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ACCREU
Assessing Climate Change Risk in EUrope

D3.2 Adaptation case study analysis

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1. Changes with respect to the DoA

Changes made with respect to the DoA are limited and concern changes related to stakeholders or case study locations. Reasons for change are twofold. First to better align stakeholders' availability to the project research activity, and second, to facilitate the "policy-first" perspective and co-creation processes of ACCREU.

The specific changes include:

- CS3.2 shifted its focus from a European scale to a local case study in the Venice lagoon.
- CS4.2 changed its focus region from North Rhine Westphalia to Bremen, resulting in a change of stakeholder.
- CS6.1 transitioned its stakeholder from UIC (International Union of Railways) to the Federal Ministry for Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management. Further, a case study owner was added (from just Deltares to Deltares and UniGraz).
- CS7.1 expanded its scale from the Glasgow region to a national assessment, leading to a shift from a regional stakeholder (Glasgow City Region) to a national stakeholder (Department for Environment, Food & Rural Affairs, United Kingdom). Moreover, CS7.1 and CS7.2 results are reported together due to large synergies across cases. Further, for CS7.2, there is now an additional partner working on it (UniGraz).

2. Dissemination and uptake

This deliverable serves multiple purposes. First, it facilitates learning among case study partners by documenting the niches, challenges, and methodological approaches of each case study. Second, it supports Task 3.3 of this work package by identifying potential for upscaling and cross-case collaboration. Third, it utilizes a policy-first approach and several case studies have already informed policy decisions: the UK adaptation costs were provided to HM Treasury and the Climate Change Committee; and Cyprus cost assessments supported Cabinet adoption of the National Adaptation Strategy. The frameworks and findings may be relevant to external stakeholders addressing similar adaptation challenges.

3. Short summary of results

This deliverable reports the final implementation of the ACCREU framework (developed in D3.1) across fifteen case studies spanning seven adaptation decision types: flood risk, forestry & ecosystems, water-food-biodiversity nexus, health & justice, financial sector, transport/supply chains, and cross-cutting national programs.

The case studies employed diverse methodological approaches; cost-benefit analysis, integrated assessment models (GLOBIOM, CWatM), flood and species distribution models, social justice assessments, and stakeholder interviews, demonstrating that comprehensive economic appraisal extends beyond traditional cost-benefit analysis to systematically address co-benefits, distributional impacts, barriers, path-dependencies, and flexibility under deep uncertainty.

Common findings emerged across the case study contexts. Financial constraints (high upfront costs, limited capital), institutional challenges (fragmented responsibilities, weak coordination), knowledge gaps (climate uncertainty, limited effectiveness evidence), technical limitations (concentrated supply markets, infrastructure legacy), and social resistance (public opposition, distributional concerns) constrain adaptation implementation. Success factors include strong stakeholder engagement, multi-level coordination, clear organizational responsibilities, adequate financing, and long-term planning frameworks.

Several case studies supported directly the implementation of adaptation or adaptation policy action. UK case studies (CS7.1/7.2) informed HM Treasury spending reviews and Climate Change Committee inputs. Cyprus (CS7.3) provided the first comprehensive national adaptation cost assessment, supporting Cabinet adoption of the revised National Adaptation Strategy. Italy (CS3.2) research will support Venice lagoon protected dune-area management.

Detailed case study results are provided in Section 3, with complete framework implementations in Annex D. Section 3.3 synthesizes cross-cutting findings and lessons learned for broader European adaptation practice, informing Task 3.3 on Adaptation Decision Types.

4. Evidence of accomplishment

The evidence of accomplishment includes a summary of the bilateral exchanges (Annex A), a completed framework iteration for each case study (Annex D), and a description of results in Section 4. Besides the results reported here, the cases also contributed to the following:

Reports:

- Caloia, F. G., van Ginkel, K. C. H. and Jansen, D., 2023. Floods and financial stability: Scenario-based evidence from below sea level. DNB Working Paper No. 796. [Also under review for a peer-reviewed scientific publication.]
- Zachariadis T., Gavrouzou M., Zittis G., Hadjinicolaou P., Economou T., Kekkou F., Giannakis E. and Zoumides C. (2025). Assessment of Physical and Economic Impacts of Climate Change in Cyprus. Available at https://www.cyi.ac.cy/index.php/stedi-rc/research-information/stedi-rc-scientific-publications.html
- Zachariadis, T. **Investment Needs and Benefits from the Adaptation of Cyprus to Climate Change.** April 2025. Available in Greek and in English.

Reports in prep

- A policy brief on CS7 is being developed. The information provided to the Climate Change Committee will be published as part of the citizen surveys and will also feed into the CCRA4 reports that will be published in 2026.
- Policy brief on CS4.1

Manuscripts under review:

- Bacca, S. et al. (*under review*). Valuing global coastal wetlands loss: A comparison of benefit transfer and biophysical production function methods.
- Endendijk, T., van Ederen, D., de Moel, H., van Ginkel, K., Aerts, J.C.J.H., Botzen, W.J.W. (*under review*). Physical Climate Risk Assessment Framework for Real Estate Investments and Mortgages. http://dx.doi.org/10.2139/ssrn.4902445
- van Tilburg, A.J., van Ginkel, K.C.H., Brusselaers, J., Botzen, W.J.W. (*under review*). Intergenerational equity in cost-benefit analysis of multifunctional flood adaptation measure: case study on a superdike project in the Netherlands. http://dx.doi.org/10.2139/ssrn.5044351

Manuscripts in preparation

- Bacca, S. et al. “The archetypes and costs of managed realignment and coastal restoration.”
- Haas, J., & Hinkel, J. "Reviewing adaptation modeling in large scale economic flood risk assessments"
- Manuscript in preparation for CS3.1b
- Manuscript in preparation for CS5.2
- Manuscript in preparation on the costs of adaptation in the UK, which is writing up the results of the UK costing case study (CS7.1/7.2).

Code

- DIVACoast.jl library: https://github.com/GlobalClimateForum/DIVACoast.jl.git
- Published piece of code on Zenodo: Bacca, S. (2025). SebastianoBacca/Coastal-Wetlands-Economic-Valuation: Coastal wetlands valuation toolkit (v1.0.0). [Code]. Zenodo. https://doi.org/10.5281/zenodo.15536288

Weblinks

- van Ginkel, K., Caloia, F., Jansen, D.J., 2023. Overstromingen en financiële stabiliteit in Nederland: een toelichting voor de watersector. https://www.h2owaternetwerk.nl/h2o-podium/uitgelicht/overstromingen-en-financiele-stabiliteit-in-nederland-een-toelichting-voor-de-watersector
- Five questions about the impact of floods on the financial sector. News article on the website of Deltares and on the website of the Dutch Central bank. https://www.deltares.nl/en/news/five-questions-about-the-impact-of-floods-on-the-financial-sector & https://www.dnb.nl/algemeen-nieuws/achtergrond-2023/vijf-vragen-over-de-gevolgen-van-overstromingen-op-de-financiele-sector/ (20 December 2023).

Table of Contents

1. Introduction

Work package (WP) 3 of the ACCREU project focuses on adaptation decisions from micro-level to macro-level. The first objective of this work package is to economically appraise the adaptation options for a selection of stakeholders that face practical adaptation decisions in a diverse set of case studies. This is the objective of Task 3.2, of which this is the final deliverable.

This deliverable reports on the outcomes of the 15 case studies spanning seven adaptation decision types (ADTs) (Figure 1). Table 1 provides an overview of all case studies, including their title, partner organization, stakeholder, spatial scale and location. All case studies followed the same protocol for data reporting, with the conceptual and methodological framework developed as part of D3.1.

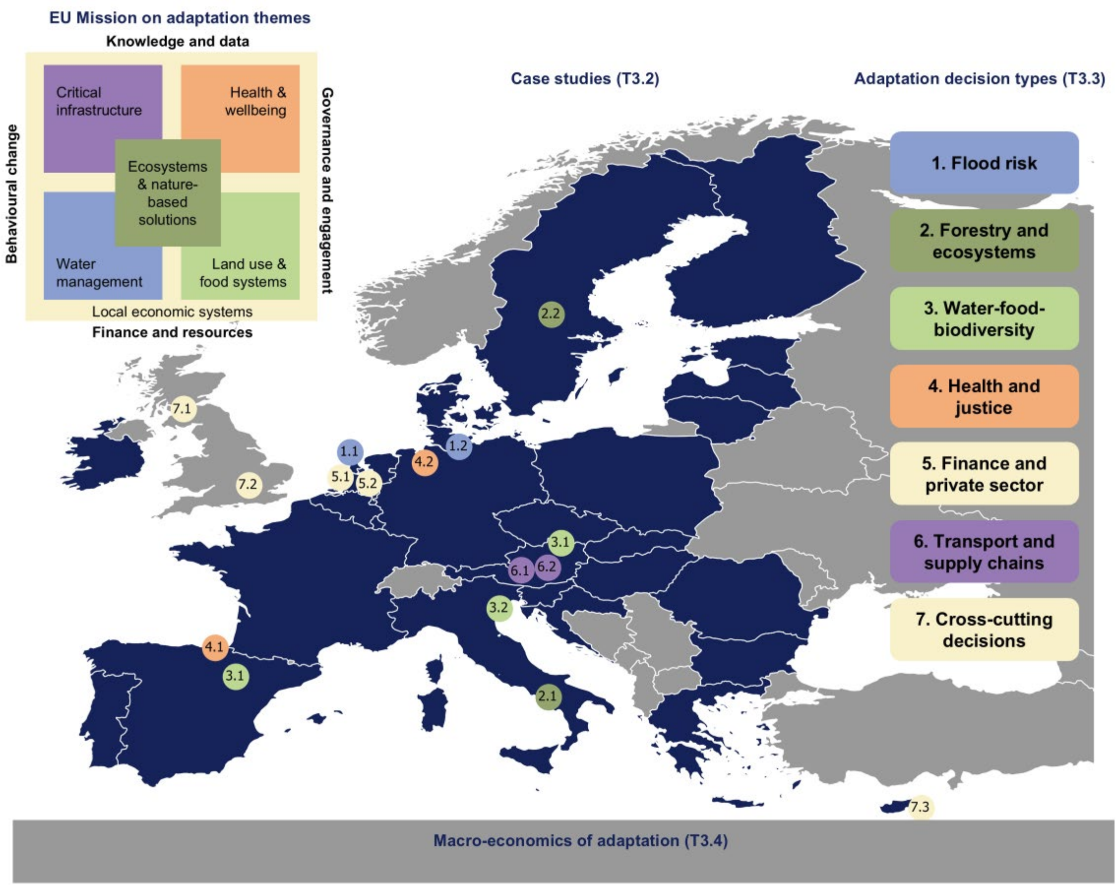


Figure 1: Overview of ACCREU adaptation decision types and case studies.

Framework development and implementation

The interaction with stakeholders, coordinated by WP1 and WP3 and facilitated by "case study owners" developed through an iterative process. A first framework iteration was shared with all case study owners[1] in October 2023 (template used for collecting inputs in Figure 2). All partners completed this version with their stakeholders to test the framework and initiate the case study analysis, which focused on the analysis of adaptation options.

[1] All case study owners does not include CyI here, as they joined the consortium after D3.1 and M3.1a were due.

Based on the partners' input, a second part was added to this framework, concentrating on adaptation strategies (template used for collecting inputs in Figure 3). This updated framework was distributed to all WP3 partners in February 2024, with completion expected by end of April 2024.

In March 2024, bilateral exchanges were conducted with all case study owners to: i) check progress; ii) provide additional support ; iii) assess niches and key dimensions of each case study; and iv) agree on deliverables for milestone 3.1b. Annex A documents these bilateral exchanges and additional exchanges conducted since the first milestone

Deliverable Structure
This deliverable is structured as follows: Section 2 synthesizes case study progress, methodological approaches and cross-cutting findings. Section 3 presents detailed results for all 15 case studies organized by adaptation decision type. Section 4 documents policy uptake and real-world impact. Section 5 concludes with key findings, policy implications, and connections to Task 3.3 on Adaptation Decision Types.

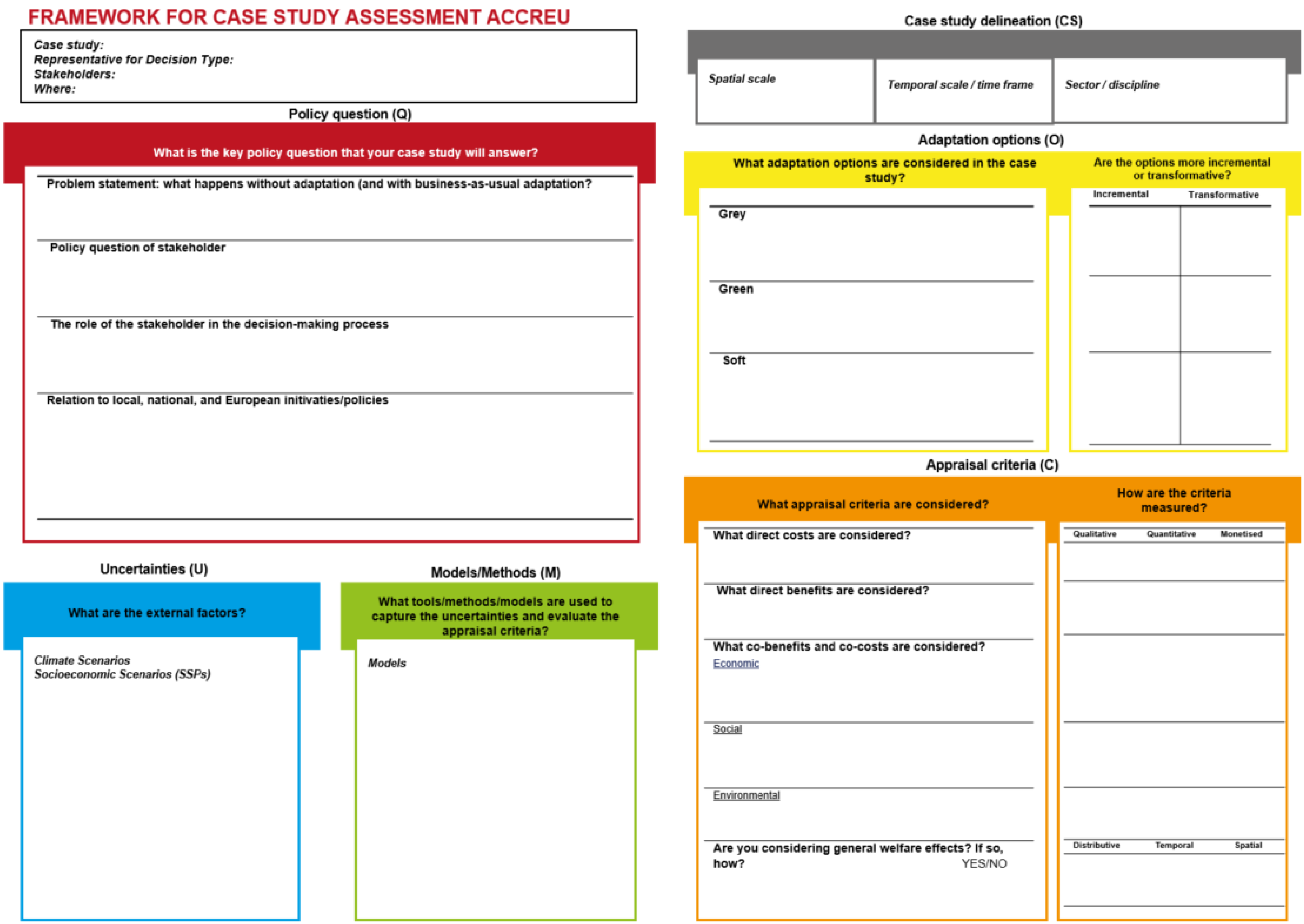


Figure 2: Template for ACCREU case-study Framework Analysis – part 1: appraisal of adaptation options.

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1			
2			
3			
4			
…	…	…	
n	…	…	

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governance and institutional (G).

#	Barriers	Cat
1		
2		
3		
4		
…		
n	…	…

Assessment of strategies (SA)

	Do you encounter path-dependencies in the identified strategies? If yes, how?	What are the transfer costs like?	What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?	Who will finance the strategy?	What are the main distributional effects of the strategy?	Will be you be able measure the direct costs and benefits qualitatively, quantitatively, or monetised?	For which co-costs and co-benefits could you provide an order of magnitude?
#	Path-dependencies	Transfer costs	Timing	Financing of strategies	Distributive effects	Direct costs & benefits	Co-costs & -benefits
1							
2							
3							
4							
…	…	…					
n	…	…					

Figure 3: Template for ACCREU case-study Framework Analysis– part 2: from options to strategies.

