environmental Change 48: 97–107. Link.
114 TopDad. 2016. TopDAd - Next Generation Toolset. Link.
115 Impact2C. 2015. IMPACT2C - Quantifying projected impacts under 2°C Warming. Link.
116 Krausmann, E., L. Feyen, L. Alfieri, et al. 2019. Climate Change and Critical Infrastructure: Floods. Publications Office. JRC. Link.

ANNEX 2. Overview of Methodologies for Climate Change Adaptation Costing

Table 7. Overview of methodologies with their advantages and disadvantages

METHODOLOGY	DESCRIPTION	DESCRIPTION	EXAMPLE	REFERENCES
MODELLED/ECONOMIC-BASED APPROACH (TOP-DOWN)				
Sector integrated assessment/damage costs	– Main source of cost of adaptation estimates in the literature – Involve the use of sector models (global, regional, national, local) to assess future climate change impacts and then technical adaptation responses (and associated costs and benefits) – Used commonly for coastal and river protection and agriculture	+ Strong theoretical basis + Objective to make rational CCA investments + Address future climate change scenarios and ranges of projected climate impacts – Highly stylized CCA analysis (neglects adaptive capacity, process of CCA, and policy context) – Focused on technical options – Centered on 2050s horizon (no short-term information/ immediate needs and finance needs and costs for CCA + not aligned with 5-year reporting periods Paris/National Adaptation Plans) – Static (if-then) approach to capture the spectrum of projected climate change impacts, one scenario at a time; if addressed with DMUU approaches in recent literature, it involves more complexity, time, and resources and primarily applied at the project level	EC study (BASE), Austria (PACINAS, COIN), Global (DIVA model)	Jeuken et al. 2016. COIN 2022. Brown et al. 2021.
IAMs	– Combine the scientific and economic aspects of climate change within a single, integrated analytical framework – Can quantify the economic impacts of climate change and, in some cases, the costs and benefits of adaptation, albeit in a stylized form – Primarily applied at the global level but also used to downscale results to regions/countries		EC (ECONADAPT, NAVIGATE, 7FWP project 'ClimateCost')	EconAdapt 2015. EC 2022. Watkiss 2009.
CGE modelling	– Macro-economic models that allow analysis of how impacts cascade across sectors of the economy as well as price effects – Often use sector impact and adaptation studies as inputs		EC (JRC PESETA, COACCH), USA (the American Climate Prospectus project), Austria, Bulgaria, Germany	Juan-Carlos Ciscar et al. 2019. COACCH 2019. Watkiss and Watkiss 2021. Bednar-Friedl et al. 2017. Republic of Bulgaria 2019.
Macro-structural modelling	Structural models presenting the flows of funding at macroeconomic level by mapping out main economic variables in national accounts, balance of payments, labor markets, and financial sectors. They generally are consistent with both economic theory and the dynamics of real-world economy.		World Bank CCDR Studies (Türkiye, Pakistan, Nepal), International Monetary Fund (IMF) study	World Bank 2022a. World Bank 2022b. World Bank 2022c. Parry et al. 2018.
Econometric modelling	Use econometric (statistical) analysis of current climate and economy links and use these relationships to look at future climate impacts and in some cases adaptation		Germany, AFDB study, Pakistan (World Bank CCDR)	Stoever et al. 2022. Africa Development Bank 2019. World Bank 2022b.

METHODOLOGY	DESCRIPTION	DESCRIPTION	EXAMPLE	REFERENCES
INVESTMENT NEEDS/PROGRAM OR PROJECT-BASED APPROACH (BOTTOM-UP)				
Sector, program, project, and activity-based costing	- Approach dominates the international costs of adaptation reported by developing countries as part of their submissions to the UNFCCC and for adaptation finance needs.	+ Relatively simple to complete + Provide practical information on near-term actions to inform adaptation finance needs and early implementation – Partial capture of challenges with estimating CCA costs – Typically, long lists of identified activities – Usually based on an estimate of costs of activities (that is, national program of climate-smart agriculture) rather than a result of analysis/appraisal – Lack of strategic approach (focus on short-term programs or project priorities and direct government interventions rather than implementation costs, enabling conditions and so on) – Rarely considers economic efficiency considerations that is, benefits of CCA (that is, reducing climate change impacts), adaptation effectiveness, analysis of costs and benefits of CCA, or appropriate level and scale of CCA – Rarely consider longer-term horizons and a range of projected climate impacts – Include activities associated with the existing adaptation deficit and broader developments (broad climate rationale)	EC study (BASE, EconAdapt, Climate-ADAPT), World Bank and EC study, Austria,	• UNFCCC 2011. • BASE 2015. • EC 2016. • Climate-ADAPT 2023c. • World Bank and European Commission 2021. • Knittel et al. 2017.
IFF analysis	– Focus on the likely costs of planned adaptation. – Based on analysis of current financial flows, now and in the future, and apply an adaptation mark-up to these. An example is the UNDP Assessment of Investment and Financial Flows (IFF) to Address Climate Change (UNDP 2011), which provided national/sector estimates in 15 countries.		UNFCCC study, France	• UNDP 2022. • UNFCCC 2007. • I4CE 2022.
Variation of IFF	Analysis of adaptation costs (and benefits) based on climate budget tagging/Climate Public Expenditure and Institutional Reviews (CPEIR) studies, aligning to national development planning		UNDP study, Austria, France, Bangladesh, Nepal (UNDP)	• UNDP and ODI. 2012. • Knittel et al. 2017. • Alexandre et al. 2019. • Bangladesh 2021. • UNDP 2018.
Decision support tools	– Decision support methods that can be used for adaptation, to identify priorities, and which generate cost estimates – Suite of standard decision support tool, with the use of cost-benefit analysis, cost-effectiveness analysis, which are often suitable for no- or low-regret adaptation but do not account for a range of projected climate impacts – More commonly used for project appraisal rather than producing national estimates		EC study (Climate-ADAPT), Netherland	• Climate-Adapt 2020. • Doukas and Nikas 2019. • Government of the Netherlands 2022.
Decision-making under uncertainty			EC study (Climate-Adapt), IPCC studies	• Climate-Adapt 2023b. • Kunreuther et al. 2014. • Moure et al. 2023.

Source: World Bank based on sources as noted in the table.

Table 8. Overview of methodologies and approaches used for case studies

NEW CASE STUDY/ CASE STUDY FROM LITERATURE	OVERALL METHODOLOGY	ECONOMIC MODELS/ ASSESSMENTS	DISASTER ANALYTICS FOR NEW CASE STUDIES UNDER THIS REPORT	EXPECTED RESULTS
Bulgaria; Austria, France, UK (external)	Sector, program, project, and activity-based costing. Hybrid approach using adaptation measure portfolios	Bottom-up CCA costing approach	Results from CIMA fire modeling and heat analytics	Costing and informing prioritization of measures for 2030s and 2050s considering current and future selected climate risks in a cross-cutting manner
Croatia, Aurelia (fictional), Netherlands (external)	IFF analysis	Investment-focused costing; BCA	Results from CIMA fire modeling and heat analytics, seismic, and energy efficiency analytics[117]	Identifying investment mark-ups required to climate-proof selected infrastructure to inform smart prioritization and decision-making
Sweden; UK, Germany, Norway (external)	Decision support tools	Sectoral based assessment; BCA	Current and future wildfire risk analytics and economic analysis of costs of wildfires	Costing investments for a portfolio of CCA measures to tackle wildfire risk in the forestry sector
Romania; **Serbia,** **Türkiye (external)**	Sector integrated assessment/damage costs	Criticality analysis based on vulnerability assessment and costs of interventions for the transport sector	Flood risk and impact assessments for future climate scenarios and high-level economic cost analytics	Sectoral impact assessments to consider in macro-models and for detailed sector-based CCA costing
Romania; **Austria,** **Germany,** **Spain (external)**	CGE and/or macro-structural models	Macroeconomic modelling based on high-level costs of interventions and benefits; MFMod (from World Bank) and CGE models	Results from sector integrated assessments and damage and cost analysis of selected hazards (floods, heat, wildfire, and drought)	Determining high-level net benefits of investing in adaptation from the perspective of the Ministry of Finance

Source: World Bank.

117 World Bank and European Commission, forthcoming.

Table 9. Overview of type of data and modelling results used for case studies

COUNTRY CASE STUDIES	TYPE OF DATA	SOURCE	TYPE OF ANALYSIS	TYPE OF CCA COSTING ANALYSIS INFORMED
WILDFIRES				
Bulgaria **Romania** **Sweden** **Croatia**	Historical data on fire occurrence	EFFIS (previous number of events and burnt area) National data from CP and/or forestry agencies (burnt area by land types)	Initial analysis of trends; historical economic costs of wildfires	Sector, program, project, and activity-based costing IFF analysis Decision support tools Sector integrated assessment/damage costs
Bulgaria **Romania** **Sweden** **Croatia**	Historical data on fire impacts	EFFIS (air pollution from fires) National data from CP and/or forestry agencies, mostly collected for extreme events (for example, carbon emission costs, suppression costs, property and infrastructure damages, and so on)	Simple first assessment of societal costs of wildfires	Sector, program, project, and activity-based costing Decision support tools Sector integrated assessment/damage costs
Bulgaria **Romania** **Croatia**	Wildfire risk indexes (current climate)	JRC Pan-European Wildfire Risk Assessment - risk maps Exposure maps based on EC/OSM data and pan-European fire danger layers Detailed assessment of susceptibility, hazard, risk, and social vulnerability-based on national data and results from modelling by CIMA (vulnerability assessment)	Detailed wildfire risk analytics for current climate at high resolution	Sector, program, project, and activity-based costing IFF analysis Decision support tools Sector integrated assessment/damage costs
Bulgaria **Romania** **Croatia**	Wildfire risk indexes (future climate)	PESETA IV, IPCC, national climate risk assessments (background) Bias-adjust future climate projections from Inter-Sectoral Impact Model Intercomparison Project phase 3 (ISIMIP3b) and comparison with EURO-CORDEX/RCMs Detailed assessment of susceptibility, hazard, risk, and social vulnerability based on national data and results from modelling by CIMA (vulnerability assessment)	Detailed wildfire risk analytics for future climate at high resolution	- Sector, program, project, and activity-based costing - IFF analysis - Decision support tools - Sector integrated assessment/damage costs

COUNTRY CASE STUDIES	TYPE OF DATA	SOURCE	TYPE OF ANALYSIS	TYPE OF CCA COSTING ANALYSIS INFORMED
HEAT				
Bulgaria **Romania**	Historical data on heat events	Daily all-cause mortality for Sofia from 2010–2019 from the National Statistical Institute Daily climate variables for Sofia from 2010 to 2019 from the Executive Environment Agency Historical heat impacts for Romania and urban heat analytics from CCDR	Model calibration (Bulgaria) or setting the context/baseline for macro analysis (Romania)	Sector, program, project, and activity-based costing (example of benefits quantification for adaptation measure portfolio)
Bulgaria **Romania**	Extreme heat days 2020-2050, RCP4.5 (future)	National disaster risk profile of Bulgaria: Daily maximum temperature and relative humidity of the climate model MOHC-HadGEM2-ES/SMHI-RCA4 (RCP4.5 simulation) from the Copernicus Climate Change Service Bulgaria: Heatwave data from Copernicus Climate Change Service Romania: Daily maximum temperature and relative humidity of the climate model MOHC-HadGEM2-ES/SMHI-RCA4 (RCP4.5 simulation) from the Copernicus Climate Change Service	Heat-attributable deaths, labor productivity losses (Bulgaria) and to use in macro analysis (Romania)	Sector, program, project, and activity-based costing (example of benefits quantification for adaptation measure portfolio)
FLOODS				
Romania	Flood risk (current)	RO-Floods Technical Assistance Project, JBA (2021), Flood Risk Analysis for EU MSs, European Commission, (2021), Current Practice in Flood Risk Management in the European Union Results from transport network analytics (CCDR); Feyen et al. (2021)	Baselining, flood hazard, vulnerability and risk mapping	IFF analysis
Romania	Flood risk (future)	RO-Floods Technical Assistance Project, JBA (2021), Flood Risk Analysis for EU MSs, European Commission, (2021), Current Practice in Flood Risk Management in the European Union Analytics for transport network (simplified approach)	Risk analytics for transport network	IFF analysis

Source: World Bank.