Table 1: Case study description

#	Description
1.1	Title: Sub-national adaption investments for coastal floods. Partner: Deltares Users: Province North Holland, Water Board Hollands Noorder-Kwartier Spatial scale: Local Location: Den Helder, the Netherlands
1.2	Title: Large scale and long-term coastal nature-based solution policies for rural regions in Europe and the German Baltic coast Partner: GCF Users: WWF Germany; IUCN; German coastal protection authority for state of Schleswig-Holstein Spatial scale: European Location: German Baltic sea coast; Europe
2.1	Title: Multi-sectoral adaptation to wildfire risk in a densely populated region with high natural values Partner: DTU Users: STRESS S.c.a.r.l. ; Campania region including transport authorities; municipality of Sorrento Spatial scale: regional Location: Campania region, Italy
2.2	Title: Adaptation options for reduction of forest fire Partner: DTU Users: Miljö och Skog i Leksand Aktiebolag Spatial scale: Local Location: Leksand, Sweden
3.1	Title: Integrated adaptation decisions in managing the water-food nexus in Europe, Spain and Czech Thaya river catchment Partner: IIASA Users: Ministry of Agriculture (Czech Republic); Ebro River Basin Authority (Spain) Spatial scale: River basin scale Location: Ebro river (Spain), Thaya river (Czech Republic)
3.2	Title: Integrated species distribution model for estimating potential economic impacts of conservation and impact mitigation preservations Partner: CMCC Users: WWF Italy Spatial scale: Local Location: Venice lagoon, Italy
4.1	Title: Adaptation policy assessment, focus on health and distributional aspects Partner: BC3/Ecologic Users: Basque Government Environment Ministry Spatial scale: Regional Location: Basque region
4.2	Title: Qualitative assessment of social justice dimensions of climate policy Partner: Ecologic/BC3 Users: Federal State of Bremen, Department Adaptation to Climate Change Spatial scale: Regional/Local Location: Bremen
5.1	Title: Adaptation options for enhancing financial stability Partner: Deltares Users: Dutch Central Bank Spatial scale: National Location: the Netherlands
5.2	Title: Stimulation of private sector adaptation through insurance arrangements Partner: VU Users: Dutch association of insurers Spatial scale: National Location: The Netherlands
6.1	Title: Adaptation to minimize the risk of disruptions of trade corridors Partner: Deltares, UniGraz Users: Austrian Federal ministry for Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management

	Spatial scale: National Location: Austria
6.2	Title: Reduction of critical raw material supply chain risks for the photovoltaics industry Partner: UniGraz Users: Fronius & AT&S Spatial scale: National/sector Location: Austria
7.1	Title: Costs and benefits of national adaptation programmes Partner: PWA Users: UK HMT; OBR; Defra Spatial scale: National Location: United Kingdom
7.2	Title: Implications of adaptation for the Government budgets Partner: PWA, UniGraz Users: UK HMT; OBR; DEFRA Spatial scale: National Location: United Kingdom
7.3	Title: Cross-sectoral economic analysis for adaptation Partner: CyI Users: Ministry of Agriculture, Rural Development and Environment of Cyprus; Ministry of Finance of Cyprus Spatial scale: National Location: Cyprus

2. Case study synthesis

2.1 Overview of case studies and framework implementation

Each case study focused on specific analytical components selected by the ACCREU consortium in consultation with stakeholders. These key dimensions enhance the adaptation analysis by covering aspects beyond traditional cost-benefit analysis, including co-benefits, barriers, distributional impacts, path-dependencies and strategy-level appraisal.

Figure 4 synthesizes which dimensions, or 'niches' were covered by each case study and to what extent, based on the bilateral exchanges, framework implementations, and final results. The nine analytical components assessed are: i) transformational adaptation options; ii) hard (grey) adaptation options; iii) green adaptation options; iv) soft adaptation options; v) co-benefits of adaptation; vi) barriers and limits to adaptation; vii) time- and path-dependencies and lock-in of adaptation options or strategies; viii) distribution of adaptation outcomes; and ix) appraisal of adaptation strategies.

As figure 4 shows, there is notable coverage of hard, green, and soft adaptation options across the case study. Many case studies also considered transformative adaptation options. Additionally, many case studies incorporated the assessment of co-benefits. However, economic appraisal at the strategy level (combining multiple options) and assessment of distributional impacts were covered by only a limited number of case studies, indicating opportunities for further development of these approaches.

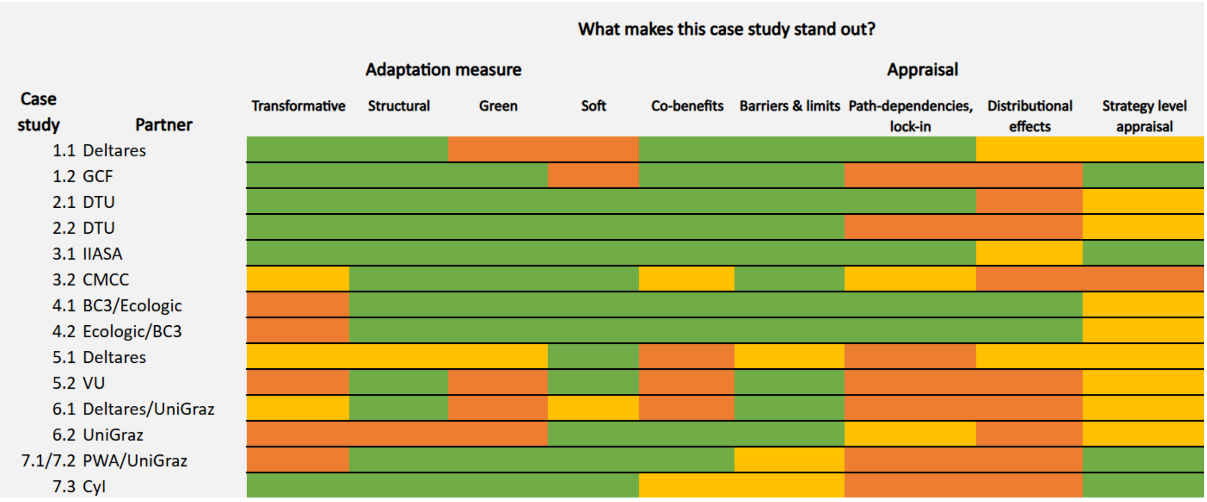


Figure 4: Components of all case studies. Green: included; yellow: partially included; orange: not part of case study.

Table 2 provides a more detailed synthesis of the unique contributions (niches) and upscaling potential for each case study. This information was gathered through the bilateral exchanges conducted in March 2024 and a WP3 coordination call held in April 2024, where case study owners presented their progress, identified key dimensions, and discussed potential for scaling up their approaches to inform Task 3.3 on Adaptation Decision Types.

Table 2. Unique contributions, and upscaling potential for each case study

Case study (Partner)	Unique contribution (niche)	Upscaling potential
1.1 (Deltares)	Specific attention to temporal aspect: path-dependency/lock-ins, and intergenerational justice	The intergenerational justice component could be upscaled. Upscalability potential for assessment of multifunctional dikes. Comprehensive CBAs is the focus of this ADT report, which relates to the justice focus in this case study.
1.2 (GCF)	Comparison across two regions, and a cost-efficiency analysis of adaptation solutions	CBA can be used by regions/countries to select optimal adaptation solution for them. Co-benefits (ecosystem services) in the CBA links to the ADT focus on comprehensive CBAs.
2.1 (DTU)	Holistic nature of the policy question (combined function of the case study area, with tourism, protected forest, agriculture, etc.). Further, assigning economic values to nature and biodiversity as part of CBA and planning	The analysis can be upscaled to other areas. Further, the analysis has close alignment to ADT policy question.
2.2 (DTU)	Coverage of private adaptation. Good local cost estimates for adaptation from local stakeholders.	Approach of case study can be upscaled; however, since cost estimates are local, upscalability of those estimates could be limited. However, case study analysis has a close alignment to the ADT policy question.
3.1 (IIASA)	Integrated analysis with biophysical and socioeconomic drivers. Assessment conducted for two regions.	The framework they apply can be upscaled to other regions (e.g., EU level, EU member states). Data availability could potentially be a constraint. The case studies have a close alignment to the ADT focus.
3.2 (CMCC)	Rich discussion on barriers and limits. Focus on adaptation with the main aim of protecting biodiversity.	The species distribution model combined with sea-level rise modelling could be upscaled to other areas.
4.1 (BC3/Ecologic)	Climate justice approach to economic impact assessment for health sector	The methodological framework has high upscalability potential; the numbers are not upscalable, due to the regional scale of the assessment. There is a close connection to the ADT focus.
4.2 (Ecologic/BC3)	Detailed social justice assessment of heat adaptation plan.	Results and approaches like the scoring framework would be relevant to other regions; however, economic upscaling is more difficult as vulnerable groups are location specific and adaptation options are also very specific to a region. There is a close connection to the ADT focus.
5.1 (Deltares)	There is a specific attention to extreme risk scenarios, instead of the standard EAD approach.	The applied methodology is upscalable to other countries. Further, there is a close connection to the ADT, which addresses a wide range of adaptation strategies for the financial sector.
5.2 (VU)	Assessment of adaptation incentives for businesses (through insurance) - which has so far only been done for households.	High upscaling potential to EU level; data could be a constraint to upscaling. Close connection to the ADT analysis: by providing input on insurance as adaptation strategy.
6.1 (Deltares, UniGraz)	High-resolution country-wide climate risk assessment for transport infrastructure, informing strategic dialogue about national adaptation strategy.	Close relationship to ADT 1 & ADT 5 through the focus on flood risks on transport. Approach could be upscalable to other regions.

6.2 (UniGraz)	Focus on business-level adaptation; working with two differently sized companies in Austria	Close relationship to ADT 1 & ADT 5 through the focus on flood risks on supply chains. The methodology could be extended to other countries/companies; upscalability of numbers might be limited, due to the local nature of the data.
7.1/7.2 (PWA, UniGraz)	Comprehensive overview of adaptation costs across sectors	National-level assessment, which is highly relevant for other countries.
7.3 (CyI)	Comprehensive overview of adaptation costs	National-level assessment, which is highly relevant for other countries.

2.2 Methodological diversity and stakeholder engagement
The 15 case studies employed different analytical approaches tailored to their specific decision contexts, demonstrating that comprehensive economic appraisal of adaptation extends beyond traditional cost-benefit analysis.

Methodological approaches
The case studies applied various quantitative and qualitative methods, often in combination, to match with specific policy questions, available data and stakeholder needs:

- **Cost-benefit analysis:** Applied in multiple case studies (CS1.1, CS1.2, CS2.1, CS2.2, CS4.1, CS4.2, CS7.3) to systematically compare costs and benefits of adaptation options, including long-term and intergenerational considerations (e.g. CS1.1)
- **Integrated assessment models:** Linking biophysical and socioeconomic systems (CS3.1a, CS3.1b: GLOBIOM for agricultural systems, CWatM for water resources) to analyse complex trade-offs in water-food-biodiversity nexus.
- **Risk modelling:** Flood and financial risk models (CS5.1: flood impacts on financial stability, CS5.2: GLOFRIS and DIFI models for insurance analysis) to assess systemic risks and adaptation incentives.
- **Ecological models:** Species distribution models (CS3.2) to evaluate climate impacts on biodiversity and assess conservation measures.
- **Social justice frameworks:** Systematic assessment of equity dimensions (CS4.2) examining recognition, participation, distribution and restorative justice in heat adaptation policies.
- **Econometric-based health impact assessment:** Econometric models (CS4.1) to quantify heat-related mortality and morbidity costs and evaluate adaptation effectiveness.
- **Qualitative approaches:** Semi-structured interviews (CS6.2) to understand private sector adaptation barriers, co-benefits, and path-dependencies in supply chain management.

Stakeholder engagement and relevance
All case studies adopted a policy-first, co-creation approach with "deep engagement stakeholders"[2], to make sure the research matches practical adaptation challenges. The case studies provide decision-relevant insights for stakeholders at local, national, sectoral and European levels:

CS1.1: Informs a Dutch coastal municipality (stakeholders: province and water board) on trade-offs between robust long-term (superdike) versus incremental dike reinforcement strategies under deep sea-level rise uncertainty, with insights on intergenerational equity transferable to coastal regions across Europe.

[2] These are the case studies stakeholders that engage in a more structured, constant and frequent interaction with the ACCREU research team. ACCREU also features stakeholders participating to the more standard engagement process (stakeholder meetings and workshops).

CS1.2: Provides European-level insights on optimal timing and locations for coastal retreat strategies, with sub-national analysis for the German Baltic coast informing regional authorities on cost-efficiency of grey versus green coastal adaptation.

CS2.1: Offers multi-sectoral wildfire adaptation strategies for the Sorrento Peninsula in Italy combining tourism, biodiversity conservation and human safety considerations, relevant to Mediterranean regions facing increasing fire risk.

CS2.2: Supports private forest owners in Sweden with cost-benefit analysis of wildfire prevention measures, demonstrating approaches for private sector adaptation applicable to forest management in other Northern European countries.

CS3.1: Informs water basin authorities in Spain (Ebro) and Czech Republic (Thaya) on optimal water allocation between agriculture, drinking water, and ecosystems under climate change, with integrated modelling approaches transferable to other European river basins.

CS3.2: Supports WWF Italy in managing a dune and natural reserve protected area in the Venice Lagoon by assessing biodiversity impacts of sea-level rise and evaluating nature-based conservation measures.

CS4.1: Provides the Basque Government (Spain) with health impact assessments of heat risks and a distributional analysis of adaptation outcomes across social groups, relevant to regional health authorities across a warming Europe.

CS4.2: Informs the Federal State of Bremen (Germany) on social justice dimensions of heat action plans, offering a systematic framework for assessing equity in adaptation policies applicable to urban areas throughout Europe.

CS5.1: Supports the Dutch Central Bank in assessing flood risks to financial stability and exploring macroprudential policy options, with methodological approaches relevant to central banks across Europe concerned with climate-related financial risks.

CS5.2: Informs the Dutch association of Insurers on designing flood insurance for commercial properties that incentivizes business-level adaptation, with insights on insurance market design transferable to flood-prone regions across Europe.

CS6.1: Provides the Austrian Federal Ministries (BMLUK and BMIMI) with national transport network climate risk assessment to support mainstreaming adaptation in infrastructure planning, relevant to national authorities responsible for critical infrastructure protection.

CS6.2: Supports two Austrian companies (photovoltaics sector) in understanding supply chain climate risks and soft adaptation options, offering insights on private sector resilience strategies applicable to businesses across Europe.

CS7.1/7.2: Informs UK government (Defra and HM Treasury) on national adaptation costs, sectoral investment needs, distributional impacts, and macroeconomic implications, with comprehensive costing approaches transferable to other national governments developing adaptation strategies.

CS7.3: Provides Cyprus government with the first comprehensive national adaptation cost assessment, supporting Cabinet adopting of the revised National Adaptation Strategy and offering a model for national-level adaptation planning in small island states.

The diversity of contexts, scales and stakeholder enhances the transferability of findings to other European regions facing similar adaptation challenges. Detailed methodological descriptions for each case study are provided in Section 4 (individual case study results) and Annex B (comprehensive methods and relevance overview).

2.3 Cross-cutting findings and lessons learned

Drawing on the insights from all 15 case studies, this section synthesizes several key patterns, common challenges and transferable lessons that can inform adaptation decision-making across Europe.

2.3.1 Framework application and methodological insights

The ACCREU framework proved to be flexible and robust across different contexts, from local biodiversity conservation (CS3.2) to national adaptation planning (CS7.1–7.3). Case studies employed various methods, such as cost-benefit analysis, integrated assessment models, flood and species distribution assessments, and qualitative interviews, showing that comprehensive economic appraisal extends beyond traditional CBA.

The framework also demonstrated key challenges:

- **Quantification gaps:** it remains difficult to monetize co-benefits (e.g. ecosystem services, biodiversity, social justice outcomes), limiting their influence on decision-making.
- **Strategy-level appraisal:** Most case studies focused on individual options rather than integrated strategies,
- **Distributional analysis:** Only a few cases assessed equity impacts across social groups due to data and methodological constraints

2.3.2 Common barriers to adaptation

The analysis across the case studies revealed six recurring barrier types. Table 3 presents them ranked from most to least frequent, with specific sub-barriers and the case studies in which they were identified.

Table 3. Categorisation of adaptation barriers in ACCREU case studies.

Barrier Type Barrier	**Frequency**	**Case Studies**
1. Institutional & governance (100%)		15/15
Fragmented responsibilities / coordination challenges		CS1.1, CS1.2, CS2.1, CS3.1a, CS3.1b, CS3.2, CS4.2, CS6.1, CS6.2, CS7.1/7.2, CS7.3
Lack of political support/feasibility		CS3.1a, CS3.1b, CS3.2, CS5.2, CS6.1
Planning horizons restrict options		CS1.1, CS1.2 CS2.2
Legal/regulatory frameworks limiting implementation		CS1.2, CS2.1, CS5.2, CS6.2
Competing policy objectives		CS1.1, CS1.2, CS5.1, CS5.2
Lack of stakeholder support		CS4.1, CS4.2
Resistance to transformative / top-down planning		CS6.1
2. Financial (93%)		14/15
High costs of measures		CS1.2, CS2.1, CS2.2, CS3.1a, CS3.1b, CS3.2, CS6.1, CS6.2, CS7.1/7.2, CS7.3
Limited financial resources		CS1.1, CS5.2
Lack of (long-term) funding		CS4.1, CS4.2
Financing structures favour incremental measures		CS1.1, CS6.1
3. Social & cultural (73%)		11/15

Public opposition to measures		CS1.1, CS1.2, CS2.1, CS3.1a, CS3.2
Locked-in behavior/reluctance to change practices		CS1.2, CS2.1, CS2.2
Distributional concerns and equity issues		CS4.1, CS4.2, CS5.1
Challenging to reach vulnerable groups		CS4.1, CS4.2
Difficulty inducing behavioral change		CS3.1b, CS4.2
Lack of public awareness		CS3.2, CS5.1
Place attachment		CS1.1
4. Knowledge & information (47%)		7/15
Limited evidence on effectiveness		CS1.2, CS3.1a, CS4.1, CS5.2
Limited knowledge on suitable measures		CS3.1a, CS3.1b
Low awareness of adaptation options		CS1.2, CS2.2
Challenges merging data sources		CS4.1
Lack of knowledge on specific impacts		CS1.1
Uncertain parameters		CS3.1a, CS3.1b
Reliability of forecasts/data		CS5.1, CS6.2
5. Technical & psychical (47%)		7/15
Geographical/terrain constraints		CS2.1, CS2.2
Lack of water/land resources		CS1.1, CS3.1a
Infrastructure legacy/path-dependencies		CS3.2, CS1.1
Technology limitations		CS2.1
Meteorological conditions		CS2.1
Physical limits with extreme climate change		CS5.1
6. Human capital (40%)		6/15
Lack of trained personnel		CS2.1, CS2.2, CS4.1, CS4.2, CS6.2, CS7.3
Lack of training time		CS4.2
7. Economic (40%)		6/15
Market dynamics/concentration		CS3.1a, CS6.2
Economic losses for stakeholders		CS3.1b, CS3.2
Extreme events/economic crises		CS3.1a
Water/resource competition between sectors		CS3.1a
Affordability limits insurance uptake		CS5.2
economic feasibility under extreme conditions		CS5.1

3. Enabling conditions and success factors

Despite the different barriers, twelve case studies also identified some critical success factors. Table 4 categorises them from most frequent to less frequent enabler types.