ANNEX 3. Details on Costings of CCA Measures in Case Studies

Bulgaria

Table 10. Overview of CCA measures costed addressing extreme heat risks in selected sectors

MEASURE	DESCRIPTION	MAIN KPIS
ADAPTATION MEASURES PORTFOLIO: **HEALTH**		
NHHAP ***Measure type:*** low regret	NHHAP's objective is to prevent and lessen the impact of heat on people's health and well-being. It includes a set of strategies related to heat early warning system; actions to prevent negative health effects of heat targeted at the general public and specific vulnerable groups, including preparedness of the health and social care system; communication plan to raise awareness and improve preparedness in stakeholders and citizens; and governance structures to coordinate actions and collaborations.	Heat-related mortality and morbidity; number of people reached (HEWS); demand for emergency and health care services
HEWS ***Measure type:*** low regret	Improvement on the existing general early warning system in Bulgaria, to consider impact-based triggers based on meteorological and epidemiological parameters to forecast heat events and their health impacts. Enhancements are to be made along the service delivery value chain, which includes foundational modeling, forecasting and multi-tier alert system, targeted communication and training, and end user uptake. HEWS should have two communication channels: one for the general public and one targeted at the health sector (and other institutional stakeholders) and vulnerable populations.	Heat-related mortality and morbidity; number of people reached (HEWS); demand for emergency and health care services; productivity
Data collection system for heat-related illness and mortality ***Measure type:*** low regret	A national heat-related illness and mortality data collection system would allow to collect heat-related health data in real time across Bulgaria. The system could also collect reliable temperature data in health care buildings. The objectives of such a system are to understand real-time effects of heat events on human health; allow the health care system to prepare and manage health services during heat events through early detection, real-time monitoring, and alerts; and investigate the relationship between heat and morbidity and mortality across different regions of Bulgaria. Such a system is typically a part of the syndromic surveillance system set up across many health care facilities, which allows to determine how many people who visit the emergency room are being affected by certain health conditions in real time. The system also acts as a platform for central collection and exchange of information between institutions involved in forecasting and responding to heat events.	Heat-related mortality and morbidity; demand for emergency and health care services
Establishment of cool centers ***Measure type:*** low-regret/ early adaptation activities	Cooling centers are designated public facilities that help prevent heat-related illnesses or deaths in extreme heat events. Such facilities provide cool places of public refuge and can include museums, libraries, churches, shopping centers, shaded areas, swimming pools, and other publicly accessible infrastructure. Cooling centers can also provide drinking water, power in case of a power outage, and other resources. The distribution of cooling centers in cities should aim to minimize the maximum walking distance to the centers.	Heat-related mortality and morbidity; demand for emergency and health care services

MEASURE	DESCRIPTION	MAIN KPIS
Design of new health care facilities for heat resilience ***Measure type:*** climate smart	This measure includes (a) passive design techniques to minimize heat gain and maintain comfortable indoor temperatures by, for example, orienting the building to maximize shade and natural ventilation, using high-performance insulation and glazing materials, incorporating thermal mass for temperature regulation, and increasing the albedo of hard standing surfaces; (b) design for efficient cooling systems to ensure effective temperature control and ventilation within the facility; (c) innovative green roof and façade solutions to mitigate heat by reducing the urban heat island effect, improving insulation, and promoting evaporative cooling—furthermore biophilic design absorbs solar radiation and releases moisture through transpiration, creating a cooling effect for the building and its surroundings; and (d) thermal comfort optimization via the selection of appropriate materials, that is, heat-resistant materials, high solar reflectance, and high infrared emittance and provision of appropriate ventilation systems and shading devices.	Heat-related mortality and morbidity; building overheating (comfort level)
Heat resilience improvements of existing health care facilities ***Measure type:*** climate smart	Can include insulation measures, solar control measures, ventilation modification measures, and measures in the external environment. Specific focus can be placed on, for example, (a) enhancing building design via retrofitting health care facilities with heat-resistant materials, high solar reflectance, high infrared emittance, external and internal shading, insulation and cool roofs to help reduce heat absorption and maintain lower indoor temperatures, improving/increasing natural ventilation to enhance airflow, air-conditioning, and high-performance glazing; (b) upgrading cooling system and implementing energy-efficient cooling systems; and (c) green, blue, grey, and hybrid infrastructure via incorporating green spaces to provide natural shade, green roofs, biophilic design; improve air quality; and reduce the urban heat island effect while integrating blue infrastructure, such as water features and permeable surfaces, to aid in cooling and contribute to a more resilient environment.	Heat-related mortality and morbidity; building overheating (comfort level)
Information campaigns and awareness raising ***Measure type:*** low regret	Increasing public and stakeholder awareness of heat-related risks and the respective mitigation actions required and available tools through the following: Multi-level information campaigns with tailored messaging for different target audiences across multiple channels, including mass media, social and other digital media (for example, dedicated smartphone applications), printed information materials, mid-media activities, and in-person communication such as public talks, events, discussion groups, and so on with support from community leaders. Integrated trainings for institutions and stakeholders, including state-funded volunteer organizations, to improve inter-institutional coordination and to streamline dialogue with the public. Information campaigns and programs specifically targeted at vulnerable groups. This includes programs that extend beyond the HEWS that are intended to provide vulnerable groups with additional support. Populations vulnerable to heat generally include the elderly (over 65 years), infants and children, people with chronic illness and on certain medications, the socially isolated, the homeless, low-income households, and outdoor workers. This measure can include peer-to-peer support programs and information services targeted at specific groups.	Heat-related mortality and morbidity; number of people reached (HEWS); demand for emergency and health care services

MEASURE	DESCRIPTION	MAIN KPIS
ADAPTATION MEASURES PORTFOLIO: **PRODUCTIVITY AND COMFORT**		
Labor force heat protection strategy ***Measure type:*** low-regret/ early adaptation activities	Heat stress increases workers' occupational health risks and can restrict physical functions and capabilities, work capacity, and productivity. Labor heat protection strategy outlines coordinated actions and measures at the governmental, employer, and individual levels that reduce health risks and productivity losses. The strategy should include occupational safety and health standards, measures to improve labor early warning, guidelines on ensuring adequate adaptation measures (for example, hydration, rest breaks in the shade), and personal cooling strategies and shifting work hours to cooler parts of the day. Heat stress labor regulations can vary from prescribing maximum temperatures to which workers may be exposed to less prescriptive national legislation that requires employers to provide (at a minimum) a safe place of work and identify and control risks and hazards. The effect and trade-off of shifting labor hours should also be investigated and considered in the strategy, with particular attention to the most affected sectors such as agriculture and construction.	Heat-related mortality and morbidity including heat stress, heat stroke; productivity
Urban heat island strategy at city level ***Measure type:*** early adaptation activities	This measure includes identification of cities that are or will be at risk of UHI effect in the upcoming decades. These cities have an increased risk to extreme heat and will require city-level strategies to mitigate the additional negative impacts. The development of UHI strategies should include local mapping of UHI effects (similar to that of Sofia city) to understand the most impacted and vulnerable areas, for prioritized actions. The UHI strategy should include heat adaptation options and actions at the city, local, and individual levels, which can take different forms (hard and soft, physical implementations, policy reforms, and new programs).	Heat-related mortality and morbidity; demand for emergency and health care services; UHI index; air quality; cooling degree days (energy consumption); building overheating (comfort level); building overheating
Improved access to cooled public transport ***Measure type:*** climate smart	This measure includes ensuring the accessibility and connectivity of public transport, introducing requirements for air conditioning and reflective window materials in public transport vehicles, and implementing measures to reduce temperatures at public transport stops and stations as outlined in the measures below.	Productivity; transport overheating
Building standards for new development ***Measure type:*** climate smart	This measure includes the following: (a) develop climate-responsive design including optimizing building orientation and spatial planning, utilizing shading devices, incorporating natural ventilation systems, and integrating green and blue spaces to mitigate heat buildup and enhance thermal comfort via, for example, biophilic design; (b) prescribe heat-resistant materials with high solar reflectance and low thermal conductivity which thereby help reduce heat absorption, minimize heat transfer, and maintain lower surface temperatures; (c) design energy-efficient cooling systems such as high-efficiency air conditioning units and heat pumps, to provide effective cooling while minimizing energy consumption, and furthermore consider smart and responsive cooling technologies that adjust operation based on occupancy and temperature conditions; (d) design urban heat island mitigation strategies to create a more comfortable microclimate and reduce the overall heat stress on buildings and infrastructure, for example, green roofs, cool pavements, and urban greening; and (e) enhance water management and conservation via incorporation of water-efficient landscaping, rainwater harvesting systems, and permeable surfaces to reduce stormwater runoff and manage water resources effectively.	Heat-related mortality and morbidity; demand for emergency and health care services; UHI index; air quality; cooling degree days (energy consumption); building overheating (comfort level); building overheating

MEASURE	DESCRIPTION	MAIN KPIS
Building improvements of existing buildings ***Measure type:*** climate smart	Include the above considerations for retrofitting the building stock as part of low-income household energy efficiency and heat resilience improvement programs/part of implemented initiatives such as The BGN 2 billion state-funded National Programme for Energy Efficiency of Multi-Family Residential Buildings (2015–2023) and its planned BGN 1.13 billion successor program under the EU's Recovery and Resilience Plan and Other EU, national, and municipal public investment programs for retrofitting of existing infrastructure.	Heat-related mortality and morbidity; demand for emergency and health care services; UHI index; air quality; productivity; cooling degree days (energy consumption); building overheating (comfort level); building overheating; green and blue spaces (proxy for ambient cooling and outdoor comfort)
Urban greening and blue solutions ***Measure type:*** climate smart	Creating and preserving blue-green 'arches' and public spaces is a relatively simple and effective way to lower surface and air temperatures. Specific measures include Using urban greening solutions such as increasing the number of trees and other plants, particularly in strategic locations around buildings, streets, and parking lots (including by using cost-effective permeable green-gray parking surfaces); Improving the integration of rivers and green spaces into the urban fabric; Constructing decorative as well as drinking water fountains; and Implementing short-term measures during extreme heat events such as using water to cool streets and public spaces.	UHI index; air quality; cooling degree days (energy consumption); building overheating; green and blue spaces (proxy for ambient cooling and outdoor comfort)

Source: World Bank.

Table 11. Overview of costs of CCA measures addressing extreme heat risks in selected sectors

MEASURE	SUMMARY OF ACTIVITIES AND COSTS	TOTAL 5-YEAR BUDGET OUTLOOKB	TOTAL NPC FOR 2023–2050C	KPIS RELEVANT TO THE MEASURE
ADAPTATION MEASURES PORTFOLIO: **HEALTH**				
NHHAP ***Measure type:*** low regret	Development of the NHHAP: €50,000 (5-year)/€176,000 (NPC) Implementation of NHHAP includes the following: Heat early warning system: costed as part of HEWS CCA measure Actions to prevent negative health effects of heat, targeted at the general public and specific vulnerable groups, including preparedness of the health and social care system: €26.0 million (5-year)/€83.8 million (NPC) Communication plan to raise awareness and improve preparedness in stakeholders and citizens: costed as part of information campaigns and awareness raising CCA measure Governance structures to coordinate actions and collaborations: €700,000 (5-year)/€2.19 million (NPC)	€26.7 million (excluding HEWS and information campaign, which are costed separately)	€86.1 million (excluding HEWS and information campaigns, which are costed separately)	Heat-related mortality and morbidity; number of people reached (HEWS); demand for emergency and health care services
HEWS ***Measure type:*** low regret	HEWS implementation costs: €167,000 (5-year and NPC) Annual operating costs: €963,000 (5-year)/€3.01 million (NPC) Variable costs for heatwave events (considering RCP8.5): €0.50–1.68 million, average €1.02 million (5-year)/€2.00–6.72 million, average €4.10 million (NPC)	€1.63–2.81 million (average €2.15 million)	€5.18–9.90 million (average €7.28 million)	Heat-related mortality and morbidity; demand for emergency and health care services
Data collection system for heat-related illness and mortality ***Measure type:*** low regret	System implementation cost: €133,000 Annual operating cost: €273,000 (5-year)/€854,000 (NPC) Periodic system upgrade and enhancements: N/A (5-year)/€179,000 (NPC)	€0.41 million	€1.17 million	Heat-related mortality and morbidity; demand for emergency and health care services
Establishment of cool centers ***Measure type:*** low-regret/early adaptation activities	Considers between 1,240 and 1,826 facilities Upgrade of 60% of facilities' cooling systems over a 10-year period: €1.11–1.64 billion (5-year)/€1.81–2.67 billion (NPC) Training of personnel for support during heatwaves: €0.74–1.10 million (5-year)/€2.33–3.43 million (NPC)	€1.11–1.64 billion (average €1.38 billion)	€1.81–2.67 billion (average €2.24 billion)	Heat-related mortality and morbidity; building overheating (comfort level)

MEASURE	SUMMARY OF ACTIVITIES AND COSTS	TOTAL 5-YEAR BUDGET OUTLOOKB	TOTAL NPC FOR 2023–2050C	KPIS RELEVANT TO THE MEASURE
Design of new health care facilities for heat resilience ***Measure type:*** climate smart	Considers 20% obsolescence/attrition of existing health care stock (hospitals and clinics) over the time horizon Assumed that current portfolio level is maintained. This may be adjusted to allow for changes in population and demographics over the period considered. Costs presented considering, for example, (a) lower estimate of design for heat resilience allowing for, for example, sealed mechanical ventilation installed and maintained plus sealed glazing, and (b) upper estimate for cost allowing for premium for, for example, advanced natural ventilation system and energy efficient cooling system, provision of heat resistant materials, external and internal shading, high performance glazing plus green, blue, and hybrid solutions. Marginal costs can be estimated from the ranges presented.	€72–154 million (average €113 million)	€315–675 million (average €495 million)	Heat-related mortality and morbidity; building overheating (comfort level)
Heat resilience improvements of existing health care facilities ***Measure type:*** climate smart	Considers 10% of existing healthcare stock retrofitted per 5-year cycle over time horizon (that is, to 2050). By 2050 60% of stock retrofitted. Considered stock includes 242 hospitals and 134 clinics as detailed in EU regional shared risk datasets. Assumed that current portfolio level is maintained. This may be adjusted to allow for changes in population and demographics over the period considered. Costs presented considering, for example, (a) lower estimate of design for heat resilience allowing for, for example, sealed mechanical ventilation installed and maintained plus sealed glazing and (b) upper estimate for cost allowing for premium for, for example, advanced natural ventilation system and energy efficient cooling system, provision of heat resistant materials, external and internal shading, high performance glazing plus green, blue, and hybrid solutions. Marginal costs can be estimated from the ranges presented.	€448–961 million (average €705 million)	€1.97–4.22 billion (average €3.1 billion)	Heat-related mortality and morbidity; building overheating (comfort level)

MEASURE	SUMMARY OF ACTIVITIES AND COSTS	TOTAL 5-YEAR BUDGET OUTLOOKB	TOTAL NPC FOR 2023–2050C	KPIS RELEVANT TO THE MEASURE
Information campaigns and awareness raising ***Measure type:*** low regret	Multi-level information campaigns for the public: €0.37 million to €0.68 million annually Programs specifically targeted at vulnerable groups (establishment of support call center): €0.05 million to €0.09 million annually Integrated capacity building trainings at national and regional level for institutions and stakeholders: €0.09 million to €0.12 million annually	€2.58–4.41 million (average €3.49 million)	€8.06–13.77 million (average €10.92 million)	Heat-related mortality and morbidity; number of people reached (HEWS); demand for emergency and health care services
ADAPTATION MEASURES PORTFOLIO: **PRODUCTIVITY AND COMFORT**				
Labor force heat protection strategy ***Measure type:*** low-regret/early adaptation activities	Strategy development: €50,000 GDP losses due to reduction of labor during extreme heat events: Estimates from previous studies: For 2020, €17.1–267.6 million (average €75.8 million) For 2050, €0.13–1.96 billion (average €0.50 billion) COACCH study: For 2020, €9.84 million	€50,000 (strategy development only, not considering enforcement costs and losses due to reduced labor)	€176,000 (strategy development only, not considering enforcement costs and losses due to reduced labor)	Heat-related mortality and morbidity including heat stress, heat stroke; productivity
Urban heat island strategy at the city level ***Measure type:*** early adaptation activities	Considers a requirement for UHI reports for 100 largest cities (by population) in Bulgaria. The UHI strategy should include local mapping of UHI effects (similar to that of Sofia city) to understand the most impacted and vulnerable areas, for prioritized actions. The UHI strategy should also include costed heat adaptation options and actions at the city, community, and individual levels, which can take different forms (hard and soft; physical implementations, policy reforms and new programs). This estimate considers strategy development only (not its implementation and assumes periodic upgrade and enhancement of the strategy on 10-year cycle.	€1.89 million (strategy development only, not considering strategy implementation costs)	€6.57 million (strategy development only, not considering strategy implementation costs)	Heat-related mortality and morbidity; demand for emergency and health care services; UHI index; air quality; cooling degree days (energy consumption); building overheating (comfort level); building overheating

MEASURE	SUMMARY OF ACTIVITIES AND COSTS	TOTAL 5-YEAR BUDGET OUTLOOKB	TOTAL NPC FOR 2023–2050C	KPIS RELEVANT TO THE MEASURE
Improved access to cooled public transport ***Measure type:*** climate smart	Replacement of urban public transport vehicles over a 5-year period to ensure the availability of air conditioning in Settlements above 1,000,000 citizens (Sofia): average €621.92 million; Settlements between 100,000 and 1,000,000 citizens (Plovdiv, Varna, Burgas, Ruse, Stara Zagora): average €121.31 million; and Settlements between 30,000 and 100,000 citizens (remaining 20 largest settlements): €56.92 million.	€836.1–924.1 million (average €880.1 million)	€780.14–840.16 million (average €800.15 million)	Productivity; transport overheating
Building standards for new development ***Measure type:*** climate smart	Considers a requirement for 20 standards/guidelines in design, planning, and so on to be revised/developed over the period considered. Assumes requirement for periodic upgrade and enhancement on 15-year cycle.	€1.6 million	€5.58 million	Heat-related mortality and morbidity; demand for emergency and health care services; UHI index; air quality; cooling degree days (energy consumption); building overheating (comfort level); building overheating
Building improvements of existing buildings ***Measure type:*** climate smart	Considers 10% of existing stock retrofitted per 5-year cycle over time horizon (that is, to 2050). By 2050, 60% of stock retrofitted. Assumed that current portfolio level is maintained. This may be adjusted to allow for changes in population and demographics over the period considered. Costs presented considering (a) lower estimate of design for heat resilience allowing for, for example, sealed mechanical ventilation installed and maintained plus sealed glazing and (b) upper estimate for cost allowing for premium for, for example, advanced natural ventilation system and energy efficient cooling system, provision of heat resistant materials, external and internal shading, high performance glazing plus green, blue, and hybrid solutions. Marginal costs can be estimated from the ranges presented.	€2.28–4.89 billion (average €3.59 billion)	€10.1–21.6 billion (average €15.85 billion)	Heat-related mortality and morbidity; demand for emergency and health care services; UHI index; air quality; productivity; cooling degree days (energy consumption); building overheating (comfort level); building overheating; green and blue spaces (proxy for ambient cooling and outdoor comfort)

<table>
<tr><th>MEASURE</th><th>SUMMARY OF ACTIVITIES AND COSTS</th><th>TOTAL 5-YEAR BUDGET OUTLOOKB</th><th>TOTAL NPC FOR 2023–2050C</th><th>KPIS RELEVANT TO THE MEASURE</th></tr>
<tr><td>Urban greening and blue solutions

Measure type:
climate smart</td><td>Creating and preserving blue-green ‘arches’ and public spaces is a relatively simple and effective way to lower surface and air temperatures. Specific measures include using urban greening solutions such as increasing the number of trees and other plants, particularly in strategic locations around buildings, streets, and parking lots (including by using cost-effective permeable green-gray parking surfaces) improving the integration of rivers and green spaces into the urban fabric constructing decorative as well as drinking water fountains implementing short-term measures during extreme heat events such as using water to cool streets and public spaces.</td><td>Not assessed specifically for Bulgaria</td><td colspan="2">UHI index; air quality; cooling degree days (energy consumption); building overheating; green and blue spaces (proxy for ambient cooling and outdoor comfort)</td></tr>
</table>

Source: World Bank.
Note: The costs are estimated in 2022 euros (€) for 2023–2040.
a. Costs are estimated considering an RCP8.5 scenario for heatwave occurrence and other modeling.
b. 5-year budget outlook considers undiscounted costs over the shorter-term 5-year planning horizon.
c. Net present cost: the present value of costs for 2023–2050, considering a 3 percent discount rate.

Table 12. Overview of CCA measures costed addressing wildfire risks in selected sectors

CCA MEASURE	DESCRIPTION	MAIN BENEFITS
ADAPTATION MEASURES PORTFOLIO: **WILDFIRE HAZARD, EMERGENCY PREPAREDNESS, AND RESPONSE**		
Strengthen the potential of fire responders to cope with wildfires ***Measure type***: low regret	The measure would allow purchasing of new equipment for firefighting teams and personal protection equipment. It will also address training of fast-response firefighting groups in the forest enterprises as well as in the volunteer groups in villages. This measure will improve the efficiency in fighting forest fires and decrease losses and chances for loss of human life and property.	Increased capacity and resources to effectively respond to wildfire emergencies Decreased wildfire-related mortality and losses of high-value resources and assets (HRVAs)
Create a team for airborne firefighting and purchase the necessary specialized aircraft and other equipment ***Measure type:*** low regret / early adaptation activities	This measure will allow faster response to wildfire emergencies, especially in remote areas and steeper mountain terrain, where road network is not dense enough to allow fast response with specialized vehicles.	Increased capacity to effectively respond to wildfire emergencies, including in steep terrains and remote areas Reduced response time and improved efficiency of firefighting Reduced estimated share of arson/ intentional cases in wildfires
Build national system for rapid fire detection and response to this and other natural calamities ***Measure type:*** low regret / early adaptation activities	The system, suggested in the National Climate Change Adaptation Strategy and Action Plan for the Republic of Bulgaria (2019), will allow to have a centralized observation and coordination facility. It will ensure quick detection and decision support in case of occurrence of fires and other natural disasters in forest territories.	Reduced time in identification of fires and other hazards in forests and surrounding areas and increased efficiency in response
Education and public outreach activities ***Measure type:*** no regret	The measure includes education campaigns, regular public messages, and activities during fire-prone seasons and awareness messages during days with high fire danger through television, radio, highway information systems, and internet media. It also includes training activities for citizens and specialized personnel at municipalities, schools, forest enterprises, and other organizations related to fire risk. The aim of this measure is to increase knowledge in stakeholders, especially in farmers, about the risk of wildfires and the high losses they cause. It also aims at improving the knowledge on how to respond in case of wildfires.	Improved knowledge of most vulnerable stakeholders about wildfire risk and impacts Behavioral change linked to improved understanding of wildfire initiation and ignition causes Increased measures of stakeholders for preparedness and prevention of wildfire risk and impacts Reduced risk of human life loss

CCA MEASURE	DESCRIPTION	MAIN BENEFITS
ADAPTATION MEASURES PORTFOLIO: **WILDFIRE HAZARD, FORESTRY MEASURES**		
Legal activities ***Measure type:*** early adaptation activities	The measure aims to analyze and promote appropriate legal activities to increase responsibility and punishment for deliberate causing of fires. In addition various adaptation measures will require modifications in Ordinances and other legal acts.	Reduced risk of fire initiation and large wildfires
Fire mitigation and risk reduction actions in forest and agriculture lands ***Measure type:*** climate smart / early adaptation activities	The measure will aim to promote various activities in forest territories which reduce the chance of fire initiation, spread, and growth and hence reduce the risk of high losses. It is related to initial preparation and annual maintenance of various mineralized stripes and similar fire barriers in forests, building and regular maintenance of forest roads, measures for reduction of fuel in high-risk zones such as removing of low vegetation, branches, controlled grazing, controlled burning. Building accessible small water dams helps fill water tanks for firefighting operations. The measure will also aim at creating and maintaining defensible spaces and special measures for reducing the risk of fires in WUIs.	Reduced risk of human life loss and damages in ecosystems
Improving the plans for protection of forest territories ***Measure type:*** climate smart / low regret	This measure will allow to change the approach in planning mitigation and risk-reduction measures in forest territories. It will include modelling of wildfire risk at the national and local levels and changing the rules and approaches for preparation of the plans for protection of forest territories.	Improved planning for mitigation and risk reduction measures Improved investments in resources and capacity to respond to wildfires

Table 13. Overview of costs of CCA measures addressing wildfire risks in selected sectors

MEASURE	SUMMARY OF ACTIVITIES AND COSTS	TOTAL 5-YEAR BUDGET OUTLOOK (€, MILLIONS)	PRIORITIZATION AND COST-BENEFIT
ADAPTATION MEASURES PORTFOLIO: **EMERGENCY MANAGEMENT**			
Strengthen the potential of fire responders to cope with wildfires ***Measure type:*** low regret	Renewal and upgrading of the equipment of the firefighting brigades at the firefighting services: €71 million (5-year) Equip and train fast-response firefighting groups in the forest enterprises: €10 million (5-year) Equip and train volunteer groups in villages in forested regions: €10 million (5-year)	91	High priority and urgency to increase the capacity for firefighting and decrease the risk of human life loss and high environmental capital losses
Create team for airborne firefighting and purchase the necessary specialized aircrafts and other equipment ***Measure type:*** low regret / early adaptation activities	Build national system for airborne firefighting—purchase the necessary firefighting specialized aircraft, build ground-based operation sites, and create team Annual maintenance costs for maintaining the system	170	High priority to increase the capacity for firefighting in extreme wildfires
Build national system for rapid fire detection and response to this and other natural calamities ***Measure type:*** low regret / early adaptation activities	Installation of equipment for autonomous detection of fires Creational of national monitoring system	8	High priority; necessary to detect quickly problems in forested regions and organize fast and coordinated response
Education and public outreach activities ***Measure type:*** no regret	Multi-level information and education campaigns, regular public messages, and activities during fire-prone seasons and awareness messages in days with high fire danger through television, radio stations, highway information systems, internet media: €2 million (5-year) Training activities for citizens specialized personnel at municipalities, schools, forest enterprises, and other organizations related to fire risk: €3.5 million (5-year)	5.5	High priority and cost-benefit ratio; crucially important to reduce the risk of wildfire initiation

MEASURE	SUMMARY OF ACTIVITIES AND COSTS	TOTAL 5-YEAR BUDGET OUTLOOK (€, MILLIONS)	PRIORITIZATION AND COST-BENEFIT
Legal activities for improved fire risk management and responsibility ***Measure type:*** early adaptation activities	Analysis and initiatives to propose legal changes	0.3	High priority
ADAPTATION MEASURES PORTFOLIO: **FORESTRY**			
Fire mitigation and risk reduction actions in forest and agriculture lands ***Measure type:*** climate smart / early adaptation activities	Forest road maintenance and building new roads in areas with low road density: €25 million (5-year) Initial preparation and annual maintenance of various mineralized stripes and similar fire barriers in forests: €5 million (5-year) Measures for reduction of fuel in high-risk zones - removing of low vegetation, branches, controlled grazing, controlled burning: €5 million (5-year) Maintenance of fire-watch towers, equipment, costs for hiring fire watchers: €3 million (5-year)	38	High priority and cost-benefit ratio; on-site activities for reduction of the risk for fire initiation and spread
Improving the plans for protection of forest territories ***Measure type:*** climate smart / low regret	Modelling of wildfire risk at the national level Changing the rules and approaches for preparation of the plans for protection of forest territories to comply with wildfire risk maps at the national and regional levels and initiatives to introduce the new system in action Periodic plans upgrade and enhancements	1	High priority and cost-benefit ratio; this is a crucial step necessary for managing and mitigating wildfire risk.

Source: World Bank.

Romania

Table 14 offers an overview of CCA measures in selected sectors in Romania, based on the Draft National Strategy for CCA and corresponding Action Plan (referred to as 'NAP'), as well as the measures/proposed alternatives for achieving the Flood Risk Management Plans' objectives, in accordance with the World Bank Floods RAS.[118]

Table 15 provides a more detailed overview. All the figures included in the table are based on the draft version of the National Strategy for CCA and Action Plan dated August 2023.[119] The categories/packages of measures presented were proposed by the World Bank team for the analysis and do not necessarily reflect the view of the MEWF or Government of Romania. The measures proposed in the draft NAP primarily took into account the allocations/financing available through European or international funding mechanisms, targeting both public funds and, where possible, private funds. The calculation of the amounts provided by the MEWF in the NAP was based on both an expert judgement and a summing of the values of the financing lines available (MEWF noting the list of financing lines covered is not exhaustive). Based on this, a value that was considered to be accessible and achievable for the authorities and the implementing stakeholders was proposed and included in the draft Action Plan.