Table 4. Categorisation of adaptation enablers mentioned in ACCREU case studies.

Enabler Type Enabler	**Frequency**	**Case Studies**
Governance & institutional (58%)		
Policy supporting integrated measures		CS2.2
Collaboration and robust governance frameworks		CS3.1a
Inter-agency cooperation		CS3.1b
Multi-level governance and coordination		CS3.2
Balancing different policy goals		CS1.2
Clear responsibilities and accountability		CS6.2
Mandatory distributional impact checks and equity criteria		CS4.1
Financing (42%)		
Compensation schemes for surrendered land/real estate		CS1.2
Availability of financial resources		CS3.1a
Financial resources to enable implementation conditions		CS3.1b
Establishing long-term investment		CS4.2
Cross-subsidization of premiums across risk levels		CS5.2
Social & Cultural (33%)		
Communicating costs and benefits clearly		CS1.2
Stakeholder engagement and participation		CS1.2, CS2.2
Knowledge sharing		CS3.1a
Advance cultural transformation		CS3.1b
Communicate new technical and agronomic knowledge		CS3.1b
Temporal scale (33%)		
Long-term planning		CS2.2, CS4.2
Consider different climate scenarios		CS6.2, CS7.3
Monitoring (17%)		CS4.1
Monitoring, evaluation, reporting, and learning		
Equity-focused monitoring		CS4.1
Publishing disaggregated, post-season evaluations		CS4.1
Continuous monitoring systems		CS7.3
Opportunity Tipping points (17%)		
Making use of existing policies or developments (housing removal)		CS1.1
Linkage to infrastructure programmes for climate proofing		CS7.1/7.2

Additionally, besides these enabling or success factors for adaptation implementation, five case studies provide some more technical recommendations:

- Long-endurance drone platforms and AI-enhanced fire modelling (CS2.1);
- Harmonizing supply-side measures with demand-side interventions (CS3.1a);
- Ensuring retention of staff with targeted skill sets (CS4.2);
- Structured onboarding process for suppliers, incorporating climate risks (CS6.2);
- Promoting integrated strategies (CS2.2, CS6.2)

4. key insights on adaptation options and strategies

Through the case studies, several key insights became apparent:

- **Incremental vs. transformative**: The case studies showed that the distinction is context-dependent; what is transformative in one region may be incremental elsewhere. Transformative options were explored in multiple case studies (CS1.1: superdikes, CS1.2: managed realignment, CS3.1a: from rainfed to irrigated agriculture, CS3.1b: demand-side water management, CS6.1: network and systems change); they may face greater barriers but may also offer superior long-term outcomes under deep uncertainty.
- **Multi-functional adaptation**: Combining objectives (CS1.1: flood protection + housing, CS1.2: flood protection + nature restoration, CS2.1/2.2: wildfire + biodiversity + recreation, CS4.2: grey + green + soft heat measures) can potentially improve benefit-cost ratios.

Sometimes it can potentially create a lock-in if assumptions about additional functions prove incorrect.

- **Nature-based solutions** were prominent in many case studies. Coastal wetlands (CS1.2), dune protection (CS3.2), and urban green infrastructure (CS4.2) can be cost-competitive while providing co-benefits, but face challenges in quantifying benefits, longer benefit timeframes, performance uncertainty, and space competition.
- **Soft measures** proved important across multiple contexts. Early warning systems, training, awareness raising, and organizational improvements (CS2.1/2.2, CS4.2, CS6.2) have lower upfront costs but face knowledge, awareness, and organizational barriers.
- **Temporal considerations** were examined in several case studies. Some identified path-dependencies in water infrastructure (CS3.1b), supply chains (CS6.2), and coastal development (CS3.2) that can create lock-in risks. Large investments (CS1.1) may become maladapted under extreme scenarios or if demand assumptions prove incorrect. This highlights the importance of robust design, adaptive management, and maintaining flexibility.

5. Growing recognition and valuation of co-benefits

Figure 4 shows that many case studies incorporated the assessment of co-benefits, reflecting growing recognition that adaptation decisions should consider broader societal impacts. Many case studies recognized co-benefits, such as environmental (carbon sequestration, biodiversity, ecosystem services), social (mental health, recreation, social cohesion), and economic (property values, tourism, health cost savings), but struggled to quantify and monetize them for inclusion in formal appraisals (e.g., CS2.1, CS2.2, CS3.1, CS3.2, CS4.1, CS6.1). This systematic undervaluation may disadvantage adaptation options, particularly nature-based solutions, despite their importance for building political support and aligning with broader policy objectives.

Only a subset of case studies (CS4.1, CS4.2, CS5.1) explicitly addressed distributional impacts, showing that adaptation can either reduce or exacerbate inequalities. Heat measures can protect vulnerable groups or burden them disproportionately (CS4.1, CS4.2); credit constraints reduce financial risk but limit housing access for young and less wealthy people (CS5.1).

The prominence of co-benefits in stakeholder discussions (across all case studies during bilateral exchanges) suggests they are important for:

- Building political support for adaptation investments
- Overcoming climate skepticism or inaction
- Justifying larger upfront investments
- Aligning adaptation with other policy objectives

3. Results case studies

The following sections provide the main outputs of each case study, organized by Adaptation Decision Type. The filled in case study frameworks are included in Annex D.[3]

1 Flood risk

Case study 1.1 – Sub-national adaptation investments for coastal floods (Netherlands)
Partner: Deltares
Spatial scale: city scale, in the Netherlands
Stakeholders: Province North-Holland; Water board Hoogheemraadschap Hollands-Noorderkwartier

1. Decision context

This case study focuses on the Den Helder, a coastal city in the northwestern part of the Netherlands, in the province of North-Holland. The northern part of the province experienced a downward population and economic trend in recent decades. While this trend has been reversed, maintaining this requires ongoing effort (AT Osborne, 2022). Considering this, the province and municipality of Den Helder are interested in improving the spatial quality of the area as well as increasing the housing supply, to deal with the ongoing housing crisis in the Netherlands. As space for building housing is limited, a proposed solution is to build residential houses in the area currently reserved for future sea dike reinforcements. However, to avoid having to remove the houses in the near future because of rising sea-levels, the proposed plan is to raise and widen the existing dike (suitable for 3.5 meter of sea-level rise), so houses can be built on top of the dike. With this proposed solution referred to as a 'superdike', stakeholders in the area aim to avoid a decline in spatial quality that they expect will occur because of the current, incremental, way of reinforcing dikes. The deep engagement stakeholders involved in this case study are the province of North-Holland and the regional water board (Hoogheemraadschap Hollands-Noorderkwartier, HHNK hereafter). HHNK has the final say in deciding on this project, as they are tasked to ensure the safety of the dike. The overarching policy question of the stakeholders is how to adapt to sea-level rise while maintaining or improving the spatial quality of the urban area. The detailed policy question regarding this measure is whether multifunctional adaptation can lead to lock-in and whether lock-in changes the outcome of the economic appraisal. June 2025, HHNK approved of the superdike designs; moving the project forward to the next planning phase with all stakeholders involved (Snel, 2025).

2. Current and future risk

In the current situation, the inner side is considered safe and does not need to be reinforced until around 2100/2120, depending on the sea-level rise (SLR) scenario (De Jonge, 2022). With the standard dike reinforcement approach, the dike is reinforced incrementally based on nationally determined norms. Because of sea-level rise, flood risk in the area will increase over time. Sea level rise is highly uncertain and could range from approximately 0.3 to 2.8 meter in 2100 and from 0.6 to 18.4 meter in 2300 (van Dorland et al., 2023). Without adaptation, Den Helder is projected to flood every 3–10 years with 2 meters of SLR (Zanting & Bouw, 2023).

3. Identifying adaptation options

The superdike measure is compared to the standard Dutch approach of incremental dike reinforcement in the economic appraisal (Figure 1.1.1). The superdike plan that is appraised here encompasses 700 meters of dike reinforcement, allowing for 556 new houses. For incremental dike reinforcement, it is assumed that half of these houses could still be built behind the dike. As a sensitivity analysis, two alternatives are also considered: i) a superdike along 1400 meters allowing for 956 new houses in total; and ii) a superdike along the whole dike segment. The superdike along 700 meters and 1400 meters are under consideration by the stakeholders (Phase 1-2 and Phase 3-4 of the project, respectively). The superdike is a transformative adaptation option, following the definition of Kates et al. (2012). All

[3] For the case studies in the cross-cutting Adaptation Decision Type, this framework is less applicable; hence, for 7.1/7.2, the framework is not appended, for case study 7.3, only the first part of the framework is included. For CS1.2, also only the first part of the framework is included.

options are gray (structural) forms of adaptations. The CBA that is conducted (Section 4.1), provides insight into the circumstances under which incremental or robust, multifunctional adaptation in the form of superdikes are more advantageous for current and future wellbeing. This information can be used by the deep engagement stakeholders and other regional stakeholders responsible for adaptation to sea-level rise, to determine whether incremental sea dikes or superdikes are more appropriate in the local context.

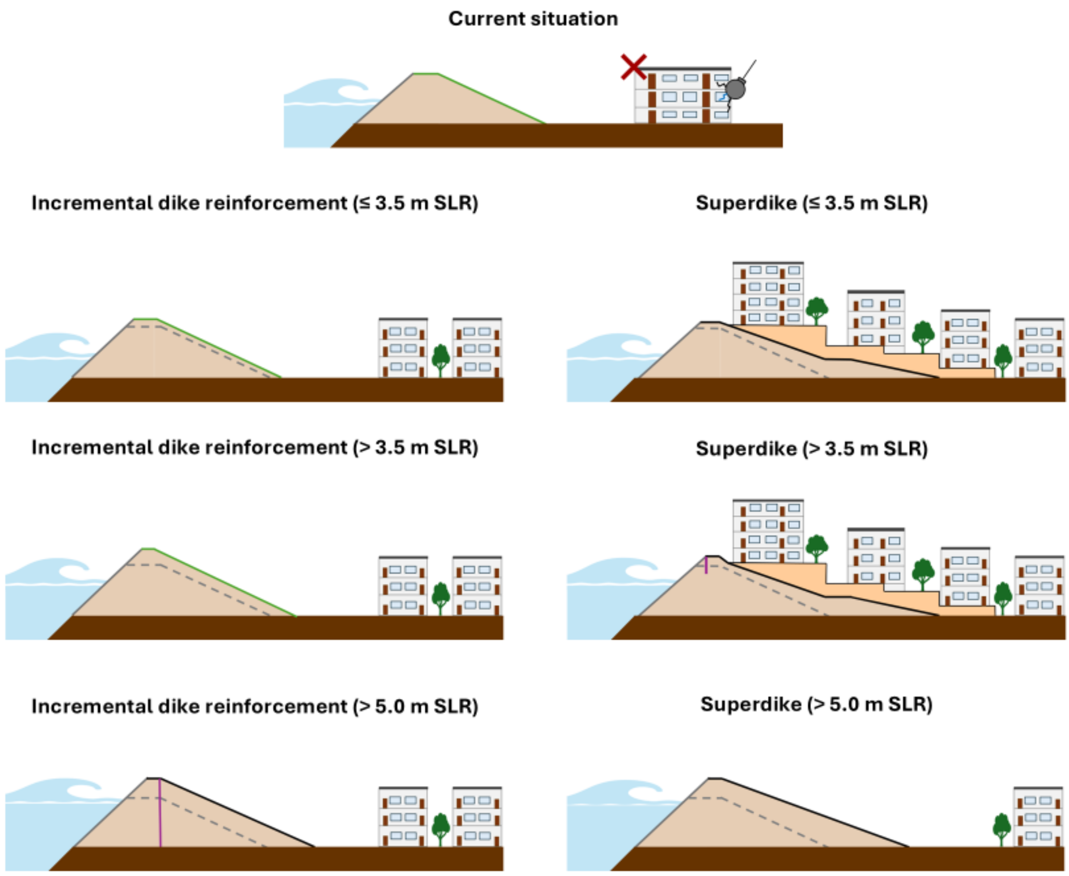


Figure 1.1.1: Schematic overview of the two adaptation measures that are compared in this case study under different sea-level rise scenarios. Pink lines refer to structural measures in the dike. Source image: van Tilburg et al. (*under review*).

4. Assessment of adaptation options

4.1 Methodology

For this case study, a cost-benefit analysis (CBA) is conducted. An emphasis is placed on potential 'lock-in' costs for the superdike design. The superdike cannot be adapted beyond 5.0 meters of SLR, so beyond that point the houses on the dike must be removed and a switch is made back to incremental dike reinforcement. To include potential lock-in costs in the CBA, the costs of switching from the superdike back to incremental dike reinforcement were included. Besides the potential lock-in costs, the CBA included direct costs of housing and dike reinforcement, direct benefits of the dike (reduced expected annual damages, fatalities, and affected people) and direct benefits of housing (sale values and rent income). Moreover, co-costs (externalities) and co-benefits (synergies) were also included: costs and benefits of additional greenery in the neighborhood; benefit of a view on open water; place attachment compensation costs for displaced residents; emissions of housing and dike reinforcement; and the spatial spillover costs of housing (Table 1.1.1). The costs and benefits were quantified for five sea-level rise scenarios and five socio-economic scenarios. For SLR, the following scenarios are used: RCP2.6 17th percentile; RCP2.6 83rd percentile; RCP8.5 17th percentile; RCP8.5 83rd percentile; and RCP8.5 high-end (van Dorland et al., 2023). The five shared-socioeconomic pathways (SSPs) (O'Neill et al., 2017; IIASA, 2024) are used for population and gross domestic product scenarios.

Lock-in and intergenerational effects are further assessed by presenting the benefit-cost ratios for different time horizons (e.g., 2075; 2150; 2225; 2300), and for different generations (e.g., 2025–2054; 2055–2084; etc.), as well as the use of multiple ethical principles for discounting. The standard time horizon was 2025–2225, in line with the 200-year design life of the superdike.

Table 1.1.1: Evaluation criteria used in the cost-benefit analysis of the superdike measure for Den Helder.

Appraisal criteria (C)

What appraisal criteria are considered?	How are the criteria measured?		
What direct costs are considered?	Qualitative	Quantitative	Monetised
Dike construction and planning costs			X
Housing costs (construction; demolition; planning; dispossession etc.)			X
Maintenance costs housing			X
What direct benefits are considered?			
Reduction in expected annual flood damages			X
Reduction in expected annual flood fatalities			X
Reduction in expected annual people affected by floods			X
House sale income			X
Rent income			X
What co-benefits and co-costs are considered?			
Economic			
• Spatial trade-offs of housing			X
Social			
• Place attachment loss			X
• Value of trees for residents			X
• Value of water view for residents			X
Environmental			
• Tree costs			X
• Emission costs of dike and housing			X
Are you considering general welfare effects? If so, how?	Social	Temporal	Spatial
YES/NO		X	
• Take a lock-in perspective for the superdike measure and monetise these lock-in/regret costs • Disaggregate effects across generations • Use multiple discounting principles • Use multiple time horizons			

4.2 Results

When assuming real housing prices change depending on the annual GDP growth rates per SSP, the superdike performs better than incremental dike reinforcement in most SLR and SSP scenarios, based on the benefit-cost ratios and net present values. Only in the highest SLR scenario, in which SLR surpasses 5 meters before 2225, do the costs outweigh the benefits for the superdike, for the aggregated results. However, for the disaggregated results, the costs also outweigh the benefits in SSP4 (for generation 2 (2055–2084), 3 (2085–2114), and 4 (2115–2144)), and SSP1 (generations 4 (2115–2144) to 9 (2265–2294); these are scenarios in which population size declines, hence the additional housing on the superdike leads to welfare losses due to increased vacancy rates elsewhere in the city (Figure 1.1.2). In the second highest SLR scenario, the costs outweigh the benefits for the last included generation, as is also the case for the aggregated results with a time horizon of 2025–2300. However, when assuming that the real housing values remain constant over time and are hence not dependent on GDP growth rates, the costs outweigh the benefits for all scenarios. The full methodology and results can be found in van Tilburg et al. (*under review*).

Figure 1.1.2: Benefit-cost ratios for nine future generations across socioeconomic and sea-level rise scenarios for superdike measure in Den Helder. H.E. stands for the RCP8.5 high-end sea-level rise scenario. The moral principle applied here is classical utilitarianism (i.e., a zero percent discount rate). Bold values indicate the net present value of the superdike is higher than for the incremental dike reinforcement measure. The last column for generation nine is empty as there are no costs and benefits in that SLR scenario during that period. Source image: van Tilburg et al. (*under review*).

5. Barriers and conditions for implementation

Several factors could constrain the implementation of the superdike (Table 1.1.2). For instance, even in the scenarios and CBA assumptions under which the net present value for the superdike is positive, finance could form a barrier to implementation. Since the dike does not require reinforcement at this point in time, the new dike will not receive funding from the national government and will hence need to be financed locally. Moreover, the acceptability of making a potential overinvestment and of overtopping of the dike could constrain the desirability of this adaptation option. Additionally, the need for removal of the current housing in the project area presents an enabling condition for flood adaptation; without this need, the perceived acceptability of expropriating homeowners to reinforce a dike that does not currently require reinforcement, could reduce the legitimacy of a similar adaptation plan. Most of the barriers for the incremental dike are related to finance, whereas most of the barriers for the superdike relate to social barriers (Table 1.1.2). However, this is not an exhaustive list and more barriers may apply.

Table 1.1.2: Barriers for implementation of incremental dikes or superdikes as adaptation strategies.

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or goverannce and institutional (G).