Table 14. Overview of selected CCA measures in Romania addressing four hazards

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS
HEAT AND MULTI-HAZARD RELATED MEASURES/PORTFOLIO (€4.3 BILLION)
Urban systems (NAP): • Improving the climate resilience of urban systems • Improving existing building codes and norms to increase resilience to the effects of extreme climate events • Adapting risk analysis and hedging plans and defense plans in case of specific climate change emergencies • Development/implementation of education, research, information, and awareness programs for the population

118 Draft Action Plan for the implementation of the National Strategy on Adaptation to Climate Change for the period 2023-2030, version August 2023 published on MEWF website for public consultations; *Flood RAS/Output No. 7 - Report on advice provided to MEWF in the preparation of twelve (12) final draft Flood Risk Management Plans, under the RAS on Technical Support for the Preparation of the Flood Risk Management Plans for Romania (P170989); Output No. 7 - Report on advice provided to MEWF in the preparation of twelve (12) final draft Flood Risk Management Plans, under the RAS on Technical Support for the Preparation of Flood Risk Management Plans for Romania (P170989).

119 Romania's draft National Strategy for Climate Change Adaptation and its Action Plan have been published for public consultation on the Ministry of Environment, Water and Forests' website in August 2023, as part of the official approval process. At the time of completion of the present report, the draft Strategy and Action Plan are in the process of being approved, based on the revisions following the consultations. Therefore, the numbers analyzed and presented in this report rely on the draft Strategy and Action Plan version from August 2023, which may eventually differ from the final version to be approved by the Government of Romania.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS
Energy sector (NAP): • Increasing the resilience of the energy sector • Increasing the resilience of the heating and cooling sector • Developing education, information, and awareness programs to increase resilience in the field of energy • Establishing critical infrastructure in energy systems and implementing measures to deal with the impacts of extreme events
Transport sector (NAP): • Consolidation of ground infrastructure (road, urban, rail) to improve resilience to climate change • Consolidation of air transport infrastructure to improve resilience to climate change • Consolidation of shipping infrastructure to improve resilience to climate change • Transport sector vulnerability assessment to extreme weather events • Integrating climate change considerations into planning and decision-making processes
DROUGHT HAZARD RELATED MEASURES/PORTFOLIO (€6.1 BILLION)
Agriculture sector (NAP): • Developing an adaptation strategy in agriculture • Achieving an efficient management of agricultural land • Improving the level of knowledge of soils and agriculture and the link with climate change • Raising awareness about risk management and access to risk management tools
Water resources (reducing the risk of water scarcity) (NAP): • Updating the policy and regulatory framework based on (a) quantitative and qualitative assessments of water requirements by type of use, (b) identification of key areas potentially deficient in terms of water resources available, and (c) period assessment of the impact of climate change • Promoting the legislative, policy, and institutional framework regarding NBS and natural water retention measures • Strengthening the legal framework for protecting critical water supply sources by mapping the main areas potentially deficient in terms of water resources • Examining and updating legal regulations by taking into account changing natural conditions • Examining legal regulations and promotion of regulations to limit groundwater use • Strengthening the regulatory framework for the sustainable management of water and wastewater sector and for acceleration of the population‘s access to quality services according to European directives

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS
• Protecting and conserving water resources in areas at risk of scarcity • Adapting water resources management infrastructure and optimization of water use • Restoring natural water accumulation areas - wetlands to optimize irrigation systems with surface and/or groundwater resource • Supporting investments in the water supply network to reduce losses in water distribution network systems • Assessing the quality and feasibility of continuing to use groundwater resources in conjunction with artificial and/or natural supply of groundwater reservoirs • Assessing the feasibility of coastal desalination for drinking treatment in water-deficient coastal basins
• Reducing the effects of climate change on groundwater bodies and terrestrial and aquatic ecosystems dependent on them • Taking measures, including legislative and policy measures, to increase climate resilience • Conducting studies and research to identify and promote NBS and natural water retention measures • Strengthening transboundary cooperation on water resources management
FLOOD HAZARD RELATED MEASURES/PORTFOLIO (€6.9 BILLION FOR 2022–2028)
Flood risk reduction (NAP measures): • Developing plans, actions, and measures for the reduction of flood risk in the areas where the flood risk is high (fluvial, rainwater, coastal sources) • Increasing the safety of dams and piers (NAP measures): • Increasing the safety of flood defense infrastructure • Increasing the safety of transport infrastructure networks
Package of high-priority flood protection measures: (Flood RAS) €6.9 billion for the period 2022 to 2028, covering initial investment, replacement, operation and maintenance, land purchase, mitigation costs and revenues. **Integration of flood risk management into spatial and urban planning* (Floods RAS) - Measures not individually costed:** • Development of methodology for integration • Revision/update of relevant legislation • Information campaigns for citizens to raise awareness on urban flooding
Promoting NBS/Green Infrastructure solutions for flood risk management in urban areas* (Floods RAS) - Measures not individually costed: • Setup of national program office, including funding and inter-institutional working group • Identification of sites • Implementation of pilot projects • Monitoring and evaluation

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS
Adapting infrastructure (transport, hydrotechnical works) to increasing flood risks due to climate change* (Floods RAS) - Measures not individually costed: • Review and adapt existing technical regulations and norms • Update/improve inventory of infrastructure • Prioritize assets at risk
Erosion and torrent control program* (Floods RAS) - Measures not individually costed: • Legislative framework gap analysis • Setup of program office, including funding and inter-institutional working group • Selection of the priority locations for intervention • Design and implementation • Monitoring and evaluations
National program for further strengthening capacities for flood risk management and the implementation of the Flood Directive, including* (Floods RAS) - Measures not individually costed: • Evaluation of FRMP second cycle • Strengthening data collection and management • Monitoring of FRMP implementation • Planning development of FRMP3
WILDFIRE HAZARD RELATED MEASURES/PORTFOLIO (€2.3 BILLION)
Adaptation of forests and the forest-based sector to the impacts of climate change: • Updating the technical and legislative framework, based on scenario-based research • Encouraging the development/use of infrastructure (including forest access to increase intervention and response capacity, in case of wildfires), minimal or non-invasive forest technology and logistics • Promoting digital innovations in forestry, including through monitoring forest ecosystems • Stimulating research and innovation to enhance the effectiveness of forest management and CCA • Providing financial incentives to forest owners and managers to restore the quality and quantity of forest ecosystems

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS
Protection, restoration, and expansion of woodland: • Extend forest and tree cover through afforestation and reforestation with highly biodiverse forests and stimulate afforestation • Create and/or update afforestation programs for degraded land and legal/financial mechanisms • Create and/or update programs to extend the forest curtain system and legal and financial mechanisms to extend the forest curtain system
Boosting forest bioeconomy within sustainable limits and supporting socioeconomic functions of forests: • Promoting sustainable forest bioeconomy for sustainable, long-liferaw wood materials and products • Ensuring the sustainable use of wood resources for bioenergy • Promoting a forest bioeconomy based on the value of non-wood products
Adapting forest regeneration/restoration practices to the needs imposed by climate change: • Extension of forest and tree areas through afforestation and reforestation with forests rich in biodiversity and legal and financial mechanisms to stimulate the afforestation of land of low agricultural interest. • Creation and/or updating of afforestation programs for degraded land and legal and financial mechanisms to enable the afforestation • Establishment of programs or mechanisms to regulate forest corridors along water courses and maintain them in favorable conservation status • Creation and/or updating of programs for the extension of the forest curtain system and legal and financial mechanisms to allow to expand the system of forest curtains • Enhancement of forest multifunctionality and the role of the forest as a carbon sink, including by protecting forests and restoring forest ecosystems
Minimizing the risk of climate change on forests and through forests: • Developing knowledge on forest adaptation to climate change impacts by identifying and promoting solutions to control biotic and abiotic forest pests, forest decline, windfalls, and other natural disturbances of forest ecosystems • Developing knowledge on the impact of climate change on forests and ways to prevent, act, and respond to specific natural disasters caused by extreme weather events: landslides, drought, wildfires, windfalls, floods, and so on

Source: Draft Action Plan for the implementation of the National Strategy on Adaptation to Climate Change for the period 2023-2030, version August 2023 published on MEWF website for public consultations; *Flood RAS/Output No. 7 - Report on advice provided to MEWF in the preparation of twelve (12) final draft Flood Risk Management Plans, under the RAS on Technical Support for the Preparation of the Flood Risk Management Plans for Romania (P170989); *Flood RAS/Output No. 7 - Report on advice provided to MEWF in the preparation of twelve (12) final draft Flood Risk Management Plans, under the RAS on Technical Support for the Preparation of Flood Risk Management Plans for Romania (P170989).

Table 15. Summary of sectoral / programmatic adaptation analytics for Romania

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
HEAT AND MULTI-HAZARD RELATED MEASURES/PORTFOLIO (€4.3 BILLION)				
Urban systems (NAP)	• €793 million, out of which • €178 million for developing CCA action plans • €360 million for improving building codes and regulations • €115 million for adapting the Risk Analysis and Coverage Plans)[120] and defense plans • €140 million for developing/ implementing education, research, information, and awareness programs	• Green and white solutions to UHI (Austria)[121] • EU Tactical Level Guidance on Adapting Buildings to Climate Change[122] • Development and Appraisal of Long-Term Adaptation Pathways for Managing Heat Risk in London[123] • Economics of Climate Change, Adaptation and Decision Support in Europe[124] • Climate Change: Costs of Impact and Lines of Adaptation (France)[125]	€441,110,890–2,621,222,410	1.27–2.68
		• Sustainable urban drainage systems (EU MS) • Cooling of hospitals (EU MS)[126]	• €4.1 billion per year • €1.0–3.2 billion per year	• 0.31 (0.1– 0.6) • 0.5 (0.2–1.5)

120 The Risk Analysis and Coverage Plan represents a document that includes the potential risks identified at the level of an administrative-territorial unit, the measures, actions, and resources necessary for the management of those risks.
121 Johnson, D. 2021. A Cost-Benefit Analysis of Implementing Urban Heat Island Adaptation Measures in Small and Medium-Sized Cities in Austria. International institute for Applied Systems Analysis (IIASA). Link.
122 Climate-ADAPT 2023d.
123 Kingsborough, Ashley, Katie Jenkins, and Jim W. Hall. 2017. "Development and Appraisal of Long-Term Adaptation Pathways for Managing Heat-Risk in London." Link.
124 Paul Watkiss Associates. 2023. Economics of Climate Change, Adaptation and Decision Support in Europe. Link.
125 Climate-ADAPT. 2012. Methodologies for Climate Proofing Investments and Measures Under Cohesion and Regional Policy and the Common Agricultural Policy. Link.
126 Climate-ADAPT 2012.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
		• Public buildings retrofitting for energy efficiency and sustainability (Albania)[127]	• €40 million	• total energy cost savings are €29 million per year or €500 million over the lifetime
		• Public buildings retrofitting for energy efficiency and sustainability - emergency center (Serbia)	• €6,933,333	• 0.99-1.15
		• Public buildings retrofitting for energy efficiency and sustainability - kindergarten (Serbia)	• €1,942,308	• 0.97-1.45
		• Public buildings retrofitting for energy efficiency and sustainability - hospital (Serbia)	• €432–500 per m2	• NPV is €8.8 million for the most cost-effective option
		• UHI adaptation plan in Antwerp city (Belgium)[128]	• €70,000	
		• Green roofs against climate change (GRACC) Project (UK)[129]	• €912,263	
		• Establishment of Cool Centers (Bulgaria Case Study from this report)	• 5-year budget outlook - €1.11–1.64 billion (average €1.38 billion)	• NPC (2023 – 2050) €1.81 - 2.67 billion
		• Building standards for new development (Bulgaria Case Study from this report)	• 5-year budget outlook - €1.6 million	• NPC (2023–2050) €5.58 million
		• Urban heat island strategy at city level (Bulgaria Case Study from this report)	• 5-year budget outlook - €1.89 million	• NPC (2023–2050) €6.57 million
		• Eurocode suite revision (EU)	• €200 million	

127 Novikova, A., Z. Szalay, M. Horváth, et al. 2020. "Assessment of Energy-Saving Potential, Associated Costs and Co-Benefits of Public Buildings in Albania." Link.
128 Climate-ADAPT. 2023h. Adapting to Heat Stress in Antwerp (Belgium) Based on Detailed Thermal Mapping. Link.
129 EC. 2021d. Green Roofs against Climate Change. Link. GRO. 2021. The Gro Green Roof Code. Link.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
Energy sector (NAP)	**€123 million,** out of which • €76 million for increasing the resilience of the energy sector • €5 million for increasing the resilience of the Heating and Cooling sector • €15 million for education, information, and awareness programs • €26.5 million for critical infrastructure in energy systems and measures for extreme events	• Hydropower reservoir stations: increase in dam height (6 EU MSs)	• €16 billion per year	• N/A
		• Adaptation of electricity grids (26 EU MSs, excluding Malta)	• €0.64–0.65 billion per year	• 5.1 (0.2–10)
		• Additional cooling of thermal power plants (EU MS)	• €0.64 billion per year	• N/A
		• High efficiency ventilation in 2025 (EU MS)[130]	• €0.1–41.8 billion per year	• 1.8 (0.2 -660)
		• Renewable energy plant construction, energy efficiency improvement (Montenegro)	• €102.19–98.95 million per year	• Net Benefit: €72.31–1,187.88 million per year
Transport sector (NAP)	**€1.9 billion,** out of which • €830 million for consolidation of ground infrastructure • €475 million for consolidation of air transport infrastructure • €435 million for consolidation of shipping infrastructure • €12 million for transport sector vulnerability assessment	• Railway network electrification and climate resilience improvement (Latavia) • Patras - Pyrgos motorway (Greece) • High Speed 2 rail network (UK) • Dubrovnik Airport (Croatia)[131]	• €519.04 million • €64–74.4 million • €56 billion • €225.3 million	