Measure	Barriers	Cat
Incremental dike	1A – Competing local planning objectives	G
	1B – Availability of future resources	F
	1C – Availability of land for future reinforcements	F
Superdike	2A – unsuitable financing institutions (not nationally funded)	F
	2B – Acceptability of expropriating home owners	S
	2C – uncertain effect housing on dikes	K
	2D – acceptability of overtopping	S
	2E – acceptability of overinvestment	S
	2F – place attachment	S
	2G – Sharing of responsibilities in planning area	G

6. Reflection on superdikes as adaptation strategy

Superdikes could also be implemented as adaptation strategy elsewhere. However, several factors should be considered. Firstly, the role of lock-in and regret can depend on the size of the project area. For the 1400 meter superdike along the coasts, the benefit-cost ratios are around 21–38% higher compared to the 700 meter long superdike, depending on the discount rate applied. However, the potential switching costs as well as the co-costs in the declining population scenarios are also higher for future generations. Secondly, housing costs and benefits are the main costs and benefits for this project. Extending the superdike from the 1400 meter area to the entire dike segment for this case study, only increased total benefits with 0.01–4.8% on average (i.e., safety benefits of the dike are small). This means that the strategy could be particularly relevant for areas where dike reinforcement is already needed and there are more safety benefits from the dike in the near-term.

7. Conclusion

Multifunctional adaptation in the form of superdikes could be a way to increase spatial quality in a region. However, the measure could be prone to lock-in if there is no demand for the additional functions on the dike or if a switch is needed to a different strategy. In the context of Den Helder, however, the risk of lock-in for the latter reason is small, as the superdike has a robust design that is suitable for 5.0 meters of SLR.

Case study 1.2 – Large scale and long-term coastal nature-based solution policies for rural regions in Europe and the German Baltic coast (Germany/Europe)
Partner: GCF
Spatial scale: European and regional level (German Baltic coast)
Stakeholders: Leitung WWF Ostseebüro, Hitergrund in Paläoklimatologie und- biologie; IUCN
Status: ongoing

1. Decision context

1.1 Ecological context

Coastal wetlands are biodiversity hotspots that provide a wide range of essential ecosystem services to coastal communities. As nature-based solutions (NBS), they play a critical role in addressing both climate mitigation as nature climate solutions (NCS) and adaptation challenges in the form of ecosystem-based adaptation (EbA) (Schuerch et al., 2018; Taillardat et al., 2020; Tiggeloven et al., 2022; van Zelst et al., 2021). These ecosystems, including seagrass meadows, salt marshes and mangroves, act as carbon sinks by absorbing and storing greenhouse gases, thus contributing significantly to climate mitigation. Additionally, they serve as natural defenses against erosion and the impacts of storm surges and wave action (Duarte et al., 2013), making them strategic tools for climate adaptation, particularly in vulnerable coastal regions (Tiggeloven et al., 2020, 2022; van Zelst et al., 2021).

Despite their critical ecological and societal functions, coastal wetlands face severe threats. Historically, their importance has been overlooked, and they were often converted for agricultural, industrial, or residential purposes, leading to widespread habitat loss (Davidson, 2014; Fluet-Chouinard et al., 2023). Alarmingly, the rate of coastal wetland destruction surpasses that of tropical rainforests (Davidson et al., 2018; Newton et al., 2020). The challenge is further exacerbated by rising sea levels and socio-economic development, as urban development, infrastructure expansion and the construction of coastal defences restrict the horizontal space available for wetlands to migrate inland. Sediment starvation impedes the vertical accretion especially in delta areas where dredging activities are performed to improve the navigation. If these two biophysical mechanisms are blocked then we expect severe wetlands losses facing 21st century sea-level rise (Schuerch et al., 2016, 2018, 2025).

1.2 Stakeholder engagement and co-design process

To understand the needs, priorities and perspectives of practitioners and policymakers involved in coastal adaptation, a series of stakeholder round tables was organized. These discussions brought together representatives from environmental organizations, research institutions, and public authorities at both European and local level. The sessions were introduced with a guiding question: How can research best support coastal adaptation, particularly through NBS?

The round tables combined expert presentations and interactive discussions to jointly explore the current state and future potential of NBS in Coastal Flood and Erosion Risk Management (CFERM) setting. Presentations by researchers and practitioners provided empirical insights into managed realignment (MR) projects and their integration into coastal protection strategies in different regions of the German Baltic coast. These inputs served as a foundation for dialogue on scientific evidence, administrative practices and implementation challenges.

The co-design process revealed several key insights. Participants emphasized the need for better quantification of the effectiveness of hybrid solutions that combine hard infrastructure and ecosystem restoration. While economic efficiency and flood risk reduction remain central objectives, social acceptance and transparent communication with local communities were identified as critical preconditions for implementing MR and other NBS. Stakeholders noted that MR projects often face resistance due to conflicting land-use interests, long planning horizons, and limited awareness of co-benefits such as habitat creation, carbon sequestration, and recreation.

The discussions also highlighted regional contrasts: some coastal states have more extensive experience with MR, often driven by nature conservation objectives, whereas others have fewer but increasingly climate-oriented projects. This divergence underscores the importance of tailoring adaptation strategies to local governance structures and social contexts. Participants agreed that future research should strengthen the evidence base for NBS, particularly through cost-benefit analyses, modeling of wetland flood attenuation and assessments of co-benefits.

Overall, the round tables fostered a collaborative environment for co-designing research questions and policy-relevant outputs. By integrating practitioner experience with scientific modeling and policy analysis, the engagement process helped to identify pathways for more adaptive, socially accepted and ecologically sound coastal protection strategies in the face of accelerating sea-level rise.

1.3 The German Baltic Sea coast context

The German Baltic coast, with an estimated total length of 2538 km (van der Pol et al., 2021) is projected to experience some of the highest increases in extreme sea levels in Europe until the end of the century due primarily to relative SLR. Without rethinking existing adaptation strategies, Germany is anticipated to suffer substantial absolute flood damages (Kiesel et al., 2023).

CFERM along the German Baltic coast has a long history, with roughly one third of the shoreline protected by dikes (Hofstede, 2024). Protection standards vary, though both Schleswig–Holstein (SH) and Mecklenburg–Vorpommern (MV) are progressing toward safeguarding against a 200-year flood event plus a 0.5 m sea-level rise. However, recent analysis reveals that uniform hazard-based protection can be inefficient; some floodplains with towns like Flensburg and Rostock may be under-protected, while others are over-protected (Kiesel et al., 2023).

To address future uncertainties, state authorities have adopted the "climate dike concept," allowing for dike height increases of up to 1.5 m, thereby improving long-term adaptability (Kiesel et al., 2023). Complementing this, MR has emerged as a promising hybrid, nature-based solution that repositions flood defences landward to restore tidal exchange and coastal ecosystems producing the "double dividend" of coastal protection and coastal restoration. In particular, the German Baltic coast holds a potential MR area of about 60,750 ha 77% in MV primarily consisting of low-value assets such as agricultural land and meadows (Kiesel et al., 2023).

One of the main results of the stakeholder workshops on MR on the German Baltic coast were the insights into the decision context. We identified a diverse set of stakeholders with different interests that define the context for MV and SH. There are two separate systems in place for coastal protection. In principle, the responsibility of coastal protection lies with the landowners, except for places of public interest that are protected by the state governments, mostly through state dikes (Landesschutzdeiche) or beach and dune nourishment. The investment costs for state dikes are shared between the Federal Government (70%) and the State Governments (the remaining 30%), while the responsibility for maintenance lies entirely with the States. Beyond the state dikes, local Water and Soil Associations (Wasser- und Bodenverbände), whose members are municipalities and farmers, maintain so-called regional dikes (Regionaldeiche), predominantly in order to protect agricultural production in polders.

This division of responsibility leads to two main motivations for MR in the German Baltic Sea (A. de la Vega-Leinert et al., 2024; A. C. de la Vega-Leinert et al., 2017):

1. For the realignment of regional dikes, the main motivations are cost savings and nature restoration. The main driver behind the implementation of nature-based solutions are environmental protection NGOs who often initiate MR projects of regional dikes. Typically, they approach the Water and Soil Associations, some of which are struggling to keep up with the maintenance cost of dikes and propose nature-based solutions. For the Water and Soil Associations the main benefit and motivation is cost saving. The main motivation on the part of the environmental organisations is the protection and restoration of ecologically important

ecosystems, mainly salt marshes. Today, adaptation to climate change and SLR plays at best a minor role in the realignment of regional dikes.

2. For the realignment of state dikes, the main motivation is flood protection and human security, with maintenance cost only playing a minor role. Recently the federal government released the Action Program for Natural Climate Protection (ANK), a multi-billion program promoting nature based solutions which will also help fund salt marsh restoration on the North and Baltic sea. The plan specifically highlights the multifaceted role salt marshes can play. Besides their ability to sequester CO_2 and provide habitat for many bird species and insects, they are an important element in coastal protection by attenuating wave energy, which can contribute to the prevention of damages to dikes and other structures (BMUV, 2023).

Therefore, NBS have emerged as promising alternatives in rural coastal areas or complements to engineered defences as in the case of MR with coastal restoration. Despite their advantages, the implementation of NBS faces several challenges, including variability in site-specific effectiveness, integration with existing infrastructure and the need for broad stakeholder support backed by strong evidence of cost-efficiency and reliability.

1.4 Stakeholder challenges and research question

The stakeholder discussions revealed several persistent challenges in advancing nature-based coastal adaptation. Key issues include limited social acceptance of MR, complex and lengthy planning procedures, conflicting land-use and conservation objectives and insufficient quantitative evidence on the effectiveness and cost-efficiency of hybrid solutions. Practitioners and policymakers emphasized the need for clearer guidance on when and where NBS can complement or replace traditional flood protection. Building on these insights, we compiled a summary table (Table 1.2.1) highlighting the most urgent questions regarding coastal restoration and MR as a combined hybrid solution to address flood risk, reduce protection costs and achieve ecological goals.

Table 1.2.1: Stakeholders-driven research questions, existing gaps to fill and possible problems.

Research Questions	**Gaps (research and policy)**	**Problems**
How effective are NBS such as MR in reducing flood risk?	- Limited empirical data on flood protection effectiveness - Need for robust flood and cost-benefit models	- Simplified models may be unrealistic
What are the co-benefits of NBS (carbon sequestration, biodiversity, tourism) and how to quantify them?	- Lack of integrated assessments including ecological and socio-economic benefits - Conflicting goals between habitat creation and flood protection	- Not all ESS can be effectively assessed - Establishing trade-offs between ESS is not straightforward
How can social acceptance of MR projects be increased?	- Lack of public communication and clear mandates	- Initial rejection by local communities - Limited participation and compensation mechanisms
What policy and governance frameworks best support the planning and implementation of NBS?	- Incomplete integration of SLR considerations in policy	- Differences between administrative and scientific approaches - Long, complex planning processes
How to reconcile conflicting goals between coastal protection and nature conservation in MR?	- Zoning challenges and multi-stakeholder interests	- Conflicts between habitat needs (e.g., water exchange) and narrow breaches for flood control
What role do hybrid solutions (combining NBS and traditional infrastructure) play in coastal adaptation?	- Need for better modeling of combined approaches - Limited evidence on hybrid system effectiveness	- Lack of real case studies data (especially on the costs)
How can long-term coastal visions be developed to guide adaptation strategies?	- Lack of clear, shared visions for future coastline	- Difficulty integrating climate projections and stakeholder expectations
What are the barriers to scaling up MR and how can they be overcome?	- Resistance from locals and conservation groups - Insufficient funding or legal clarity	- Planning uncertainties and long timelines
Can "quick and dirty" scientific assessments provide useful guidance for early-stage adaptation planning?	- Risk of oversimplification but need for timely decisions	- Tension between rapid assessment and need for robust data
How does vertical land movement and compound events (storm surge + rainfall) affect flood risk and NBS performance?	- Complex interactions poorly understood in current models	- Dikes may hinder rainwater outlet, increasing risk

The central research question emerges: How can nature-based and hybrid coastal protection measures be effectively designed, implemented and evaluated to enhance resilience while balancing ecological, social and economic objectives?

2. Current and future risk

In this context, we aim to address the most pressing questions raised by stakeholders by assessing and comparing the costs and benefits of different coastal adaptation strategies in the face of sea-level rise (SLR) and coastal flooding. Specifically, we evaluate grey infrastructure, nature-based solutions (NBS) coupled with hybrid approaches (as MR) under a range of future SLR scenarios. The key risks for European coastal communities are not only the physical impacts of SLR and flooding but also the ecological loss of coastal wetlands and their ecosystem services (ESS). Particularly in rural and low-exposure areas, these challenges present opportunities to reduce coastal protection costs while simultaneously promoting ecological restoration.

To conduct this assessment, we employ the Dynamic Interactive Vulnerability Assessment (DIVA) coastal impact model (Hinkel et al., 2014; Lincke & Hinkel, 2021) together with a global wetland change model (Schuerch et al., 2016, 2018). Using these tools, we analyse and compare two main adaptation strategies across European floodplains with a specific focus on the German Baltic Sea coast:

1. Managed Realignment (hybrid solution) coupled with ecological restoration (through sediment nourishment) as green solution
2. Sea dike construction and heightening as a grey infrastructure approach

We consider four climate scenarios consistent with the ACCREU scenario matrix: SSP2 combined with RCP2.6, RCP4.5, and RCP7.0, using the median quantile (0.5) for all three, and additionally the high quantile (0.95) for RCP7.0 to represent an extreme SLR scenario. This results in a total of four SLR scenarios. A 3% discount rate is applied to estimate the present value of total costs and benefits over the 2020–2100 period. The results are evaluated using the Benefit–Cost Ratio (BCR); in floodplain areas where the BCR ≥ 1, MR and coastal ecosystem restoration are deemed economically superior to conventional sea dike protection.

To support decision-making, we propose the development of a comprehensive MR and restoration map for European coastal regions and, in greater detail, for the German Baltic coast (Figure 1.2.1 and Figure 1.2.2). This map will function as a decision-support tool, guiding policymakers and planners in selecting and implementing the most suitable restoration and protection strategies according to regional conditions. The core objective of this mapping effort is to identify priority areas for MR and coastal ecosystem restoration that can effectively cope with projected sea-level rise.

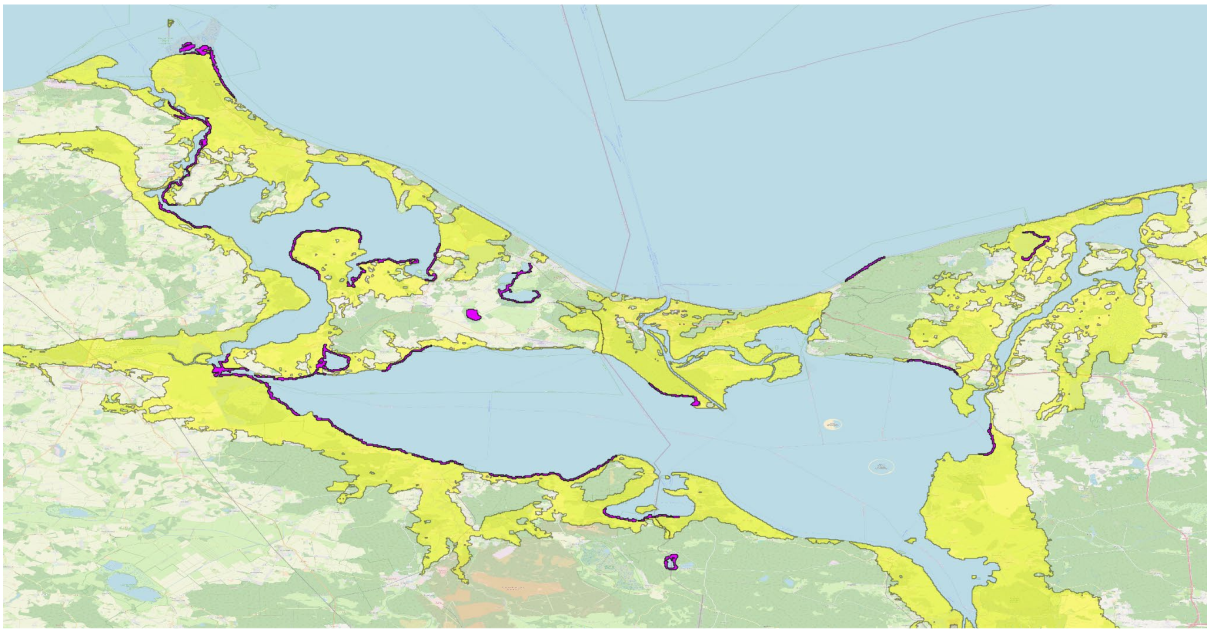


Figure 1.2.1: Coastal wetlands in the East German Baltic Sea coast at the border with Poland. In yellow the DIVA floodplain and in purple the tidal flats areas.

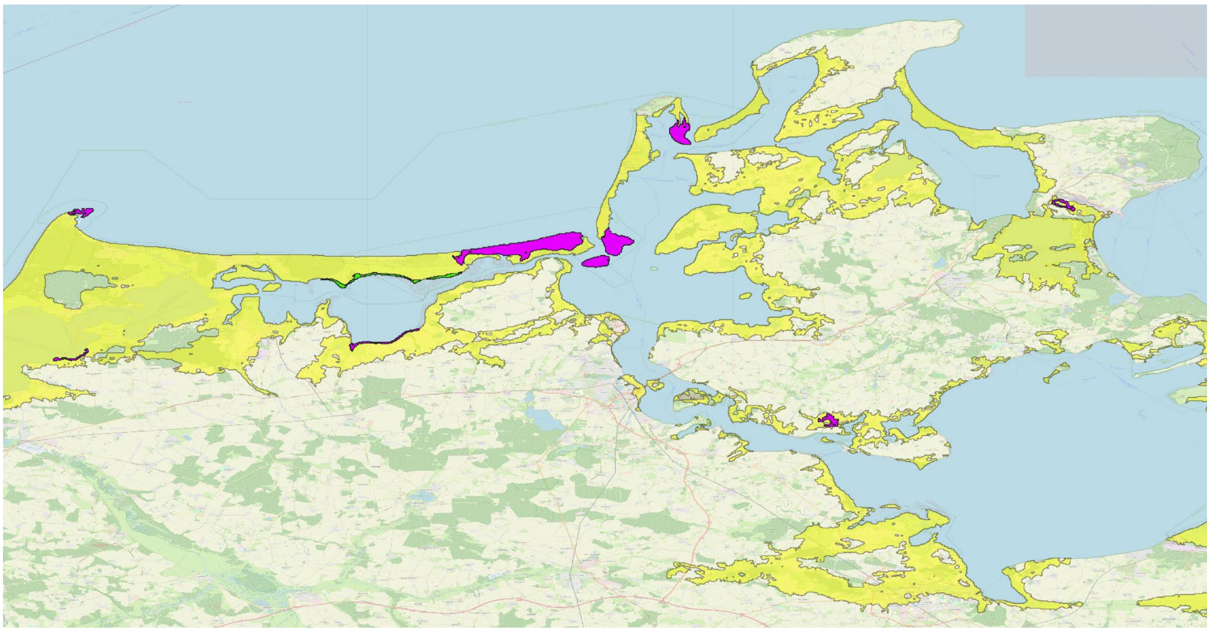


Figure 1.2.2: German Baltic coast Mecklenburg-Western Pomerania. In yellow DIVA floodplains, in purple tidal flats and in green salt marshes.

3. Adaptation strategies

The cost of adaptation can vary significantly depending on the protection strategy used. Lincke & Hinkel (2018) highlighted the need for further research on alternative adaptation options, such as a combination of hard defences (e.g., dikes) with accommodation and retreat strategies. This approach could potentially offer a more cost-effective and sustainable solution especially for rural and low-populated areas.

NBS offer a complementary or alternative approach, leveraging the inherent protective capacities of ecosystems such as wetlands, salt marshes and tidal flats. These ecosystems can attenuate storm surge events and wave energy, reduce erosion and store excess water, all while providing co-benefits such as carbon sequestration, habitat provision, and enhanced biodiversity.

Table 1.2.2: Adaptation options classified and their classification in Incremental or Transformative.

Adaptation options (O)

What adaptation options are considered in the case study?	Are the options more incremental or transformative? Incremental	Transformative
Grey		
• Dike reinforcements	✓	
• Building new dikes		✓
Green		
• Wetlands restoration (using sediment nourishment)		✓
• Managed realignment		✓
Soft		

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?
Trade-off between grey and green adaptation strategies and hybrid strategies (managed realignment and coastal restoration)

The main adaptation strategies on the German Baltic coast to date are hard protection measures such as dikes or soft-protection measures such as beach and dune nourishment. A more transformative approach is MR (Table 1.2.2), where dikes are slashed or relocated further landwards on the coast in order to create coastal wetlands such as salt marshes. MR on the German Baltic coast has a large potential, with suitable land area of close to 61.000 hectares. Much of land identified as suitable is agricultural land, meadows or forests. In Mecklenburg-Vorpommern only a fraction of the potential is so far exploited as a recent inventory of MR projects shows (Table 1.2.3) (A. de la Vega-Leinert et al., 2024).

Table 1.2.3: Inventory of managed realignment cases on the Baltic sea. Source: ECAS baltic project https://globalclimateforum.org/portfolio-item/ecas-baltic/ (A. C. de la Vega-Leinert et al., 2024)**.**

Case and location	Measure	Reason for measure	Area (ha)	Begin	End
Landesdeich Püttsee-Puttgarden near Westermarkelsdorf	Realignment of dike	- Cost savings: due to shorter dikeline - Nature protection: Reinforcement of existing dike line would have caused greater interference with nature	10	2002	2003
Landesdeich Püttsee-Puttgarden near Fastensee	Realignment of dike				
Geltinger Birk	Realignment of dike	- Habitat creation: lagoons and salt marshes - Coastal protection: Better protection of the village of Falshöft through new state dike	250	1988	2014
Kleines Noor	Breach of dike	- Habitat creation - Improve water quality	14 -15	-	2002
Landesdeich Probstei, bei Wendtorf	Realignment of state dike	- Compensatory measure for dike reinforcement - Habitat creation and restoration of natural coastal dynamics	40 - 50	-	1989
Strandseenlandschaft Schmoel					
Regionaldeich zw. Dahme und Kellenhuse, Dahmer Moor	Removal of regional dike	- Lack of funding: Dike was severely damaged during a storm in 2020. Landowner was unwilling to bear his own share of the costs for repair (estimated to 300,000 and 400,000 €)	60	-	2022

Table 1.2.4: Adaptation strategies and their cost, benefits and underlying biophysical link marked with X if applicable.

Adaptation strategy	Control variable	Cost				Benefit		Biophysical mechanism		
		Sea-dike investment	Sea-dike maintenance	Relocation of people and assets	Volume of sediments	Coastal protection	Protection cost reduction	Vertical accretion (area increase)	Inland migration (area increase)	Wetlands squeeze (area loss)
Grey (dikes, surge barriers)	Add Sea-dike	x	x			x				x
Hybrid (Managed realignment and wetlands restoration)	Add sediments				x	x	x	x		
	Remove sea-dike			x		x	x		x	
	Add lower sea-dike inland	x	x			x				x
Green (NBS, i.e. wetlands)	Add sediments				x	x	x	x		
	Migration			x		x	x		x	

The adaptation strategies considered in our decision support tool and their associated cost and benefit components are summarized in Table 1.2.4 that links each intervention to its relevant cost categories, expected benefits and the biophysical mechanisms it influences.

4. Assessment of adaptation options

To evaluate the different adaptation options (Figure 1.2.3), we estimated the costs and benefits associated with each strategy. For grey adaptation, costs are divided into two categories: investment costs, representing the expenses of constructing or upgrading sea dikes, and maintenance costs, referring to the annual expenditures required to ensure their continued functionality. In comparison, the hybrid adaptation strategy includes both the cost of MR covering the relocation of people and assets within floodplains and the cost of sediment nourishment, which reflects the volume of sediment required to replenish and restore degraded wetland areas.

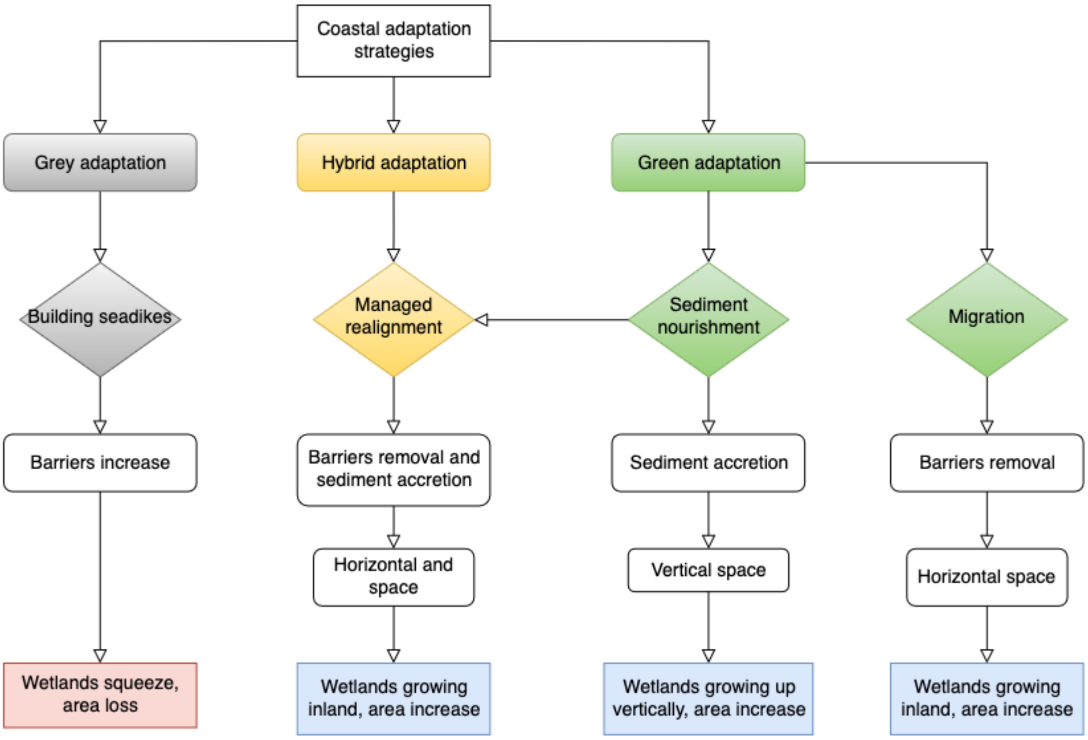


Figure 1.2.3: Adaptation options in DIVA and their link with the biophysical processes.

The benefits of wetland protection are defined as a reduction in residual flood damages and a decrease in sea dike investment and maintenance needs, as restored wetlands attenuate storm surges, allowing for lower or fewer sea dike constructions. Additionally, we calculate the annual absolute carbon storage ability of tidal flats and saltmarshes and monetize the climate mitigation benefits using the global social-cost of carbon 187 USD/tCO2e as estimated in Estrada et al. (2025).

The estimation of costs and benefits for both grey and hybrid strategies is based on the constant flood protection standard framework within the DIVA model, which assumes that countries maintain their current levels of protection over time (Table 1.2.5). Under this assumption, dike heights are incrementally raised in line with future SLR projections to preserve existing protection standards.

Migration is considered as autonomous (or reactive) following Lincke & Hinkel (2021) people migrate as soon as the area in which they live is located in the 1-in-1 year floodplain without protection, meaning that they experience more than one flood event per year and therefore the area is considered uninhabitable thus abandoned.

The wetland change model calculates wetland losses according to two main factors: the population density threshold within the 1-in-100-year floodplain (representing horizontal space availability) and the availability of suspended sediments (indicating the potential for vertical accretion). Losses are computed for each time step across the simulation period. It is further assumed that, in each floodplain containing coastal wetlands, coastal planners actively restore the wetland area lost using a combination of MR, which lowers population density by relocating people and assets, and sediment nourishment, which compensates for sediment deficits in sediment-starved floodplains.

Table 1.2.5: Initial protection table rule as outlined in Nicholls et al. (2019) based on protection standards outlined in Sadoff et al. (2015) and Hallegatte et al. (2013). Income classes are in US$ 2012 prices.

Wealth Class (2014 US$ GDP per capita, PPP)	**Urban (>1000 people/km²)***	**Rural (30–1000 people/km²)***	**Uninhabited (<30 people/km²)***
Low income (<= $1,035)	1:10	No protection	No protection
Lower middle income ($1,036 – $4,085)	1:25	No protection	No protection
Upper middle income ($4,086 – $12,615)	1:100	1:20	No protection
High income (> $12,615)	1:200	1:50	No protection
Special case: Netherlands	1:10,000		
Special case: 136 large coastal cities	Hallegatte et al. (2013) protection levels		

***Population density thresholds in the 1-in-100-years floodplain**
- Protection levels are expressed as return periods (e.g., 1:100 means protection against a 1-in-100-year event)

5. Barriers and conditions for implementation
5.1 Barriers for implementation
From our stakeholder engagement process and the separate workshops we held, we identified several barriers to the implementation of wetland restoration and coastal retreat at different levels (summarised in Table 1.2.6 and 1.2.7). Locally, one of the main barriers is the lack of social acceptance of MR among the inhabitants of coastal regions. Agricultural landowners, in particular, tend to oppose adaptation options that result in the loss of land previously converted into arable land. This opposition stems from both economic and emotional reasons, as landowners fear losing their livelihoods and question the effectiveness of wetlands for flood protection.

For environmental protection NGOs, climate change adaptation is often only a secondary benefit of MR. Their primary goal for the implementation of MR projects is the restoration of ecosystems. There are however trade-offs that need to be considered when relocating or slashing dikes. For adequate flood protection, maintaining most of the dike with only small breaches to create wetlands behind it is preferred. This approach can, however, restrict the outflow of water after a flood, leading to the formation of saltwater pools that hinder the development of healthy salt marshes.

Table 1.2.6: Implementation barriers

Category	**Barrier Description**
Technical and Scientific Gaps	- Limited data on effectiveness of NBS - Need for better models to assess long-term viability
Social Acceptance and Stakeholder Conflicts	- Resistance against NBS from local communities and interest groups - Unclear communication from the state to communities and lack of public engagement
Legal and Policy Constraints	- Coastal protection laws and administrative traditions prioritize hard measures and sand nourishment - Lack of clear mandates for managed realignment

Table 1.2.7: Upscalability barriers

Category	Barrier Description
Economic Considerations	- High upfront costs (e.g., managed realignment), long-term benefits not yet visible - Cost-benefit analysis not sufficiently emphasized (not mandatory in Germany as in other EU countries)
Institutional and Planning Challenges	- Fragmented governance- State is responsible for coastal protection and human security, but managed realignment is organized locally per project - European agricultural policy constraints- Complex land ownership and leasing issues
Uncertain Climate and Risk Perception	- Slow realization of sea-level rise (SLR) impacts in policy and planning - Need for "visionary" long-term coastal strategies

5.2 Conditions for implementation

To overcome these barriers, policymakers need to establish suitable incentive structures. This includes compensation schemes for land or real estate that is surrendered and fostering active participation in the planning process at the local level. Clear communication about the costs and benefits of wetland restoration is essential to increase acceptance among local populations. Providing reliable information about future sea-level rise, flood risk and the future costs of maintaining dikes can help create realistic expectations and increase the willingness to support MR.

Examples from regional dike associations demonstrate how creating wetlands can help compensate for the increasing maintenance costs of dikes under the pressure of sea level rise. For instance, the removal of the regional dike of the Dahmer Moor after severe storm surge damage highlights a practical application of this approach. The dike association was unwilling or unable to pay their share of the repair costs of the dike and opted instead to remove the dike completely.

These findings are supported by two case studies in MV, conducted by A. C. de la Vega-Leinert et al. (2017). The case studies show that fear of losing land and livelihoods is a primary driver of local resistance to MR projects. However, the authors also highlight that successful negotiations involving all relevant stakeholders can lead to the effective implementation of MR, benefiting all parties involved.

For effective wetland restoration, it is desirable to allow mostly unrestricted inflow and drainage of water, but this comes at the expense of flood protection. This trade-off is particularly critical during extreme water levels, where evidence shows that the attenuation rate of salt marshes created through MR is reduced (Kiesel et al., 2022). A careful design of MR projects that balances the goals of flood protection and ecosystem restoration is therefore necessary.

6. Modelling assessment to support adaptation decisions and results

We applied the DIVA coastal impact model across all floodplains in EU27 and the United Kingdom with a coastline, calculating the Benefit–Cost Ratio (BCR) for each to assess the economic viability of managed realignment (MR) and wetland restoration as adaptation strategies. Floodplains with a BCR ≥ 1 are classified as economically justified, meaning that the benefits of MR and restoration outweigh their costs, while those with BCR < 1 represent cases where the costs exceed the benefits.

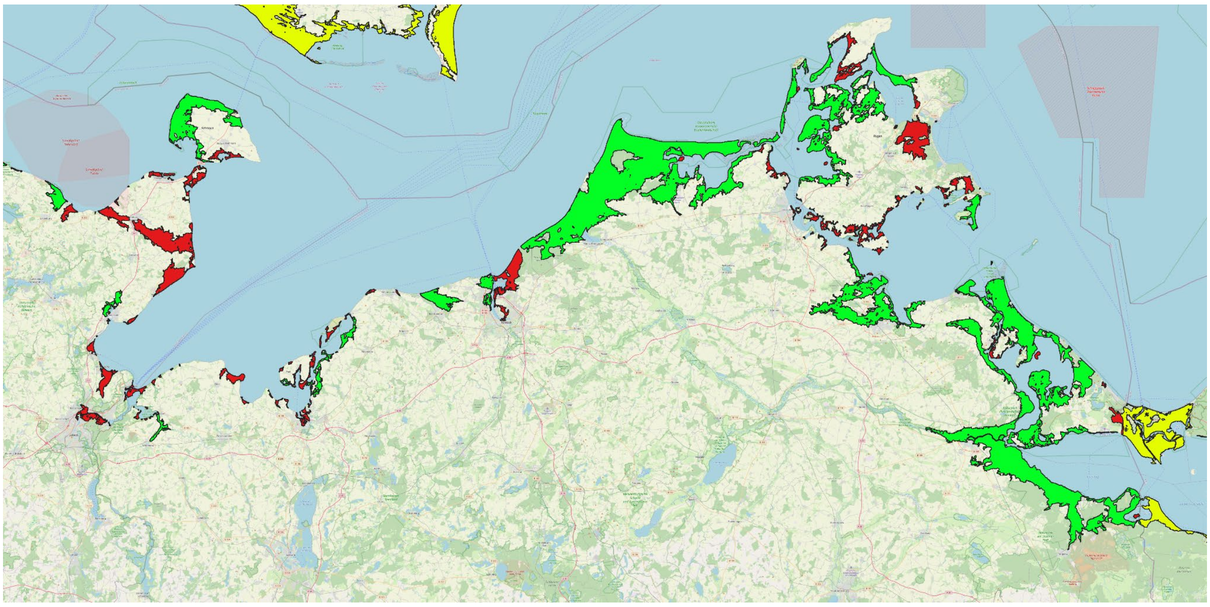


Figure 1.2.4: German Baltic Sea coast floodplains. Green floodplains have BCR ≥ 1; Red floodplains have a BCR below 1; Yellow floodplains are outside Germany.