130 Climate-ADAPT 2012.
131 EC 2018.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
		• Resilient road assets (Albania)[132] • Adapting tracks to higher temperatures (EU MS) • Adapting roads to higher temperatures (EU MS) • Adapting roads to increase in precipitation (EU MS)	• €6.3–32.1 million • €0.06–0.26 billion per year • €2.9–8.9 billion per year • €0.03–0.14 billion per year	• 0.1–1.1 • 2.0 (0.34–9) • 0.41 (0.2–0.9) • 0.45 (0.1–1.9)
	• €130 million for adapting of planning and decision-making processes	• Better surface asphalt for European runways (EU MS) • Retrofitting existing infrastructure of airports' drainage system (EU MS)[133]	• €0.14–0.43 billion per year • €0.04–0.18 billion per year	• N/A • N/A
		• Improved access to cooled public transport (Bulgaria Case Study from this report)	• 5-year budget outlook €836.1 million – €924.1 million (average €880.1 million)	• NPC (2023–2050) €780.14 million €840.16 million (average €800.15 million)

132 Xiong and Alegre 2019.
133 Climate-ADAPT 2012.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
DROUGHT HAZARD RELATED MEASURES/PORTFOLIO (€6.1 BILLION)				
Agriculture sector (NAP)	**€4.5 billion,** out of which • €423 million for developing an agriculture adaptation strategy • €4,036 million for achieving an efficient management of agricultural land • €53 million for improving the level of knowledge • €2.5 million for awareness raising and risk management tools	• Irrigation, drainage, and fertilizer improvement in the agriculture sector for climate resilience (North Macedonia)[134]	• US$310–9,600 (2009 value)	• Net Benefit US$400–74,000 (2009 value)
		• Additional farm advisory service (EU MS) • Irrigation efficiency (EU MS) • On-farm harvesting and storage of water (EU MS) • Plant winter cover (EU MS) • Improvement animal rearing conditions (EU MS)[135]	• €0.053–0.198 billion per year • €0.331 billion per year • €0.33–5.27 billion per year • €0.95–1.21 billion per year • €0.76 billion per year	• N/A • N/A • 10.9 (2.8–136) • 1.0 (0.7–1.4) • 1.3
		• Modernization of existing on-farm irrigation infrastructure (NSP for the EU CAP as per the CCDR)	• €400 million	
		• Establishment of new, small irrigation systems at the farm level (NSP for the EU CAP as per the CCDR):	• €85 million	

134 Sutton, W., et al. 2013. Reducing the Vulnerability of the Former Yugoslav Republic of Macedonia's Agricultural Systems to Climate Change. Link.
135 Climate-ADAPT 2012.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
Water resources (reducing the risk of water scarcity): (NAP)	**€1.6 billion,** out of which • €990.5 million for measures to strengthen the legislative and regulatory framework, as relevant/ applicable • €200 million for adaptation of existing water resources management infrastructure and optimization of water use • €250 million for restoration of natural water accumulation areas - wetlands to optimize irrigation systems • €50 million for supporting invest-ments in the water supply network	• Options for sustainable agricultural production and water use in Cyprus under global change ("AGWATER") (Cyprus)[136]	• €68,440	
		• Water management in a new district in Rouen (France)[137]	• €60 million	
		• Data-modelling system and the decision support tool for the integrated marine and inland water management for use of institutions related to water management (Estonia)[138]	• €2.044 million	
	• €55 million for the development and implementation of a National Program for ecological restoration of rivers • €15 million to conduct studies and research to identify and promote NBS and natural water retention measures • Others	• Integrated marine and inland water management (Estonia)[139] • Establishment of systems for information exchange on climate change adaptation • Implementation of strategies and measures for adapting to a changing climate	• €6.9 million	
		• Measures to reduce the climate change related impacts of impoundments in key water bodies (Updated National Basin Management Plan cited in the CCDR)	• €1.05 billion	

136 EC 2018.
137 EC 2018.
138 EC 2018.
139 EC 2018.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
FLOOD HAZARD RELATED MEASURES/PORTFOLIO				
Flood risk reduction (NAP)	**€3.32 billion** • Developing plans, actions, and measures for the reduction of flood risk in the areas where the flood risk is high (fluvial, rainwater, coastal sources) • Strengthening knowledge on the impact of climate change on water resources, on the use of nature-based solutions, on how to prevent, act and respond to specific natural disasters caused by extreme weather events	**Measures proposed in achieving the Flood Risk Management Plans' objectives Floods RAS):** • Avoid/control risks associated to floods • Reduce the negative impact of floods on population • Reduce the negative impact of floods on infrastructure and economic activity • Reduce the negative impact of floods on cultural heritage • Reduce the negative impact of floods on environment and achieve/maintain the environmental objectives in accordance with Water Framework Directive (WFD)	**€6,89 billion** (Includes the implementation of all proposed alternatives with the priority classes very high, high, and moderate, covering the initial investment, replacement, operating,(maintenance, land purchase, mitigation costs and revenues).	
Increasing the safety of dams and piers (NAP)s	**€500 million** • Increasing the safety of dams and piers - as appropriate, by prioritizing the implementation of NBS, natural water retention measures, rehabilitation of existing defense lines, rehabilitation of existing dams that require emergency interventions for safe operation	• Enhance the level of awareness and resilience concerning flood risks, as well as increase the capacity for early warning, alarm and intervention, and response in case of emergency • Enhance the level of adaptation to climate change impacts	These values are based on the implementation of the measures prioritized at the local level. This entails a need for direct investment of approximately €3.45 billion.	

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
		• Maximize efficiency in achieving flood risk objectives, considering the costs and available funding • Improve the involvement of all stakeholders	**€2.4 billion total costs for the implementation of flood protection measures** for the 2023–2027 planning cycle: approx. (within FRMP cycle 2, excluding operation-maintenance cost).	
		Preparedness package (Floods RAS) • Consists of 29 measures	**€400 million** (preparedness package)	
Integration of flood risk management into spatial and urban planning (Flood RAS)	• Development of methodology for integration • Revision/update of relevant legislation • Information campaigns for citizens to raise awareness on urban flooding ***Measures not costed***	• North West Bicester Eco Development (UK) • Flood adaptation urban planning in Central Denmark Region (Denmark)[140]	• £20 million • €11,683,058	

140 EC 2018.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
Promoting Nature-Based Solutions/Green Infrastructure solutions for flood risk management in urban areas (Flood RAS)	• Setup of national program office, including funding and inter-institutional working group • Identification of sites • Implementation of pilot projects • Monitoring and evaluation ***Measures not costed***	• Green and grey infrastructure (Poland)[141]	• €217 million	• 2
		• Enhance floodplain management (EU MS)[142]	• €73.9–79.3 billion per year	• 1.4 (1.1–1.7)
		• Chimney Meadows National Nature Reserve (UK) • Padgate Brook River Restoration (UK) • Sigma plan for flood protection (Belgium) • woody barriers and land management in Yorkshire (UK) • Mayes Brook River Restoration project (UK)[143]	• €3,030–3,080 • £0.25 million • €132 million • €4.5 million • £3.8 million	• 1.5–4.8 • 18 • 1.87–5.52 • 1.5–5.6 • 7
		• The Connecting Nature project - promoting nature-based solutions for adaptation in urban areas (Ireland)[144]	• €12 million	
Adapting infrastructure (transport, hydrotechnical works) to increasing flood risks due to climate change (Flood RAS)	Review and adaption of existing technical regulations and norms • Update/improve inventory of infrastructure • Prioritize assets at risk ***Measures not costed***	Measures to reduce vulnerability of the transport sector flood risk (current and future projected)	• £0.25 million	• NPV €1.34–5.38 billion

141 EEA 2023a.
142 Climate-ADAPT 2012.
143 World Bank and European Commission. 2021. Economics of Prevention and Preparedness: Investment in Disaster Risk Management in Europe Makes Economic Sense - Background Report. Washington, DC: World Bank. Link.
144 EC 2018.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
Erosion and torrent control program (Flood RAS)	• Legislative framework gap analysis • Setup of program office, including funding and inter-institutional working group • Selection of the priority locations for intervention • Design and implementation • Monitoring and evaluations ***Measures not costed***	• Watershed management (Nepal)[145]	• €132 million	• 1.15–4.38
		• Drainage trench for landslide and erosion management (Italy)[146]	• €17,652 (+ €400 per year maintenance cost)	• NPV €17,277.75
WILDFIRE HAZARD RELATED MEASURES/PORTFOLIO (€2.3 BILLION)				
Adaptation of forests and the forest-based sector to the impacts of climate change	**€425 million** • Update the technical and legislative framework, based on continuous, scenario-based research on the impact of climate change on forests • Strongly encourage the development/ use of infrastructure (including forest access to increase intervention and response capacity, in case of wildfires)	• Financial contributions of planning applications for heathland fire prevention (UK)[147] • Integrated forest adaptation and fire management plan (the Alpine region)[148] • Digital forest sensing and monitoring system (UN)[149] • Waste removal (EU LIFE project)[150]	• £21.7 million • €16.3 million • €1.4–21.6 (US$2–30) per km^2 • €1–11.76 per ton, mean cost €3.87 per ton	

145 World Bank. 2019c. Valuing Green Infrastructure Case Study of Kali Gandaki Watershed, Nepal. Link.
146 Salbego, G., M. Floris, E. Busnardo, M. Toaldo, and R. Genevois. 2015. "Detailed and Large-Scale Cost/Benefit Analyses of Landslide Prevention vs. Post-Event Actions." Nat. Hazards Earth Syst. Sci. 15: 2461–2472. Link.
147 EEA. 2018. Climate-ADAP - 10 Case Studies: How Europe Is Adapting to Climate Change. Link.
148 Müller, Vilà-Vilardell, and Vacik 2020.
149 UNFCCC. 2009c. Cost of Implementing Methodologies and Monitoring Systems Relating to Estimates of Emissions from Deforestation and Forest Degradation, the Assessment of Carbon Stocks and Greenhouse Gas Emissions from Changes in Forest Cover, and the Enhancement of Forest Carbon Stocks - Technical Paper. FCCC/TP/2009/1. Link.
150 JRC. 2015. Costs of Restoration Measures in the EU Based on an Assessment of LIFE Projects. Link.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
	• Promote digital innovations in forestry, including by creating and/ or promoting current programs and mechanisms on monitoring forest ecosystems, traceability of timber and control of illegal logging • Stimulate research and innovation to enhance the effectiveness of enhanced sustainable forest management and adaptation of the forest-based sector • Provide financial incentives to forest owners and managers to restore the quality and quantity of forest ecosystem	• Building forest fire resilience using recycled water (Spain)[151]	• €5.49	
		Wildfire national strategy (Greece)[152] • **Pillar One:** Upgrade of Infrastructure, Facilities, and Provision of Educational Programs • **Pillar Two:** Early Warning Systems and Means of Prevention • **Pillar Three:** Equipment and Means of Support and Coordination • **Pillar Four:** Aerial Firefighting Equipment and Ground Infrastructure	• €1.76 billion	
		• Fire mitigation and risk reduction actions in forest and agriculture lands (Bulgaria case study from this report)	• €38 million for 5-year budget outlook	
		• Improving the plans for protection of forest territories (Bulgaria case study from this report)	• €1 million for 5-year budget outlook	
Protection, restoration, and expansion of woodland	**€1.06 billion** • Extension of forest and tree cover through afforestation and reforestation with highly biodiverse forests and use of legal and financial mechanisms to stimulate afforestation	• Peatland restoration (UK)[153]	• €172–8,037 (£150–7,000) per ha	• BCR 3–12, with a typical value of 4
		• Vegetation replanting (EU LIFE project)[154]	• €1,006–9,009 per ha, mean cost €4,857 per ha	

151 Climate-ADAPT. 2022b. Building Fire Resilience Using Recycled Water in Riba-Roja de Túria, Spain. Link.
152 International Trade Administration. 2022. Greece Wildfire National Strategy. Link.
153 Watkiss, P., et al. 2019. The Impacts of Climate Change on Meeting Government Outcomes in England. Support Research for the 2019 Progress Report. Link.
154 JRC 2015.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
	• Creation and/or updating of afforestation programs for degraded land and legal and financial mechanisms for afforestation of degraded land • Creation and/or updating of programs to extend the forest curtain system and legal and financial mechanisms to extend the forest curtain system	• New woodland creation based on carbon sequestration (Sweden)[155]	• €32–121 million (mixed tree species); €51–217 million (spacing between trees to increase resilience against wildfire risk)	• BCR 4.3–12.3
Stimulating forest bioeconomy within sustainable limits and supporting socio-economic functions of forests	**€134 million** • Promoting sustainable forest bioeconomy for sustainable, long-life raw wood materials and products • Ensuring the application of sustainability criteria in the production of biomass from forestry for energy use, contributing sustainably to tackling energy poverty in local communities • Promoting a forest bioeconomy based on valorization of non-wood products	• WUI management to residential houses (Portugal)[156]	• €46.75 million	• BCR 3.1
		• WUI management to industries (Portugal)[157]	• €44.48 million	• BCR 2.1
		• Fuel management in forests for fire risk reduction (Portugal)[158]	• €2.21 million	• BCR 11.9

155 Phase 2 Sweden analytics.
156 World Bank and European Commission 2021, case study 18.
157 World Bank and European Commission 2021, case study 19.
158 World Bank and European Commission 2021, case study 20.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
Adapting forest regeneration / restoration practices to the needs imposed by climate change	**€377 million** • Creating programs or mechanisms to ensure maintenance in the forest only of native species specific to the non-moral and pedo-stationary floor • Establishing programs or mechanisms to regulate forest corridors along water courses and maintain them in favorable conservation status • Enhancing the multifunctionality of the forest and the role of the forest as a carbon sink, including by protecting forests and restoring forest ecosystems	• Smart bark beetle monitoring and management (background literature review)	• €0.25–5.68 million	• BCR 21.7–24.2
		• Invasive species and biodiversity management (EU LIFE project)[159]	• €500–6,356 per ha, mean cost €3,769 per ha	

159 JRC 2015.

CCA MEASURES PORTFOLIO (FROM DRAFT AUGUST 2023 NAP AND DRAFT FLOOD RAS OUTPUTS*) FOR SELECTED SECTORS	ESTIMATED COSTS IN DRAFT ROMANIA NAP	EXAMPLE CCA MEASURES TO BUILD ON CCA PLAN PRIORITIES FROM THE LITERATURE	POTENTIAL COSTS FROM THE LITERATURE	POTENTIAL COST-EFFECTIVENESS RATIOS/ BCRS FROM THE LITERATURE
Minimizing the risk of climate change on forests and through forests	**€247 million** • Developing knowledge on forest adaptation to climate change impacts by identifying and promoting solutions to control biotic and abiotic forest pests, forest decline, windfalls, and other natural disturbances of forest ecosystems • Developing knowledge on the impact of climate change on forests and ways to prevent, act, and respond to specific natural disasters caused by extreme weather events: landslides, drought, wildfires, windfalls, floods, and so on	• CCA Decision Support Tool (Austria)[160]	€188,000	• BCR 5.8, NPV of around €0.99 million
		• Information tool for fire risk forecasting and emergency fire response (Spain-Portugal)[161]	€0.7 million	• BCR 1.6
		• Integrated Forest Fire Analysis System (IFFAS) (EU)[162]	€2.34 million	

Source: Draft Action Plan for the implementation of the National Strategy on Adaptation to Climate Change for the period 2023-2030, version August 2023 published on MEWF website for public consultations; *Flood RAS/Output No. 7 - Report on advice provided to MEWF in the preparation of twelve (12) final draft Flood Risk Management Plans, under the RAS on Technical Support for the Preparation of the Flood Risk Management Plans for Romania (P170989); *Flood RAS/Output No. 7 - Report on advice provided to MEWF in the preparation of twelve (12) final draft Flood Risk Management Plans, under the RAS on Technical Support for the Preparation of Flood Risk Management Plans for Romania (P170989).

160 World Bank and European Commission 2021, case study 21.
161 World Bank and European Commission 2021, case study 24.
162 Climate-ADAPT. 2016c. CALCHAS - An Integrated Analysis System for the Effective Fire Conservancy of Forests. Link.

BOX 16. MACROECONOMIC MODELS COMMONLY USED AND HOW THEY CONSIDER CLIMATE ADAPTATION

Macro-structural models differ from CGE models from a technical and adaptation objective perspective.[163] Both CGE and macro-structural models have been used for dedicated analysis of climate and disaster shocks but are also often set up first to analyze macroeconomic outcomes of CCM policies and then CCA. CGE models capture cross-sectoral links and price effects and can consider greater sectoral details. In CGE models, adaptation is considered in an aggregated manner based on sector impact and high-level adaptation costs and benefits, when available. Macro-structural models have good dynamic properties and a well-defined equilibrium and are well suited for considering probabilistic shocks, an advantage for DRM analytics. The main difference between CGE and macro-structural models is the level of detail of sectors and the way damages and adaptation measures enter the models. CGE models typically feature a high level of sectoral detail, representing the economy with numerous sectors and inter-industry flows based on input-output tables. This allows for a nuanced understanding of how economic policies or external shocks affect different parts of the economy. Macro-structural models may have a more aggregated view, focusing on larger sectors or the economy as a whole without the same level of inter-sectoral interaction. In CGE models, damages from external shocks or policy changes are directly incorporated into the production functions or consumer utility functions, affecting the equilibrium conditions of the model. Adaptation measures can be modeled as changes in technology or preferences, which in turn influence the model's outcomes. Macro-structural models might introduce damages and adaptations in a more aggregated form, such as changes in overall productivity or growth rates, without specifying the underlying sectoral adjustments. Macro-structural models tend to generally be used more frequently by Ministries of Finance for fiscal and financial planning and considering shorter time frames (2030s–2050s), while CGE models are often used when longer timeframes are considered (2050s–2100s).

The macroeconomic analysis in this case study was undertaken using a macro-structural model, which was selected for this case study following an extensive literature and methodology review. The model was adapted from the Solow-Swan economic growth model to evaluate how damages and losses caused by disasters impact main macro-fiscal indicators such as GDP and government expenditures. It provides reference information for decision-making to implement policy measures that strengthen the resilience of public finances against selected hazards. In the case of Romania, the 'Dobrescu macro-model' was set up specifically for the MoF and used for analytics to inform the fiscal and budgetary strategy. The Dobrescu macro-model is similar to the World Bank's multisector macro-fiscal model with its climate extension (CC-MFMod),[164] which has been used for World Bank CCDRs' analytics in several countries worldwide. The macroeconomic analysis considers various inputs, including macroeconomic and fiscal indicators, hazard impacts and adaptation measures to be taken by the government, and simulations for climate change-related hazards. Outputs on hazards considered in this case study are taken from probabilistic disaster risk models (floods),[165] econometric estimates (extreme heat),[166] and machine-learning models (droughts, wildfires)[167] combined with climate model projections and spatial analyses.

163 World Bank. 2021. Climate Modeling for Macroeconomic Policy: A Case Study for Pakistan. Policy Research Working Paper 9780. Link.
164 In the CC-MFMod, the standard Cobb-Douglas specification for potential GDP was modified along five dimensions to accommodate the climate focus of the model: (a) energy was included as a factor of production (see Hassler, Krussel and Olovsson 2012) and (b) the production function was modified to account for damages from climate change, including (i) reductions in aggregate total factor productivity (TFP) due to lower agricultural productivity, (ii) reduction in labor productivity and supply due to higher temperatures, (iii) the impact of pollution on the labor force, and (iv) the impact of flooding on capital stock. Burns, A., et al. 2019. *The World Bank Macro-Fiscal Model Technical Description.* Link.
165 Underlying data on flood impacts that informed WB and EC 2021b.
166 COACCH 2022; COACCH 2021a.
167 Need reference for CIMA analytics + IIASA analytics. Rossi, Lauro, Wens Marthe, De Moel Hans, et al. 2023. European Drought Risk Atlas. Link.

In terms of macroeconomic analysis of natural hazards in Romania, outcomes from previous studies analyzed the impacts, but not adaptation aspects specifically for that country.

Under the COACCH project,[168] **assessments have been undertaken to assess the macroeconomic and sectoral impacts of climate change to inform adaptation policies.** The assessment considers a variety of models, methodological approaches, climate scenarios, and data analytics to provide a downscaled assessment of the risks and costs of climate change in Europe. Quantified by various physical and biophysical impact models, the sectoral impact of various natural and climate hazards was assessed, which includes analysis of energy demand and supply, labour productivity, agriculture, forestry, fisheries, transport, sea level rise, and riverine floods. The results from sectoral analysis were then introduced to the ICES macroeconomic CGE model, which enables the analysis of the higher-level economic implications of climate change.[169] As for the future climate and socioeconomic scenarios, COACCH used certain RCP and SSP combinations[170] to fully characterize the space for low, medium, and high impact cases in terms of a range of projected climate impacts.[171] The result of the macroeconomic, spatially resolved impact assessment shows the changes in GDP and the economic loss under various climate scenarios.[172] For instance, under the medium impact scenario, there is a negative effect of climate change on GDP throughout Europe, with the greatest reduction in GDP found in Western and Central Europe (see Figure 25). Though Romania is not among the countries that face the biggest decrease in GDP, its overall economy is still greatly affected. Meanwhile, results from sectoral analysis suggest the effect of climate change will have the most severe impact on sectoral economy in the long run (2070) under the SSP5 RCP8.5 scenario. The forestry sector will be the most affected in Romania, while the agriculture and transportation sector is expected to experience GDP loss as well (see Figure 26). The assessment also reveals a compounding effect of climate change on regional GDP.

168 COACCH 2022.
169 COACCH. 2018. The Economic Cost of Climate Change in Europe Policy Summary Europe. Link.
170 The RCP-SSP combinations considered by the COACCH assessment: RCP2.6-SSP1, RCP2.6-SSP2, RCP2.6-SSP3, RCP4.5-SSP1, RCP4.5-SSP2, RCP4.5-SSP3, RCP4.5-SSP5, RCP6.0-SSP2, and RCP8.5-SSP5.
171 COACCH. 2019. “The Economic Cost of Climate Change in Europe: Synthesis Report on Interim Results.” Policy Brief by the COACCH Project. Link.
172 Bosello et al. 2020.

Figure 25. Changes in GDP in 2050 comparing the baseline and the medium impact scenario (2007 US$, millions)

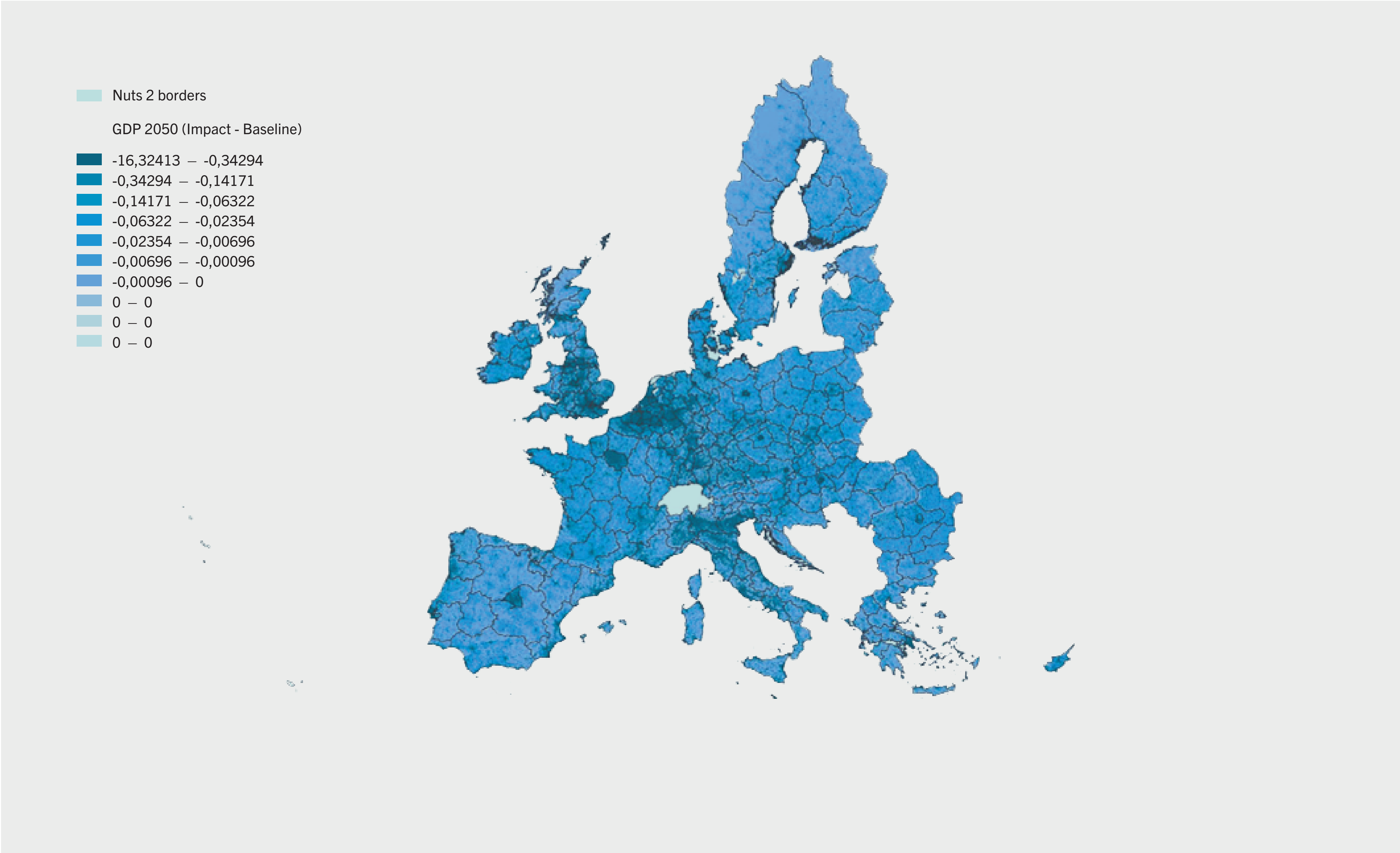
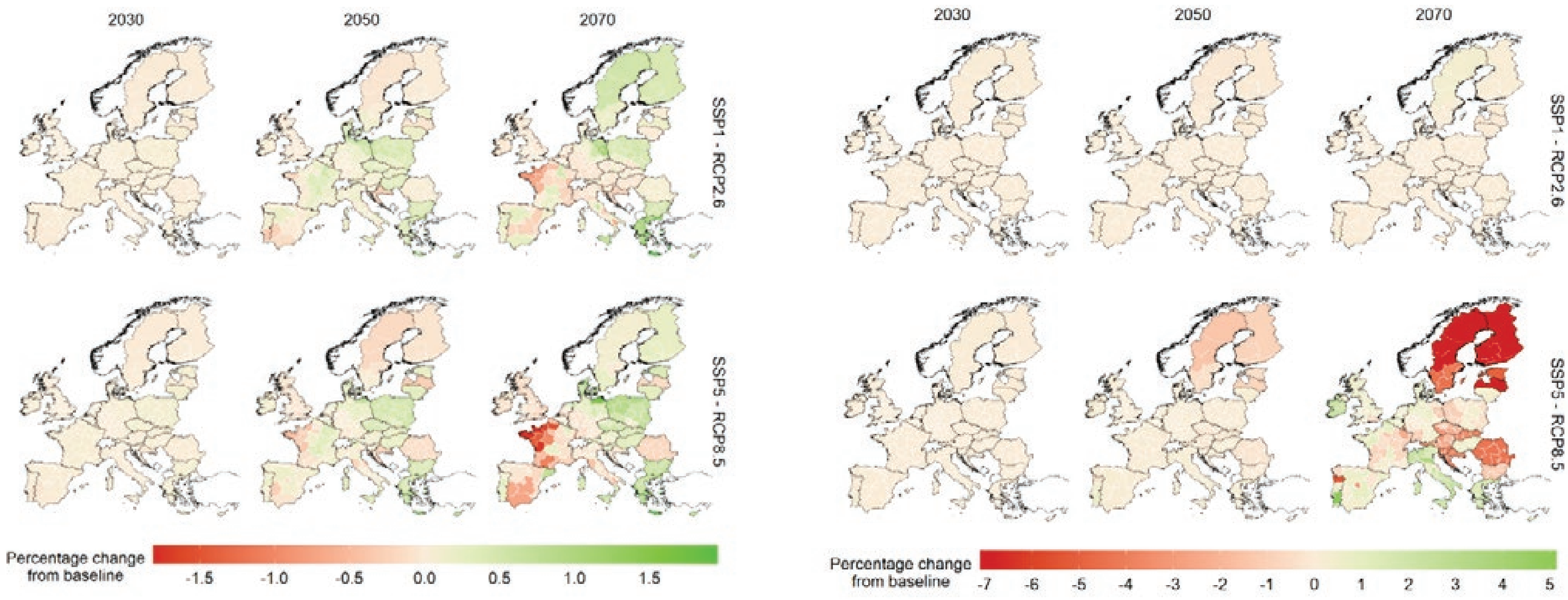