In total, 63 out of 297 floodplains in Germany show a BCR ≥ 1, indicating that MR and wetland restoration provide higher economic benefits than costs (including nourishment and relocation expenses). This finding remains consistent across all considered climate and socio-economic scenarios, with only one additional floodplain (total 64) reaching a BCR ≥ 1 under the highest SLR scenario. The majority of these economically favourable floodplains for MR are located along the German Baltic Sea coast, highlighting this region's particularly high potential for implementing MR coupled with wetland restoration as a cost-effective adaptation strategy (Figure 1.2.4).

At the European scale, the results summarized in Table 1.2.8 show the percentage of national coastlines where MR and wetland restoration are economically justified (BCR ≥ 1). The findings reveal significant variation between countries. For instance, Romania (79%), Italy (22%), France (25%), Spain (14%), and Germany (62%) exhibit the largest shares of coastline where MR and restoration are economically desirable. In contrast, many northern European countries such as Denmark, Finland, Sweden, Estonia, Latvia, and Lithuania show no coastal floodplains meeting this threshold, suggesting lower economic feasibility due to geomorphological or socio-economic constraints.

Table 1.2.8: European countries where managed realignment is economically desirable with BCR equal or bigger than 1 as a percentage of the country's total coastal length.

ISO 3 Code	Country	Total coastline (km)	% of coast length with BCR >=1
BEL	Belgium	343	0.0
BGR	Bulgaria	424	0.9
CYP	Cyprus	619	0.0
DEU	Germany	4,103	61.5
DNK	Denmark	6,070	0.0
ESP	Spain	7,107	14.2
EST	Estonia	2,364	0.0
FIN	Finland	15,093	0.0
FRA	France	8,891	24.7
GBR	United Kingdom	18,091	2.0
GRC	Greece	13,519	0.2
HRV	Croatia	4,791	0.0
IRL	Ireland	5,864	0.0
ITA	Italy	8,300	21.7
LTU	Lithuania	233	0.0
LVA	Latvia	671	0.0
MLT	Malta	161	0.0
NLD	Netherlands	3,894	12.7
POL	Poland	1,223	0.0
PRT	Portugal	3,003	0.0
ROU	Romania	794	78.8
SVN	Slovenia	40	0.0
SWE	Sweden	19,493	0.0

Overall, the results indicate that MR and wetland restoration have substantial economic potential across Europe, particularly in regions with low-lying, sediment-rich coastal plains such as the German Baltic coast and parts of Southern and Eastern Europe. These findings support the growing recognition of nature-based and hybrid adaptation approaches as viable, cost-effective strategies for managing sea-level rise and coastal flooding in Europe.

7. Discussion and conclusions

The modelling approach developed in this study was designed to address the key knowledge gaps identified during the stakeholder workshops. It does so in two main ways: first, by testing the effectiveness of wetlands in reducing coastal flood damages under various sea-level rise (SLR) scenarios, and second, by evaluating where MR and ecological restoration are economically desirable (i.e., where the benefits outweigh the costs). Through this dual focus, the tool provides a structured, evidence-based framework to assess the potential of nature-based and hybrid coastal adaptation measures in the German Baltic Sea coast and in rural coastal areas all over Europe.

Grounded in biophysical and economic models, the decision-support tool helps identify priority areas for MR and wetland restoration across European coastal regions, with a detailed focus on the German Baltic Sea coast. However, it is important to emphasize that the tool serves as an indicative, strategic instrument rather than an operational planning tool. Decisions regarding MR or restoration should always be made at the local level, drawing on site-specific data and ad hoc local models that capture the nuances of local environmental conditions, social dynamics, and governance frameworks.

Several limitations must be acknowledged. The attenuation rates used to estimate the capacity of wetlands to reduce coastal flood damages are derived from a limited number of case studies available in the literature (Vafeidis et al., 2019). Consequently, these values should be interpreted with caution, as they may not fully reflect the variability of real-world coastal environments. Similarly, the wetland change model used in this study is a simplified representation and does not comprehensively capture local wetland conditions, stressors, and geomorphological processes, which may introduce potential biases in the results.

Despite these constraints, the modelling approach has proven useful in bridging the gap between research and policy. It offers a transparent and replicable framework for assessing trade-offs between grey, green and hybrid adaptation strategies, supporting policymakers in identifying where nature-based solutions can deliver the highest value. Overall, the decision-support tool contributes to a more integrated, evidence-based approach to coastal adaptation, providing valuable insights for the development of sustainable and cost-effective strategies to cope with sea-level rise and enhance coastal resilience through ecological restoration.

2 Forestry and ecosystems

<u>Case study 2.1 – Multi-sectoral adaptation to wildfire risk in a densely populated region with high natural values (Italy)</u>

Partner: DTU
Spatial scale: Sorrento municipality and parts of the Campania region
Stakeholders: STRESS-SCARL, Sorrento and neighboring municipalities in the Campania region,
Status: Ongoing.

1. Decision context

Italy exhibits growing vulnerability to forest fires, particularly during the arid and high-temperature summer months, as a result of intersecting climatic, geographic, and anthropogenic factors (Michetti and Pinar, 2019). The country's Mediterranean climate—marked by prolonged droughts and elevated temperatures—provides conducive conditions for the ignition and rapid propagation of wildfires (Turco et al., 2018). Moreover, the expansion of urban areas into forested and rural landscapes has introduced additional complexities to fire prevention and management strategies. The socio-economic repercussions of forest fires in Italy are considerable, with notable impacts on regional economies and the social resilience of at-risk communities (Michetti and Pinar, 2019). The intensifying effects of climate change are further exacerbating the frequency, scale, and severity of these events, underscoring persistent challenges to environmental sustainability and public safety across the country (Dadkhah et al., 2025).

This project case study focuses on the municipality of Sorrento, located in the Campania region of southern Italy. The whole peninsula comprises a major tourist destination and attracts international tourists annually. Agriculture (including agritourism) – and organic and high-value agriculture like lemons, oranges, olives, and other Mediterranean products – also plays a major role for the economy and comprise an important part of the cultural heritage of the area. Positioned on the Sorrentine Peninsula, Sorrento features a coastal landscape shaped by volcanic and tectonic activity, with prominent limestone cliffs, deep valleys, and terraced hillsides. The area supports characteristic Mediterranean vegetation, including olive groves, citrus orchards, and maquis shrubland, well adapted to the region's hot, dry summers and mild, wet winters. Its proximity to protected areas such as the Punta Campanella Marine Reserve further enhances its ecological significance, contributing to the preservation of both terrestrial and marine biodiversity. The coastal area of the Sorrento peninsula poses as an example of a coastal landscape with a unique balance between natural and built environment. Within the area falls a number of NATURA 2000 sites, and Special Protection Areas (SPA). On the south side of the peninsula lies the Amalfi Coast, which was listed as a UNESCO World Heritage Site in 1997, with two of the local villages being marketed as among the most beautiful villages of Italy.

Campania's land use is predominantly agricultural, 38% of the region is forested with 30% of its territory is designated as national or regional parks (Esposito et al., 2023, Dadkhah et al., 2025). The region ranks fourth in Italy for the number of wildfire events and third for total burned area (Michetti & Pinar, 2019, Dadkhah et al., 2025). From 1990 to 2017, Campania experienced approximately 900 forest fires per year, primarily from June to September (Busico et al., 2019, Dadakhah et al., 2025). From 2007 to 2021, a total of 11,765 fire incidents were recorded across Campania, according to burnt area data provided by the Italian National Institute of Statistics (*Istituto Nazionale di Statistica*). Figure 2.1.1 below illustrates the annual distribution of these fire incidents over the specified period.

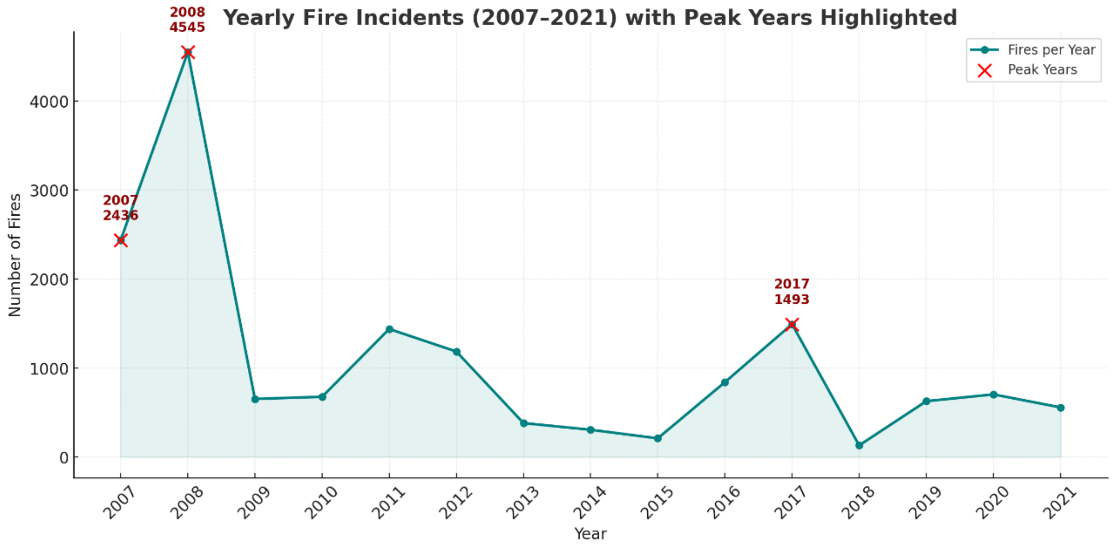


Figure 2.1.1: Number of recorded fire per year in Campania Region from 2007-2021. Source: the Istituto Nazionale di Statistica (ISTAT)

Figure 2.2.2 illustrates the number of recorded fire incidents in Sorrento between 2007 and 2021. A notable peak happened in 2007. Following this spike, the number of incidents remained low and relatively stable, with most years recording between 1 and 4 fires. Minor peak occurred in 2012 (4 incidents) and 2021 (3 incidents).

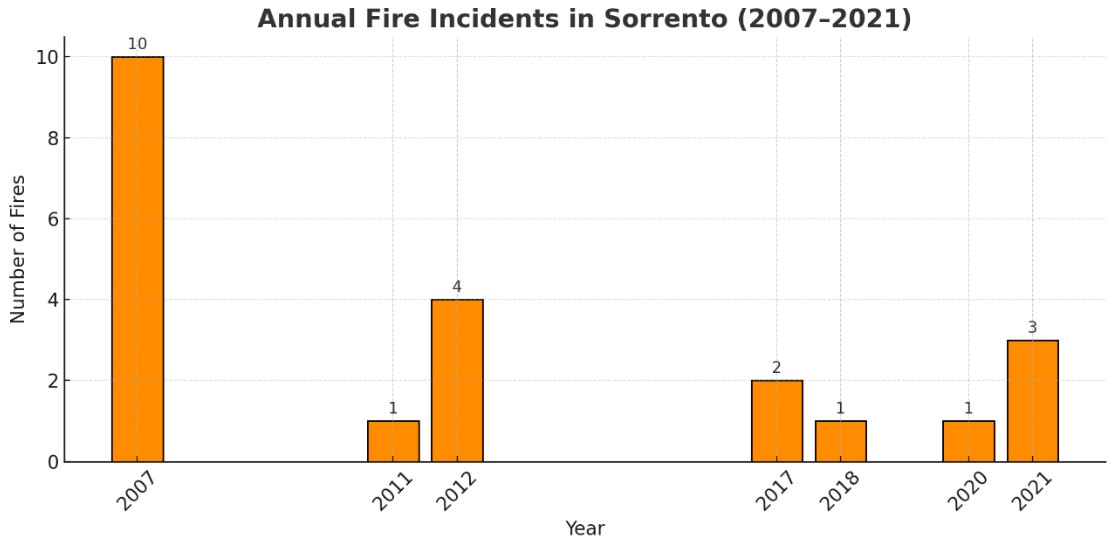


Figure 2.2.2: Number of recorded fires per year in Sorrento area from 2007-2021. Source: the Istituto Nazionale di Statistica (ISTAT)

Given Sorrento's prominence as a summer tourist destination, developing robust adaptation strategies—including enhanced fuel management, early-warning systems, and public awareness—is essential to reduce future wildfire vulnerability under evolving climate conditions. Proactive adaptation strategies are essential to mitigate fire risks during peak seasons. These measures should include enhanced early warning systems, visitor education, and improved land management practices. Implementing such approaches will help protect both residents and tourists while preserving the area's natural and economic resources.

The deep engagement stakeholder involved in this case study is STRESS-SCARL, an association of universities, private companies of the construction sector, engineering companies and other research organizations. STRESS-SCARL has already been engaged in deep communication with local stakeholders, including the municipality of Sorrento, for multiple years in the context of the EU Horizon

2020 TREEADS project (A Holistic Fire Management Ecosystem for Prevention, Detection and Restoration of Environmental Disasters). This is reportedly a difficult task, as fire prevention is only one out of many priorities for most of the local actors.

Given that unmitigated wildfire risk will exceed social and economic acceptability and challenge legislation regarding protected nature, the stakeholders' overarching policy question is to evaluate the costs and benefits of different adaptation options to reduce the likelihood of wildfires and mitigate their damage to sensitive economic and natural systems. Detailed sub-questions include: (a) what are the risks under current and future scenarios? (b) how to adapt efficiently to increasing wildfire risks in a holistic way such that the impacts on human and natural systems, e.g. buildings, infrastructure, high-value agriculture, and protected forests are minimized; and (c) what are the costs and benefits of different management practices under current and future conditions?

2. Current and future risk

Climate models consistently forecast warmer and drier conditions across southern Europe, including Campania. Faggian et al. (2018) project a 20 % or greater increase in fire danger during summer in most of Italy by 2050 under the RCP4.5 and RCP8.5 scenarios. Similarly, Dupuy et al. (2020) estimate increases in fire-prone days and burned areas of 2–4 % and 5–50 % per decade, respectively, across southern Europe—a trend directly applicable to Campania's vegetation regimes. Regional projections further suggest that extreme weather conducive to wildfires, such as heatwaves and prolonged droughts, are likely to become more frequent, intensifying fire risk during the peak summer months. Every year wildfire occurs in the region, e.g. between 2008 and 2019 more than 10,000 fires were reported by the Fire Authorities of the Campania region, the number of large fires is increasing. Many of these fires can be attributed to human activities, including controlled burns of agricultural areas.

Campania's diverse landscape—ranging from pine forests and Mediterranean scrub to agricultural land—renders it particularly susceptible to climate-driven fire regimes. A hybrid GIS AHP model applied within the region (Busico et al., 2019) classified zones into risk tiers and predicted future hazard escalation linked to climatic and land-cover factors, achieving strong correlation with historical fire events. Despite clear trends, significant uncertainties persist. Additionally, over 90 % of European wildfires are human-caused, and Campania's high summer population and tourism activity elevate ignition risk. Local differences in fuel management, land-use patterns, and fire prevention significantly influence outcomes.

To evaluate the current wildfire risk across the Campania region, especially Sorrento, a data-driven approach is employed through the application of a machine learning model. This model generates a spatially explicit daily fire risk map informed by historical fire occurrence data. A range of predictor variables is integrated into the model, including meteorological conditions, human activity indicators, land cover types, and topographic features. The fire risk map presents the daily probability of fire ignition across the Campania region, including the Sorrento area. This probability serves as a basis for estimating the expected damage losses resulting from potential fire events in Sorrento. Based on modeling conducted using historical data, the probability of fire ignition in the Sorrento area ranges from 0.27 to 0.33 during summer months.

3. Identifying adaptation options

In general, adaptation strategies to reduce wildfire damages in Italy increasingly emphasize an integrated approach encompassing (i) grey, (ii) green, and (iii) soft forms of adaptation (Table 2.1.1). Grey adaptations include investments in physical infrastructure such as firebreaks, enhanced road networks, and communication systems to support rapid emergency response, particularly in transport and urban–wildland interface zones (Arango et al., 2025). Green measures, though less prominent, are gaining attention through ecosystem-based strategies such as landscape restoration, controlled grazing, and vegetation management to reduce fuel loads (Lovreglio, 2024).

In the case of Sorrento, Campania, soft adaptation measures are identified as the most suitable approach. A discussion with the Head of Sorrento Administration was conducted on March 11, 2025. Among the aforementioned soft adaptation strategies, the implementation of advanced monitoring programs—particularly the use of unmanned aerial vehicles (UAVs), drones—emerges as a highly preferable option. Drones provide a flexible, cost-effective, and efficient means of real-time data collection and surveillance, enabling early detection of fire outbreaks and facilitating timely response efforts.

The incorporation of drone technology into environmental monitoring frameworks presents numerous advantages, such as the acquisition of high-resolution imagery, swift coverage of extensive areas, and accessibility to remote or otherwise challenging terrains. These capabilities are especially pertinent in the context of the Sorrento Peninsula, where complex topography and heterogeneous vegetation patterns hinder the effectiveness of conventional ground-based monitoring approaches.

Table 2.1.1: Overview of adaptation measures

What adaptation options are considered in the case study	**Are the options more incremental or transformative**	
	Incremental	**Transformative**
Grey		
• Increased physical protection of assets	√	
Green		
• Optimized forest management (e.g., reduced tree density, replanting more suitable tree species).	√	√
• Fire belts	√	
• Land use change		√
Soft		
• Improved risk assessment – improved fire risk management (prevention, preparedness, response)	√	
• Enhanced monitoring programs & technologies	√	
• Insurance schemes	√	
• Restriction of access to risk-prone areas (e.g., tourists are prohibited from entering protected natural areas under high-risk fire conditions to prevent a fire starting)	√	

4. Methodology: assessment of adaptation options

4.1 Expected damage loss and cost benefit analysis

To evaluate the economic implications of fire events, a cost-benefit analysis was performed using a damage estimation formula similar to that used in the insurance sector. The formula calculates expected damage or loss, $E[loss]$, as the product of fire probability and the sum of reconstruction costs and gross profit losses. Specifically, for each asset type, unit quantities and reconstruction values were multiplied, while operational downtime was used to estimate lost profits. Specifically, insurance providers determine the baseline coverage for fire incidents using a standardized formula, as outlined below:

Equation 1. Expected loss of fire conditional to climate scenarios and time horizon

$$E[loss] = \{\boldsymbol{p}\} \times \left\{\left(\sum_{i=1}^{I} a_i \times c_i\right) + \left(\sum_{i=1}^{I} t_i \times \pi_i\right)\right\}$$

Equation 2. Expected benefit from preferred adaptation strategy

$$E[B] = E[loss] - AC$$

In equation 1, $\{\boldsymbol{p}\}$ stands for the probability of fire which derived from risk map across three pathways—SSP1, SSP2, and SSP3—evaluated over five-time horizons, a_i stands for the unit measure of the asset at risk i (e.g., vineyard, restaurant, etc.,) c_i is the dollar value of the reconstruction cost, t_i stands for the operational delay time due to reconstruction, and π_i stands for the gross profit loss due to reconstruction time. Equation 2 describes the calculation of the benefit, $E[B]$, of the preferred adaptation strategy, AC is the implementation cost of the preferred adaptation strategy.

To calculate p, a modular wildfire modelling framework was developed to assess wildfire risk in Europe under both historical and future climate conditions. The analysis is restricted to the fire season (June–October) and employs multiple climate datasets, including ERA5-Land reanalysis (2008–2023) for historical evaluation and bias-corrected CLIMEX2 projections (1991–2010 and 2021–2100) for future scenario analysis (Asselin, 2024). Central to the framework is a machine learning (ML)-based fire probability model trained on wildfire observations from the EFFIS database and 23 predictors encompassing climatic, land cover, topographic, and anthropogenic variables. Among several algorithms tested, the Random Forest classifier demonstrated the highest predictive skill and was therefore selected. This model generates daily fire risk maps, from which the probability of wildfire occurrence is derived. This modelling approach was originally developed and applied within the ACCREU project (Deliverable D2.4: *Impacts on ecosystems & biodiversity*).

To integrate modelled fire probabilities into the economic appraisal, a baseline threshold of 0.5 was applied, with exceedance frequency over a 20-year horizon interpreted as the likelihood of occurrence. This likelihood, multiplied by the baseline probability, yields an adjusted factor used to scale the appraisal and capture expected wildfire impacts. Risk projections are assessed for four-time horizons (2021–2040, 2041–2060, 2061–2080, 2081–2100), although detailed climate data are available only for the historical baseline and the Distant Future under SSP1 and SSP3, with intermediate periods requiring extrapolation. Figure 2.1.3 shows the evolution of global mean surface temperature, where historical warming continues into the 21st century, stabilizing under SSP1-2.6 while increasing steadily under SSP2-4.5 and SSP3-7.0.

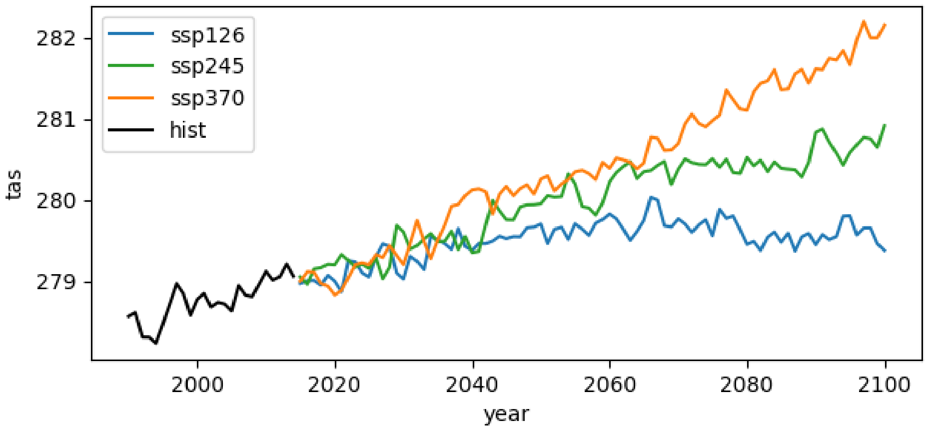


Figure 2.1.3: Evolution of the global mean surface temperature for the different climate scenarios.

To address this gap, a temperature-based scaling approach is applied. For the Distant Future (2081–2100), the likelihood of wildfire occurrence under SSP2 is estimated using a weighted interpolation between SSP1 and SSP3, based on their respective temperature differences, as show in Figure 2.1.3. The weighting factor, α, is calculated as:

Equation 3. weighting factor α

$$\alpha = \frac{T_{ssp3} - T_{ssp2}}{T_{ssp3} - T_{ssp1}}$$

Using the 2081-2100 temperature values from the MPI-ESM1-2-LR model:

Equation 4. weighting factor α conditional to 2081-2100 temperature

$$\alpha = \frac{281.7 - 280.6}{281.7 - 279.5} = 0.5$$

The scaled probability for SSP2 is then estimated as:

Equation 5. Scaling

$$P_{SSP2,2090} = \alpha \cdot P_{SSP1,2090} + (1 - \alpha) \cdot P_{SSP3,2090}$$

For intermediate horizons such as Mid-Century (2041–2060), the scaled probability is adjusted proportionally to the temperature increase relative to the historical baseline, assuming a linear relationship between temperature rise and fire probability. This is done as well for the other time horizons.

Equation 6. Scaling

$$P_{ssp1,2050} = P_{hist} + \left(P_{ssp1,2090} - P_{hist}\right) * \frac{T_{ssp1,2050} - T_{hist}}{T_{ssp2,2090} - T_{hist}}$$

To showcase the assessment, a simulated fire spread modelling is done on potential fire ignition points on a particular summer day in August in the area close to Sorento Peninsula. Fire spread modelling is employed to simulate fire dynamics and predict the most probable pathways of fire propagation, taking into account factors such as terrain elevation, fuel conditions, and wind patterns. The simulation is conducted using ignition points that are conditioned on these variables. The elevation map provides topographic data for the study domain.

To assess the financial impact of the fire damage, we identify assets within the affected area, including land use and facilities. This identification process involves overlaying the burnt area with land cover data. Several assets identified through the overlaying process area farmland, forest, vineyard, bar, café, church, hotels, restaurants, shops, etc.

4.2 Evaluation criteria adaptation options

Selecting adaptation options is done by evaluating the options against evaluation criteria used in the cost-benefit analysis of adaptation options shown in Table 2.1.2.

Table 2.1.2: Evaluation criteria used in the cost-benefit analysis of the adaptation options.

What appraisal criteria are considered?		**How are the criteria measured?**		
What costs are considered?		Qualitative	Quantitative	Monetized
- Operational costs				√
- Investment costs				√
What direct benefits are considered?				
- Reduction in expected annual risk damages			√	√
- Reduction in forest tree loss			√	
- Reduction in biodiversity loss		√		
What co-benefits?				
- Economic				
- Social				
- Environmental			√	
Are you considering distributional effects?	No			

The appraisal framework considers both costs and benefits across qualitative, quantitative, and monetized dimensions. On the cost side, the analysis accounts for operational and investment costs, both of which are measured in monetized terms. Direct benefits include the reduction of expected annual risk damages, assessed both quantitatively and monetarily, while the reduction in forest tree loss is measured quantitatively, and biodiversity loss is evaluated qualitatively. Co-benefits are also recognized, with environmental benefits assessed quantitatively, though no explicit economic or social co-benefits are detailed. Finally, the framework specifies that distributional effects are not considered in the appraisal.

5. Results

5.1 Expected Damage Loss and Cost Benefit Analysis

As mentioned in the methodology section, in this study, we apply a simulated fire spread model to potential ignition points on a summer day in August in the vicinity of the Sorrento Peninsula. The model integrates terrain elevation, fuel characteristics, and wind patterns to predict the most probable pathways of fire propagation, with ignition points conditioned on these variables and supported by topographic data from an elevation map. To estimate the financial consequences of fire damage, we further identify and map assets within the simulated burn area by overlaying fire-affected zones with land cover data. This process highlights the vulnerability of both environmental and socio-economic assets, including farmland, forests, vineyards, and community infrastructure such as cafés, churches, hotels, restaurants, and shops, thereby providing a foundation for evaluating expected damages and potential adaptation benefits. We conduct a simulation that closely replicates real-world conditions in order to estimate the expected damage losses and the anticipated benefits of the selected adaptation option. The outcomes of the fire spread modeling process are illustrated in Figure 2.1.4.

Figure 2.1.4: Simulated burnt area resulting from fire spread modelling

To conduct a showcase for damage cost assessment process, the area close to Sorento Peninsula is selected. Figure 2.1.5 shows the selected burned area and assets within the burnt area.

Figure 2.1.5: Selected burnt area and identified assets within the burnt area.

Based on the damage cost assessment (see equation 1), the projected financial loss under a scenario of complete asset destruction (i.e., 100% damage rate (loss) and 100% avoided damage rate (benefit)) is estimated at approximately €355.6 million. This total comprises a reconstruction cost of €354.5 million and an associated gross profit loss of €1.15 million. Among the various asset categories analysed, residential buildings account for the largest share of the reconstruction costs, estimated at €328 million. This is followed by forests (€5.5 million) and recreational infrastructure, including soccer fields (€6.7 million) and sport centres (€4.5 million). With respect to gross profit losses, orchards and farmland represent the most significant contributors, with estimated losses of €365,000 and €140,000, respectively.

The assessment of adaptation benefits under climate change scenarios to determine $\{\boldsymbol{p}\}$ is carried out across three pathways—SSP1, SSP2, and SSP3—evaluated over five-time horizons. As indicated in Equation 1, the inclusion of climate change scenarios incorporates the probability of wildfire occurrence $\{\boldsymbol{p}\}$ into the benefits assessment. The corresponding wildfire probability risk outcomes for each scenario and time horizon are summarized in Table 2.1.3.

Table 2.1.3: Wildfire probability under different climate scenarios and time horizons

SSP1					
	Historical (1991-2010)	Near Future (2021-2040)	Mid Century (2041-2060)	Far Future (2061-2080)	Distant Future (2081-2100)
Likelihood Fire risk > 0.50	0.530				
Temperature (K)	278.7	279.3	279.6	279.7	279.5
Probability $\{\mathbf{p}\}$	0.265	0.270	0.273	0.274	0.272
SSP2					
	Historical (1991-2010)	Near Future (2021-2040)	Mid Century (2041-2060)	Far Future (2061-2080)	Distant Future (2081-2100)
Likelihood Fire risk > 0.50	0.530				
Temperature (K)	278.7	279.4	279.9	280.4	280.6
Probability $\{\mathbf{p}\}$	0.265	0.277	0.286	0.295	0.298
SSP3					
	Historical (1991-2010)	Near Future (20212040)	Mid Century (2041-2060)	Far Future (2061-2080)	Distant Future (2081-2100)
Likelihood Fire risk > 0.50	0.530				0.649
Temperature (K)	278.7	279.5	280.2	280.8	281.7
Probability $\{\mathbf{p}\}$	0.265	0.281	0.295	0.307	0.325

In the case of Sorrento, Italy, soft adaptation measures are identified as the most suitable approach. Among these soft adaptation strategies, the implementation of advanced monitoring programs—particularly the use of unmanned aerial vehicles (UAVs), drones—emerges as a highly preferable option. Drones provide a flexible, cost-effective, and efficient means of real-time data collection and surveillance, enabling early detection of fire outbreaks and facilitating timely response efforts.

The incorporation of drone technology into environmental monitoring frameworks presents numerous advantages, such as the acquisition of high-resolution imagery, swift coverage of extensive areas, and accessibility to remote or otherwise challenging terrains. These capabilities are especially pertinent in the context of the Sorrento Peninsula, where complex topography and heterogeneous vegetation patterns hinder the effectiveness of conventional ground-based monitoring approaches. Given the market cost of advanced drone systems—ranging from €50,000 to over €200,000—the investment in drone-based wildfire surveillance is financially justifiable.

Figure 2.1.5 show the delineated burn area and corresponding assets which are identified through overlaying land cover data. These assets include farmland, forests, vineyards, residential and commercial buildings, and various recreational facilities. Assuming complete asset destruction, the total projected loss counts approximately €355.6 million—comprising €354.5 million in reconstruction costs and €1.15 million in gross profit losses. Residential properties account for the largest share (€328 million), followed by forests and sports infrastructure. Using equation 1 and 2, Table 2.1.4 shows the expected benefit from UAVs investment for different climate scenarios and time horizons.

Table 2.1.4: Expected benefit of UAVs investment for different climate scenarios and time horizons (in million Euro)

SSP1				
Adaptation Strategy	Near Future (2021-2040) $\{p\} = 0.270$	Mid Century (2041-2060) $\{p\} = 0.273$	Far Future (2061-2080) $\{p\} = 0.274$	Distant Future 2081-2100 $\{p\} = 0.272$
UAVs	95.52 – 95.67	96.58 – 96.73	96.93 – 97.08	96.22 – 96.37
SSP2				
	Near Future (2021-2040) $\{p\} = 0.277$	Mid Century (2041-2060) $\{p\} = 0.286$	Far Future (2061-2080) $\{p\} = 0.295$	Distant Future 2081-2100 $\{p\} = 0.298$
UAVs	98.00 – 98.15	101.19 – 101.34	104.38 – 104.53	105.44 – 105.59
SSP3				
	Near Future (2021-2040) $\{p\} = 0.281$	Mid Century (2041-2060) $\{p\} = 0.295$	Far Future (2061-2080) $\{p\} = 0.307$	Distant Future 2081-2100 $\{p\} = 0.325$
UAVs	99.41 – 99.56	104.38 – 104.53	108.63 – 108.78	115.01 – 115.16

Notes: As outlined in the methodology section, for simplicity and due to lack of data on the effectiveness of the intervention, the analysis shown above assumes a 100% avoided damage rate, serving as the counterfactual to a 100% damage rate for the purpose of loss estimation. If one instead assumes a lower (and arguably more realistic rate) of avoided damage, e.g. 50-60%, the damage value will similarly change.

The results presented in the table illustrate the effectiveness of UAV-based adaptation strategies under different Shared Socioeconomic Pathways (SSPs) and time horizons. Under SSP1, which represents a more sustainable development trajectory, the expected benefit from having UAV-based strategy remain relatively stable across all future periods, ranging from approximately 95.52–95.67 in the near future (2021–2040) to 96.22–96.37 in the distant future (2081–2100), with only marginal increases observed. In contrast, SSP2, characterized by a “middle of the road” scenario, shows a gradual rise in the expected benefit, beginning at 98.00–98.15 in the near future and increasing steadily to 105.44–105.59 by the end of the century. The most significant growth is observed under SSP3, which reflects a more fragmented and unsustainable development pathway. Here, the expected benefit rises markedly from 99.41–99.56 in the near future to 115.01–115.16 in the distant future. These results suggest that while UAV adaptation strategies are cost efficient across all scenarios.

5.2 Evaluation adaptation options

In response to these risks, soft adaptation measures—particularly the use of unmanned aerial vehicles (UAVs)—are identified as the most suitable approach for the Sorrento context. Drones offer a cost-effective and efficient solution for real-time monitoring, enabling early detection and faster response to wildfire outbreaks. Their capabilities, including high-resolution imaging and the ability to access remote or rugged terrain, make them especially valuable in Sorrento’s complex landscape. This technology addresses key limitations of conventional ground-based monitoring methods. The integration of UAVs into wildfire risk management enhances preparedness and situational awareness. Given that advanced drone systems range from €50,000 to €200,000, the investment is considered both technically viable and economically justified. Though UAVs are the best solution but in there are several limitations that are discussed in the following sections. Therefore, additional adaptation strategies may be considered, as outlined in Table 2.1.1. These include enhancing the physical protection of assets through the strategic placement of fire stations and equipment, as well as limiting access to high-risk areas by restricting new development within zones prone to elevated hazards.

6. Barriers and conditions for implementation

The deployment of drones as a singular adaptation strategy for wildfire management in Sorrento, Campania, is subject to considerable constraints. Although drones provide valuable capabilities in terms of surveillance, early fire detection, and spatial mapping of high-risk zones, they are inherently limited in their capacity to directly suppress wildfires or execute preventive land management interventions. The physical characteristics of the region, including steep topography, dense vegetation, and a complex urban–wildland interface, further impede the operational efficiency of drone technology. Moreover, drone performance is heavily influenced by meteorological conditions, with operational duration constrained by limited battery life and range. Their effective utilization also depends on technical expertise, robust infrastructure, and the integration of advanced data processing systems. In addition, regulatory frameworks must accommodate flexible and timely drone deployment, particularly in the context of emergency scenarios and airspace restrictions. While advancements such as long-endurance drone platforms and AI-enhanced fire modelling hold promise, the integration of drone technology within a broader adaptation framework—incorporating ecological measures and community-based approaches—remains critical for comprehensive and effective wildfire resilience.

Other factors may hinder the implementation of the adaptation options described in Section 3 (Table 2.1.1). Firstly, physical protection is costly and only affects the fire risk very locally. These interventions are therefore only applicable to particularly vulnerable assets. Large-scale changes in land use and forest management are likely to be resisted by authorities, stakeholders and practitioners, representing a very diverse group with highly varying priorities, including political and economic. Not all tree species are suitable for every location, and in addition some of the main forested areas in the region are protected, limiting the applicability of this adaptation option. Finally, forest management is costly, and forest managers may not be aware of potential adaptation strategies or will resist them because they are accustomed to certain practices such as growing local species that may not be ideal for wildfire resilience. There could also be a lack of trained personnel to carry out these adaptation options, e.g. cleaning the forest for dead wood, and hiring educated staff can be expensive. Table 2.1.5 presents a summary of the barriers associated with the implementation of the UAV-based adaptation strategy and organizes these challenges according to a defined set of evaluation criteria.

Table 2.1.5: Barriers for implementation of adaptation strategies.