Figure 26. Changes in GDP on agriculture and forestry in 2030, 2050 and 2070 comparing the baseline and the medium impact scenario (%)



Source: COACCH 2020.

Under a previous study,[173] **impacts of floods and earthquakes were also assessed on GDP.** The findings of the catastrophe risk modelling show that Romania is one of the EU countries with the highest earthquake (seismic) risk and flood (fluvial and surface water). AAL relative to the total building stock value exceeds 0.1 percent in each of the top-10 ranked countries for flood but exceeds this threshold in only four countries for earthquake. The annual average loss due to flood damage of private and public buildings is estimated at €585 million (0.28 percent of GDP), similarly to the 0.23 percent of GDP estimated by JRC.[174] Also, flood risk modelling predicts that 50-year return period flood could affect the equivalent of US$2 billion of the GDP in 2015, but by 2080, considering change in socioeconomic and climate conditions, this figure may double or even quadruple (depending on the mitigation pathway selected).

173 WB and EC 2021b.
174 World Bank. 2021c. Report on the Review of the Legal, Regulatory, and Institutional Framework Governing DRR in Romania. p. 275.

Table 16. Considerations and inputs on impacts and adaptation for macro models

IMPACTS FOR CURRENT AND FUTURE CLIMATE	IMPACTS CONSIDERING ADAPTATION/COSTS OF ADAPTATION
FLOOD HAZARD/IMPACTS FROM CLIMATE CHANGE ON **INFRASTRUCTURE**	
Macro-structural models: Asset damages (AALs and expected probability curves*; baseline and future climate, ideally for various combinations of RCPs and SSPs, multiple time horizons and return periods) **Example Romania case study:** • Based on results from EU phase 1[74] • The AAL for floods (not including emergency response costs) may vary from US$4.39 million in case of 5-year return period event, under the scenario SSP1 RCP1.9, up to US$660 million for a 100-year return period event, under SSP1 RCP1.9 scenario • Baseline US$500 million (2020 value) • Future based on 1,000 runs of SSP1 RCP1.9; SSP1 RCP2.6; SSP2 RCP4.5; SSP3 RC P7.0; SSP5 RCP8.5 for 2050 and for 5-, 10-, 20-, 50-, 75-, 100-, 200-, 500-, and 1,000-year return period events * ***Note:*** Generally average damage values are considered in terms of impacts on macroeconomic variables. The only example so far that truly considers extreme events is for Jamaica hurricane for the United States.	**Macro-structural models:** Investment needs and BCRs/benefits to make infrastructure resilient/reduce potential asset damages* **Example Romania case study:** • No results from EU phase 1. • The costs of flood protection measures vary substantially depending on (a) socioeconomic growth scenarios; (b) climate change scenarios; (c) local constructions costs (for example, depending on soil type); and (d) risk tolerance, that is, the safety standard of measures (for example, 500-year return period standard). • Cost of high priority flood protection measures, according to World Bank Flood RAS, is about €6.9 billion for 2022–2028, covering initial investment, replacement, operation and maintenance, land purchase, mitigation costs, and revenues. This is consistent with World Bank adaptation pathways analysis,[75] estimating costs in the range of about US$1 billion to US$5.6 billion per year. • Benefits of flood protection measures would accrue over the long term (while investments require substantial up-front capital expenditure for long-life structures such as dikes). * ***Note:*** As transport networks were not considered under EU phase 1 and other CCDR studies, these investment needs/benefits cannot be considered (would require integration of findings but difficult due to different methodologies).

74 Underlying data on flood impacts that informed WB and EC 2021b.
75 Rozenberg and Fay 2019.

<table>
<tr><th>IMPACTS FOR CURRENT AND FUTURE CLIMATE</th><th>IMPACTS CONSIDERING ADAPTATION/COSTS OF ADAPTATION</th></tr>
<tr><td>CGE models:
Example Austria case study:[76]
• Hazards covered: flood
• Time horizon: 2015 (current)/2030/2050
• Economic flood risk modelling: IIASA's probabilistic risk-based CATastrophe SIMulation (CATSIM) framework
• Result - current flood loss: expected direct losses of €258 million 2015
• Result - future flood loss: expected annual losses of €354 million for 2030 and €511 million for 2050</td><td>CGE models:
Example Austria case study:[77]
• Sector: transport, catastrophe management
• Hazard covered: floods, landslides, and mudflows
• Impact chain and (bio)physical impact model: for transport, road damages due to increase in floods, landslides, and mudflows are considered, based on regression analysis on past damage events and costs; for catastrophe management, building damages due to riverine floods are considered, based on simulation of flood damages in a hybrid convolution approach
• CCA cost estimate: public adaptation expenditure in the base year (2008) for catastrophe management (mainly structural flood protection) is around €197 million. Meanwhile, for the adaptation pathway until 2050, the annual total CCA cost for the water sector is estimated to be €93 million, with a shift to more expenditure to labor and capital and less for construction.
• BCRs: for flood protection measures, soft measures yield a BCR of 11, green measures yield a BCR of 2, and grey measures yield a BCR of 4.</td></tr>
<tr><td colspan="2">DROUGHT HAZARD/IMPACTS FROM CLIMATE CHANGE ON AGRICULTURE</td></tr>
<tr><td>Macro-structural models:
Agriculture productivity losses (likelihood of maximum losses); baseline and future climate, ideally for various combinations of RCPs and SSPs, multiple time horizons and return periods)
Example Romania case study:
• Based on new results from EDORA project/World Bank[78]
• Crop yield losses (maize, wheat, and so on)</td><td>Macro-structural models:
Investment needs and BCRs/benefits to make agriculture and water sector resilient/reduce potential yield losses
Example Romania case study:
• Based on insights from World Bank/IIASA report and external studies.
• Impacts on agriculture can occur through various channels (for example, heat affecting agricultural labor productivity, drought impacts on crop yields, agricultural supply chain disruptions due to flood impacts on roads)—thus making it difficult to capture them comprehensively.</td></tr>
</table>

76 PACINAS. 2017a. Flood Risk Case Study: Iterative Climate Risk Management. Link.
77 Bachner, et al. 2018. Public Adaptation to Climate Change: The Economy-Wide Costs and Benefits and Implications for Government Budgets. Link.
78 IIASA 2023; consistent with EDORA (European Drought Risk Assessment) methodology.

IMPACTS FOR CURRENT AND FUTURE CLIMATE	IMPACTS CONSIDERING ADAPTATION/COSTS OF ADAPTATION
• Baseline 2020: value of agricultural production US$13,851.80 million (2015 value) • Future based on CMIP6 runs for RCP/SSP combinations: SSP1 RCP2.6, SSP3 RCP4.5, SSP5 RCP8.5 with all years provided • Results: Reduction in value of agricultural production as % of GDP from 1.079% to 1.152% (around €2.5 billion)	• Climate related losses: yield losses due to climate change are estimated to be €200 million for maize alone (equivalent to 3% of Romania's agricultural GDP).[79] In 2022, Romania experienced a drought that is estimated to have wiped out €1 billion. • Climate change adaptation investments have not been costed individually but include measures such as adoption of drought resilient crops, irrigation infrastructure, heat adaptation for outdoor workers, and flood protection for agro-industrial facilities and supply chain networks (that is, partly overlap with measures under heat and floods above).
CGE models: Example Germany case study:[80] • Hazards covered: droughts and extreme heat • Sectors: agriculture • Time horizon: 2018–2019 (current)/2050 (future) • Climate scenarios: weak/medium/severe climate impact • Result - current: a total damage value of between €7 and just over €8 billion in the agricultural sector due to droughts and extreme heat during 2018 and 2019 • Result - future: cumulative costs in agriculture between 2022 and 2050 are estimated to be €110, €120 and €160 billion for the weak, medium, and severe climate scenario	**CGE models:** Example: Germany case study:[81] • Climate scenarios: weak/medium/severe climate impact • Time horizon: 2050 • CCA measures considered: investments in 'hard' new equipment and techniques that help farmers cope with climate impacts, such as digitization, enhanced crop production systems, advanced agricultural technology and technical systems, and improved irrigation systems ('soft' measures such as crop rotation and cultivation area management are found to have no significant impact on expenses and income and thus not included in the model) • CCA cost estimate: a 6% increase in capital expenditures in 2050 compared to the baseline as a result of CCA investment • Macroeconomic benefit of CCA: investing in new equipment and other assets that help farms cope with climate impacts will reduce the negative impact on GDP, bringing it back to almost zero-climate GDP over 2022–2050

79 Prăvălie, R., I. Sîrodoev, C. Patriche, B. Roşca, A. Piticar, G. Bandoc, L. Sfîcă, et al. 2020. "The Impact of climate Change on Agricultural Productivity in Romania. A Country-Scale Assessment Based on the Relationship between Climatic Water Balance and Maize Yields in Recent Decades." Agricultural Systems 179 (102767).

80 The Institute of Economic Structures Research (GWS). 2022. Schäden der Dürre- und Hitzeextreme 2018 und 2019: Eine ex-post-Analyse. Link.; Flaute, M., S. Reuschel, and B. Stöver. 2022. Volkswirtschaftliche Folgekosten durch Klimawandel: Szenarioanalyse bis 2050. Studie im Rahmen des Projektes Kosten durch Klimawandelfolgen in Deutschland. GWS Research Report 2022/02, Osnabrück. Link.

81 Flaute, Reuschel, and Stöver 2022.

IMPACTS FOR CURRENT AND FUTURE CLIMATE	IMPACTS CONSIDERING ADAPTATION/COSTS OF ADAPTATION
HEAT HAZARD/IMPACTS FROM CLIMATE CHANGE ON **PRODUCTIVITY**	
Macro-structural models: Impacts on labor productivity (productivity losses3, baseline and future climate, ideally for various combinations of RCPs and SSPs, multiple time horizons and return periods)	**Macro-structural models:** Investment needs and BCRs/benefits to enhance resilience of the workforce/reduce potential labor productivity losses
Example Romania case study: • Based on results from COACCH project/World Bank[82] • Economic cost of extreme heat in the absence of adaptation measures: Under current climate conditions, extreme heat costs 0.2% of GDP per year, estimated to rise to 0.8% by 2050 in an RCP2.6 scenario (1.2% for RCP4.5; 1.5 % for RCP8.5). Driven by labor productivity losses. • Baseline 28507.8 Output per worker (GDP constant 2015 US$)—International Labour Organization (ILO) modelled estimates for 2022 • Future based on CMIP6 runs for RCP/SSP combinations: SSP1 RCP2.6, SSP3 RCP4.5, SSP5 RCP8.5 with all years provided • *Note: The projected GDP impacts under each scenario are as follows: • SSP1 RCP2.6 (sustainable development and low greenhouse gas emissions): A gradual GDP reduction was projected, starting at –0.1% in 2020 and reaching –0.8% by 2050. • SSP2 RCP4.5 (middle-of-the-road development and emissions): A more pronounced GDP decline was expected, with –0.2% in 2020, deepening to –1.2% by 2050. • SSP5 RCP8.5 (rapid development and high emissions): The most significant GDP decrease was forecast under this scenario, with –0.2% in 2020 and –1.5% by 2050. **Note:* Generally, productivity losses are determined for outdoor workers, as for indoor workers it would depend on factors influencing indoor temperature.	**Example Romania case study:** • Based on results from the COACCH project and external literature • Local heat adaptation interventions are relatively simple and cost-effective solutions, such as shifting working hours to avoid the hottest periods during the day, installation of shading, ventilation, and air circulation systems • Heat-specific CCA costs are estimated to be around €78 million per year, covering Romania's agriculture and industry sectors • Benefits of these adaptation measures: considering an RCP2.6 scenario, the economic cost of extreme heat could be reduced from 0.8% of GDP (without adaptation) to 0.26% (with adaptation) through reduced impacts on labor productivity (from 1.2% to 0.36% for RCP4.5).

82 COACCH 2022; COACCH 2021a.

IMPACTS FOR CURRENT AND FUTURE CLIMATE	IMPACTS CONSIDERING ADAPTATION/COSTS OF ADAPTATION
CGE models: **Example Austria case study:**[83] • Hazard: rising temperature and extreme heatwaves • Sectors: manufacturing and trade sector • Climate scenarios: three climate scenarios (mild, moderate, strong) and three socioeconomic scenarios (low, medium, high sensitivity) • Time horizon: 2016–2045 • Impacts: For the manufacturing and trade sector, the annual labor productivity losses of up to approximately €40 million for 2016–2045 and up to €140 million for 2036–2065. The damage to the overall economy will be three to four times higher if the interrelations with other sectors are considered.	**CGE models:** **Example: Germany case study:**[84] • Assessment of the macroeconomic cost due to heat-related productivity loss over a two-year period (2008–2009) in Germany based on heat-related data recorded and external literature • Result: economic cost between €8.5 billion and €10.3 billion, with a median value of around €9.2 billion; heat-related deaths not monetized due to moral and ethical issues as well as deep uncertainties in the methodological approach • CCA measure considered: installation of air conditioning systems as a low-regret option • CCA benefits: for cooling adaptation measures (that is, increase in the share of air conditioning systems), a 20% increase will result in a benefit of €1.5 billion (17% loss reduction), a 50% increase will result in a benefit of €3.7 billion (40% loss reduction), and doubling the share of air conditioning systems would have resulted in a benefit of €5.9 billion (64% loss reduction).
WILDFIRE HAZARD/IMPACTS FROM CLIMATE CHANGE ON **FORESTRY**	
Macro-structural models: (nothing found in the literature) **CGE models:** Changes in forest yields/net physical wood production (baseline and future climate, ideally for various combinations of RCPs and SSPs, multiple time horizons and return periods)	**Macro-structural models:** (nothing found in the literature) **CGE models:**

83 COIN. 2014. The Impact of Climate Change on Labour Productivity in the Austrian Manufacturing and Trade Sector. Link.
84 The Institute of Economic Structures Research (GWS). 2022. Schäden der Dürre- und Hitzeextreme 2018 and 2019: Eine ex-post-Analyse. Link.

IMPACTS FOR CURRENT AND FUTURE CLIMATE	IMPACTS CONSIDERING ADAPTATION/COSTS OF ADAPTATION
Example Austria Case study:[85] • Losses in timber production • Hazard: rising temperatures and decreased precipitation as a result of climate change as well as possible damages caused by the spruce bark beetle • Time horizon: two scenario periods, 2016–2045 and 2036–2065 • Climate scenario: moderate climate scenario with a mean temperature rise of +1.0°C in the first scenario period (2016–2045) and +2.0°C in the second scenario period (2036–2065), comparing the reference period (1981–2010) • Result: for the forestry sector itself, additional average annual costs of approximately €150–230 million are expected to arise over 2014–2039 and 2044–2069. Moreover, if the economic interrelations with other sectors are considered, then the annual average cost will increase to €463 million between 2036 and 2065.	**Example Austria case study:**[86] • Assess the current adaptation deficit and the potential future costs of adaptation up to 2050 at the national level • Hazard covered: natural and climate hazards including flooding, mass movements, and heat stress • Time horizon: 2050 • CCA cost estimate: adaptation in the forestry sector leads to an annual total cost of around €300 million per year, with a shift in expenditure towards more machinery, capital, and labor as well as construction • CCA macroeconomic effect: for the forestry sector, adaptation could lead to a 47% reduction in GDP loss, 39% reduction in welfare loss, and 35% reduction in unemployment due to climate change compared to the baseline scenario; positive GDP and welfare effects primarily due to the reduced damage to protective forests, which lead to reduced loss in timber production and more public means available to increase transfers to households

Source: World Bank based on COACCH (2019); COACCH (2021); COACCH (2022); COIN (2015); COIN (2014); PACINAS (2017) The Institute of Economic Structures Research (GWS) (2022); World Bank and European Commission (2021).

85 COIN. 2015. The Impact of Climate Change on Timber Production in Austria. Link.
86 PACINAS. 2017b. Macroeconomic Effects of PUBLIC adaptation to Climate Change. Link.; Bachner et al. 2018.

Aurelia

Table 17. Examples of CCA measures considered for climate proofing of transport networks in Aurelia (non-exhaustive list)

MEASURES
(Multi-hazard) Pave roads and railways with durable, climate-resilient materials
(Flood) Elevate and install watertight barriers for railways
(Flood) Establish barriers and water buffering for roads and highways
(Flood) Improve drainage of roads and highways
(Flood) Implement slope embankments to allow water runoff to the side and away from the road
(Flood) Use large foundations to ensure bridge stability for scour protection
(Flood) Restore floodplains to control river flooding in areas near major transportation networks
(Flood) Implement balancing culverts to accommodate high water volumes resulted from flooding
(Flood/storm) Integrate adequate camber design so that high water volume will not accumulate in the road but run through the road and into the drains
(Heat) Establish green roofs and vertical green gardens in airports to reduce urban heat island effect
(Heat) Use high-standard asphalt binder that can withstand high temperature
(Heat/fire) Build pavement with new materials resistant to extreme temperature
(Heat/fire) Plant trees and shrubs along roads and highways which could serve as fire breaks preventing wildfires from crossing and blocking roads

Table 18. Examples of CCA measures considered for climate proofing of power networks in Aurelia (non-exhaustive list)

MEASURES
(Multi-hazard) Relocate power plants to places less exposed to hazard risks, especially when the infrastructure exceeds its lifetime or when it can be severely damaged
(Multi-hazard) Install backup generators that allow power plants to continue operating even if power supplies are interrupted by hazards
(Flood) Enhance power plant protection through the construction of dikes, floodwalls, and other structural defense measures
(Flood) Enhance climate resilience of underground pipelines and cable lines

MEASURES
(Flood) Improve dam spill management for hydropower plants, which includes spillways, gated systems, and fuse plugs
(Flood) Use stainless steel materials to reduce corrosion from water damage
(Flood) Elevate electrical and mechanical facilities above the flood level
(Flood) Use water resistant materials, such as plaster-based coating or water-repellent mortar, to enhance flood resilience of power stations
(Fire) Upgrade the electricity distribution network to reduce wildfire risk from powerline ignition
(Fire) Establish fuel breaks and security buffer zones
(Fire) Upgrade the electricity distribution network to reduce potential wildfires sparked by powerlines
(Heat/drought) Improve cooling capacity for nuclear or solar power plants
(Heat/drought) Build electric cable lines and power stations with new materials resistant to extreme temperature
(Heat/drought) Establish effective water reuse and water collection system as a part of the power plant

Table 19. Examples of CCA measures considered for climate proofing of selected critical infrastructure buildings in Aurelia (non-exhaustive list)

MEASURES AGAINST MULTIPLE HAZARDS	HEALTH	EDUCATION	CP
(Multi-hazard) Implement gas-fired on-site cogeneration (CHP) to provide efficiency and redundancy for power generation in the event of grid loss or diesel generator issues (CHP infrastructure is on the roof as are emergency diesel generators)	X		
(Flood) Place the first-floor elevation at least 9 meters above the projected 500-year flood elevation while maintaining universal access for rehabilitation patients	X		
(Flood) Install flood shield and elevate floodwall	X	X	
(Flood) Place all critical patient care functions above first floor	X		
(Flood) Place all critical mechanical/electrical infrastructure on the roof and above flood elevations to minimize possibility of interruption	X		
(Flood) Elevate utilities and install check valves in sewer traps to prevent flood water backup. Construct interior barriers to stop low-level floodwater from entering basements. Seal walls in basements with waterproofing compounds to avoid seepage. Ensure that future climate flood elevations/storm intensity are considered when retrofitting or designing.		X	
(Flood) Flood resistant landscaping - using plants/rain gardens and landscaping techniques/permeable paving that can help absorb excess water and reduce runoff		X	

MEASURES AGAINST MULTIPLE HAZARDS	HEALTH	EDUCATION	CP
(Flood/heat) Implement stormwater runoff measures and extensive green roofs to mitigate stormwater discharge during heavy rainfalls and support heat resilience	X		
(Heat) Ensure high-performance envelope, including triple-glazed windows and exterior shading, to improve thermal performance and prevent low interior temperatures/freezing if heating is lost in winter months or overheating if cooling or ventilation is inoperable in summer months	X		
(Heat) Incorporate key operable windows in patient rooms, so that if the building cooling or ventilation system is inoperable, indoor overheating can be avoided in summer months and patients can shelter-in-place (after Hurricane Katrina in New Orleans, United States, indoor temperatures in sealed hospitals exceeded 100 degrees, which prompted staff to break windows with furniture to provide ventilation)	X		
(Heat) Provide improved facades for cooling (reflective materials, overhangs, shading devices, green roofs, greening of adjacent areas		X	
(Heat) Create green schoolyards to reduce urban heat island effect		X	
(Heat) (a) Use of heat-resistant materials, high solar reflectance, high infrared emittance, external and internal shading, insulation and cool roofs to help reduce heat absorption and maintain lower indoor temperatures, improving/increasing natural ventilation to enhance airflow, air-conditioning, and high-performance glazing; (b) upgrading cooling system and implementing energy-efficient cooling systems; and (c) green, blue, grey, and hybrid infrastructure via incorporating green spaces to provide natural shade, green roofs, and biophilic design, improve air quality, and reduce the urban heat island effect while integrating blue infrastructure, such as water features and permeable surfaces, to aid in cooling and contribute to a more resilient environment	X		
(Heat) Install photovoltaic on the roof, which can serve as a shading device to a roof to decrease heat gains and reduce cooling load	X	X	
(Heat/fire) Provide improved/electrified HVAC; electrification will end dependence on fossil gas-powered machines and reduce GHGs		X	
(Heat/fire) Provide improved filtration systems for smoke reduction and enhanced indoor air quality (IAQ)		X	
(Heat/fire) Build with non-toxic materials that are recycled or produced in a way that conserves raw materials and reduces cost while streamlining water and energy consumption		X	
(Heat/drought) Implement rainwater harvesting and storage system on roofs; the rainwater storage location should be protected from sunlight	X	X	
(Fire) Ensure existing and new building exterior facades are non-combustible (that is, fire requirements, weather requirements, and structural requirements are considered and compatible)	X		
(Fire) If near a WUI, maintain a defensible space. This can include fire breaks and defensible space by clearing vegetation, maintain lawns, and using non-combustible materials for landscaping within a specified perimeter (trim trees within 5 feet of structure, use fire-resistive construction materials on roof and structure, remove plants within 5 feet of the structure, keep 5 feet of non-combustible space around a structure, clear dead vegetation away from trees, keep lawns mowed)		X	
(Fire) Install fire-resistant windows and shutters to protect against embers and radiant heat; ensure roof and gutters are maintained to prevent accumulation of debris that could be flammable		X	

MEASURES AGAINST MULTIPLE HAZARDS	HEALTH	EDUCATION	CP
(Fire): Fire-rated barriers (or detached buildings) for rooms storing hazardous materials	X	X	
(Wildfires): Implement building reinforcement options including fire-proof roofs, install spark arresters, install metal screens to cover all vents, use metal gutters, use double or multi-paned tempered glass windows, use non-flammable building material for buildings, decks, and fences	X	X	X
(Passive survivability) Provide thermal safety by demonstrating indoor conditions will never breach specified overheating and under-heating thresholds during peak summer and winter analysis periods or provide standard effective temperature (SET) or achieve passive house certification (PHIUS)	X	X	X
(Passive survivability) Provide backup power for critical loads by meeting thermal safety criteria or at least three or more of the following power demands: • Operation of electrical components of fuel-fired heating systems • Operation of a fan sufficient to provide emergency cooling • Operation of water pumps if needed to make potable water available to occupants • Appropriate lighting levels • Operation of providing online access • Operation of one elevator in building (hospitals) • Clean fuels: fuel-fired backup generators must be able to operate on clean burning fuels and fuels that can be stored on-site	X	X	X

More details on the review of building code related to fireproofing can be found in Box 17:

BOX 17. FIREPROOFING BUILDING CODE IN AURELIA

Upon review of the existing fire safety ordinances and legislation, it is found that there is guidance to prevent the spread of fire and smoke within the building, to prevent fire from spreading to neighboring buildings, ensure appropriate egress to enable people to leave the building unharmed, and ensure the rescue of protection of workers. The legislation discusses the determination of safety distances at the building level, but it does not discuss elements to reduce wildfire risk encroaching buildings within the wildland urban interface. In addition, there is discussion about health care facilities but not specifically fire rescue service buildings. While the country does have specific building design guidance and regulation for fire safety of buildings, it does not yet have codes regarding spatial arrangements that can deter wildfire spread especially in the WUI. In addition, there is limited information available on the costs of fire safety for enhanced building requirements. Therefore, the country, along with its technical experts, undertakes an exercise on recommended provisions for fire safety buildings in the WUI as part of the existing building codes and legislation and to provide example costing for upgrades to incentivize owners and developers to apply enhanced fireproofing design strategies to institutional buildings such as fire stations. Potential WUI design and retrofit strategies can be placed at three scales: (a) macroscale: landscape scale is associated with large forestry and operational management strategies (for example, landscape design, fuel reduction planning, and management of strategic points for suppression); (b) mesoscale: corresponds to the level where preventative and protective measures to keep settlements safe (fuel reduced strips around communities, water supply points, and so on); (c) microscale: defensible space, design, and so on.[87] Aurelia's ordinance focuses on the microscale, although more information on macro- and meso-scale interventions could help reduce susceptibility to wildfires in the WUI.

87 Vacca et al. 2020.

ANNEX 4. References

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