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governance and institutional (G).		
Strategy:	Barriers:	Cat:
Unmanned aerial vehicles (UAVs) or also know as drones	• The region's challenging physical features—steep terrain, dense vegetation, and a complex urban–wildland interface—further reduce the effectiveness of drone operations. • Drone performance is also influenced by weather conditions and constrained by operational factors such as battery life and flight range. • Effective deployment depends on the availability of skilled personnel, supporting infrastructure, and sophisticated data processing capabilities. • Regulatory issues, particularly those concerning emergency response and airspace restrictions, must be addressed to enable	• K, P, B • K, P, B • F, H, G • S, G

7. Conclusion and reflections on adaptation strategies towards wildfires

One of the things that stands out, when wildfires are concerned, is that these hazards occur at landscape scale, and hence the effectiveness of most stationary adaptation measures are constrained to the local areas, where they are present. The most effective responses at larger scales may therefore be to reduce the probability of ignition in general and to set up comprehensive monitoring and response schemes to ensure that the fires that break out are detected immediately and contained as soon as possible, before significant damages occur, or the fire goes out of control. In a sense, the most efficient adaptation towards wildfires is therefore to limit global warming to a minimum.

Interestingly, afforestation is often highlighted as a nature-based solution that facilitates both climate change adaptation to water stresses (droughts and floods) and mitigation of climate warming. As a result, in some places it is likely that increased afforestation may in fact in the short term increase the risk of large wildfires taking place by increasing the availability of combustible fuels. To resolve this, it may here be necessary to consider (more or less) "temporary" adaptation solutions as a trade-off between mitigation and different adaptation objectives.

Case study 2.2 – Adaptation options for reduction of forest fire
Partner: DTU
Spatial scale: Local, Leksand in Sweden
Stakeholder: Forest owner and management company (Miljö och Skog i Leksand Aktiebolag)

1. Decision context

Sweden is the second most forested country in Europe, with forest covering nearly 70% of the total land area (The Royal Swedish Academy of Agriculture and Forestry [KSLA], 2024). These forests are vital for the Swedish economy by supporting key industries such as timber and biofuel, positioning Sweden as one of the leading exporters of forest industry goods globally. Beyond their economic value, forests support biodiversity by offering a habitat for countless species and maintaining essential natural processes such as water regulation, pollination, nutrient cycling, soil stabilization and climate regulation. Furthermore, the forests have important cultural value in Sweden, where the concept of "Allemansrätten" (the Right of Public Access to Nature) is a deeply rooted tradition, setting the country apart from many others (Naturvårdsverket, 2024).

A large increase in wildfire risks is expected in the Nordic countries because of climate change. The largest and most intense wildfires typically occur in rural areas facing fiscal constraints due to sparse population, limiting funding for prevention and suppression efforts, resulting in resource shortages and low levels of preparedness. Additionally, the remoteness of these areas results in longer detection and response times, critical factors in preventing fires from escalating (Eriksson, Sjöström, & Plathner, 2024).

This case study focuses on Leksand, a municipality in central Sweden that is part of the province of Dalarna. The forests around Leksand, like much of Dalarna, are a mix of coniferous trees such as pine and spruce, along with some deciduous trees like birch. These forests play an important role in the local ecosystem, providing habitat for wildlife and a resource for timber. In the summer of 2018, several wildfires ignited, burning a total area of 25.000 hectares. The province of Dalarna was one of the most affected areas (MSB, 2019).

The deep engagement stakeholder in this case study is Miljö och Skog i Leksand Aktiebolag, a forest management company in Leksand whose head is a forest operator and a forest owner. Forest vehicles operated by forest managers can sometimes ignite wildfires, for example, when metal components hit bare rock or large stones and produce sparks, especially under warm and dry conditions, which was the case in 2018 and is expected to become more common in the future (MSB, 2015). Because forest machines travel long distances to transport logs and there is a lag from a spark to the fire, the vehicle may already be at another location when the fire starts. As a result, there is no immediate response to extinguish the fire at an early stage, making it harder to prevent the fire from spreading and thus prevent damage from occurring.

Given this context, the stakeholder's policy question is to determine which adaptation options are most effective in reducing the likelihood of wildfires and specifically, what their associated costs and benefits are.

2. Current and future risk

Rising global temperatures and changing weather patterns have increased the frequency and intensity of dry periods in Sweden, increasing the risk of forest fires. Sweden has experienced significant forest fires in recent years, especially during the heatwave of 2018, which also affected the Dalarna province. The Swedish Contingency Agency (MSB) predicts that periods of high fire risk in Sweden will extend by several weeks throughout this century, with the key drivers of this trend being increased evaporation, faster drying soil, and longer dry periods, which further intensify the drying process and thereby increase the risk of wildfires (MSB, 2023).

According to MSB (2023), the duration of the fire risk season varies across Sweden, with the most severe impacts expected in the southeast. Further, the extent of this increase depends on future climate scenarios. However, across all climate scenarios (RCP2.6–RCP8.5), a significant increase in the fire season is projected. In the province of Dalarna, located in central Sweden, the fire risk period is expected to extend by 10–50 days compared to historical numbers from 1971–2000. Coniferous trees, which dominate the study area, are more flammable due to their resin content and the accumulation of dry needles on the forest floor. Without adaptation, the economic and social costs of wildfire risks and damage can exceed acceptable thresholds.

While these projections indicate a significant increase in the risk of future wildfires, several key uncertainties remain. The projections are based on weather parameters, but the exact level of warming and the pattern of weather changes remain uncertain. Warmer and drier summers are expected in Sweden, but meanwhile, higher levels of precipitation are expected too (MSB, 2023), which may help mitigate wildfire risk, creating a complex and uncertain balance of factors. However, the extent of increased precipitation remains uncertain, with projections indicating larger increases in northern Sweden and along the southwest coast (Skogsstyrelsen, 2020). Furthermore, these increases are expected to be more significant in the wintertime, when the overall risk of wildfires is lower. The influence of demographic factors on wildfire risks adds an extra layer of complexity. The risk of fire ignition is strongly correlated with high population density, primarily caused by human activity (Sjöström & Granström, 2023). Meanwhile, sparsely populated areas are associated with longer response times due to fewer resources, possibly leading to larger and more severe fires.

To reduce the risk of forest fires, a six-point Fire Weather Index (FWI) is used by MSB to assess wildfire risk levels, inform about fire risk, and determine which associated safety measures should be applied during forestry operations (MSB, 2025).[4] The Fire Weather Index is available online and as a smartphone application, providing risk maps with FWI values for the next six days across Sweden. If the index is above three, the principal, typically the forest owner, must inform the operator of the forest vehicles of the required actions. At this level, two additional fire extinguishers must be added to the four already onboard, with costs covered by the vehicle owner. If the index is four or above, fireguards are required. The number depends on the work: one guard for a harvester (moving less than 1 km) and three for a forwarder (moving longer distances). The principal is responsible for paying the guards, while the forest operator is responsible for hiring them. A course must be passed to qualify as a fire guard. Because the reliable fire index forecast is six days, forest operators may struggle with finding guards on short notice. Since these vehicles involve large investments, operators prefer to cut on other activities, such as thinning, rather than having the vehicles not operate, and thus workers may be relocated. This, however, involves an opportunity cost and a fire risk.

3. Identifying adaptation options

The adaptation options for reducing wildfire damages and enhancing resilience to wildfire focus on three main categories: (i) grey, (ii) green, and (iii) soft forms of adaptation (Table 2.2.1), and can be classified as transformative if they involve fundamental changes to the landscape or incremental, based on the definition by Kates et al. (2012). In this case study, (i) grey adaptation options include transformative options, such as creating firebreaks. While limited research exists on firebreaks, significantly more research has been conducted on fuel breaks. The two are closely related: fuel breaks involve areas with reduced vegetation, while firebreaks are areas where fuel is removed completely, such as roads (Gannon et al., 2023). Overall, fuel breaks have been shown to be effective, especially when they involve more intense fuel reduction and are well maintained, as older fuel breaks tend to be less effective in mitigating wildfires (Urza et al., 2023). (ii) Green adaptation options focus on forest management, such as reducing tree density, planting fire resistant tree species such as deciduous trees and birch trees, which do not burn easily, particularly on old arable land, and prescribed burning that requires large-scale forest owners with more than 5.000 hectares to burn five percent of annual rejuvenation areas on fire-prone land to prevent uncontrolled fires. Reducing tree density and prescribed burning are incremental adaptation options, while planting fire resistant tree species is a transformative and costly adaptation option rarely used (Chung, 2015; Keane, 2013). (iii) Soft adaptation options

[4] The Fire Weather Index is available at https://www.msb.se/sv/om-msb/informationskanaler/appar/brandrisk-ute.

include (i) using fire risk app to improve knowledge and readiness, (ii) training programs by MSB and the Swedish Forest Agency for fireguards, firefighters, incident commanders, private forest owners, forest managers and forest machine drivers, and (iii) employing fireguards for surveillance. These soft adaptation options are considered incremental.

Table 2.2.1: Overview of adaptation options

Adaptation Option	Incremental (I) or Transformative (T)
(i) *Grey*	
Creating firebreaks	T
(ii) *Green*	
Reducing tree density	I
Planting fire resistant tree species	T
Prescribed burning	I
(iii) *Soft*	
Use of fire app with fire risk index to improve knowledge and readiness	I
Training programs for fireguards and other stakeholders	I
Employing fireguards for surveillance	I

4. Assessment of adaptation options

4.1 Methodology

We conduct a simulation designed to closely approximate the actual conditions of private forests within the study area to evaluate the costs and benefits of different adaptation options. Table 2.2.2 lists and describes the adaptation options that are simulated.

In this case study, we do not conduct a costs and benefits analysis of the soft adaptation options, i.e. use of fire app with fire risk index to improve knowledge and readiness, training programs for fireguards and other responsible, and employing fireguards for surveillance (Table 2.2.1). While these strategies improve knowledge and preparedness, they do not directly influence the physical spread of fire. Our modeling framework focuses on strategies that directly influence fire dynamics, which implies that these soft options cannot be included in the model. Nonetheless, their benefits, including improved awareness and safety for forest workers, remain important, though they are more appropriately valued through qualitative assessments.

Table 2.2.2: Description of adaptation options

Adaptation option		Description	Adapted area (ha)	% of total area adapted
Creating firebreaks	Option 1	Creating an artificial fuel-free gap running diagonally through the stakeholder's forest	6,00	24
	Option 2	Creating an artificial fuel-free gap surrounding the stakeholder's forest	16,00	64
Reducing tree density		Reducing crown connectivity and fuel continuity to decrease fuel availability	25,00	100
Planting fire resistant trees		Planting fire resistant tree species so that the fire spread slowly or does not spread	25,00	100
Prescribed burning		Burning some part of the forest through controlled, low-intensity fires so that the surface fuel load is reduced for fire season	7,50	30

Firebreaks, created as artificial fuel-free gaps, are applied to an area of 6 ha running diagonally through the stakeholder's forest (Option 1), and an area of 16 ha surrounding the stakeholder's forest to prevent fire crossing into/out of the property (Option 2), corresponding to 24% and 64% of the total area, respectively. The replacement of existing species with fire resistant tree species was implemented across the entire 25 ha, ensuring full coverage of the study area. Prescribed burning, aimed at reducing fuel load prior to the fire season, was applied to 7.5 ha (30% of the area). Finally, reducing tree density to lower biomass and fuel availability was also implemented over the full 25 ha (100%). The purpose of this simulation is to provide a structured basis for assessing outcomes under different adaptation options. The overall analysis is illustrated in Figure 2.2.1.

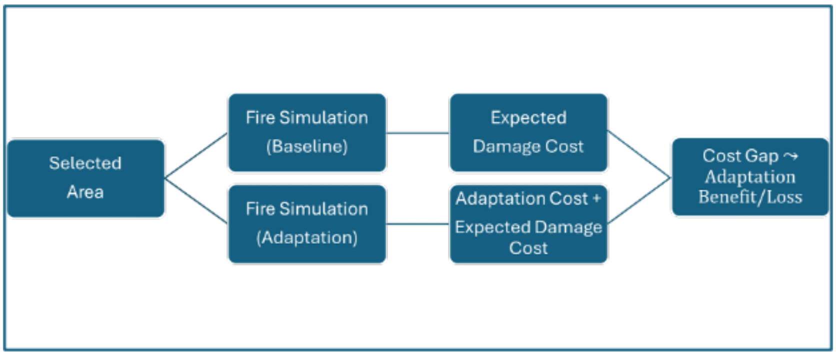


Figure 2.2.1: Structure of the cost-benefit analysis of adaptation options

The process begins with the selection of a specific study area, which is then analyzed under two types of fire simulation scenarios: a baseline scenario without adaptation and a scenario with adaptation. In the baseline scenario, the outcome is the expected monetized damage resulting solely from wildfire. In the adaptation scenario, both the cost of implementing the adaptation option and the expected residual damage costs from wildfire are considered. Finally, the difference in costs between the two scenarios represents the adaptation benefit or loss, allowing stakeholders to determine whether adaptation options are financially cost-effective.

The fire simulation is conducted using a multi-scale probabilistic fire spread model that integrates the ForeFire-Climate model developed by Filippi et al. (2014) with the six-point Fire Weather Index (FWI) proposed by MSB (2025). The analysis is applied to a typical 25-hectare privately owned forest to simulate wildfire dynamics and to predict the spatial and temporal progression of fire spread under scenarios with and without the implementation of an adaptation option. This predictive framework assesses wildfire risk by incorporating key environmental and meteorological parameters, including temperature, wind speed and direction, relative humidity, vegetation characteristics, and records of historical fires. By combining real-time meteorological inputs with long-term climate projections, the model produces high-resolution fire danger maps tailored to Swedish landscapes.

In assessing the benefits, we evaluate the avoided expected annual damages from wildfires, specifically in terms of the reduced loss of forest resources. The analysis considers progressively increasing levels of warming—represented by scenarios SSP1-2.6, SSP2-4.5, and SSP3-7.0—across multiple temporal horizons: Historical (1991-2010), Near Future (2021-2040), Mid Century (2041-2060), Far Future (2061-2080), and Distant Future (2081-2100). Under a business-as-usual scenario, wherein no adaptation options are implemented, it is assumed that the stakeholder's entire forested area has been affected by wildfire damage. To calculate the wildfire expected damage costs and benefits with or without adaptation option we use the following equations:

Equation 7. Expected damage cost given adaptation option a

$$E[WC(a)] = p \times \{area_1 \times y \times \pi\} + \boldsymbol{c}$$

Equation 8. Expected benefits from adaptation option a

$$E[B(a)] = p \times \{area_0 \times y \times \pi\} - E[WC(a)]$$

where WC denotes the expected wildfire cost under the adaptation option a, p denotes the probability of a fire occurrence, $area_1$ and $area_0$ corresponds to the total burned area in hectares with and without adaptation. The variable y denotes the timber forest productivity (volume per hectare) and π denotes the farm gate price of timber. The vector $\boldsymbol{c}$ captures the costs associated with adaptation, including investment (construction) costs, revenue losses attributable to adaptation options, and operational expenses as described in Annex C – CS2.2.

To calculate the wildfire risk probability p , a modular wildfire modelling framework was developed to assess wildfire risk in Europe under both historical and future climate conditions. The analysis is restricted to the fire season (June–October) and employs multiple climate datasets, including ERA5-Land reanalysis (2008–2023) for historical evaluation and bias-corrected CLIMEX2 projections (1991–2010 and 2021–2100) for future scenario analysis (Asselin, 2024). Central to the framework is a machine learning (ML)-based fire probability model trained on wildfire observations from the EFFIS database and 23 predictors encompassing climatic, land cover, topographic, and anthropogenic variables. Among several algorithms tested, the Random Forest classifier demonstrated the highest predictive skill and was therefore selected. This model generates daily fire risk maps, from which the probability of wildfire occurrence is derived. This modelling approach was originally developed and applied within the ACCREU project (Deliverable D2.4: *Impacts on ecosystems and biodiversity*).

To integrate modelled fire probabilities into the economic appraisal, a baseline threshold of 0,5 was applied, with exceedance frequency over a 20-year horizon interpreted as the likelihood of occurrence. This likelihood, multiplied by the baseline probability, yields an adjusted factor used to scale the appraisal and capture expected wildfire impacts. Risk projections are assessed for four time horizons– Near Future (2021–2040), Mid Century (2041–2060), Far Future (2061–2080), and Distant Future (2081–2100)–although detailed climate data are available only for the historical baseline and the Distant Future under SSP1 and SSP3, with intermediate periods requiring extrapolation. Figure 2.2.2 shows the evolution of global mean surface temperature, where historical warming continues into the 21st century, stabilizing under SSP1-2.6 while increasing steadily under SSP2-4.5 and SSP3-7.0.

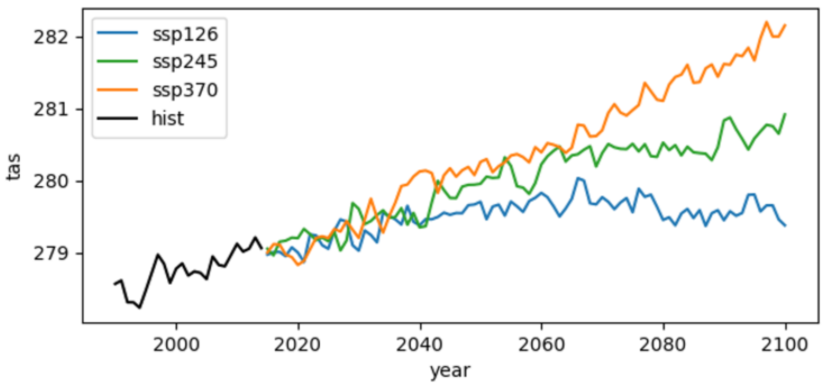


Figure 2.2.2: Evolution of the global mean surface temperature for different climate scenarios. Note: The blue, green, yellow, and black lines represent the climate scenarios SSP1-2.6, SSP2-4.5, SSP3-7.0, and historical, respectively.

To address this gap, a temperature-based scaling approach is applied. For the Distant Future (2081–2100), the likelihood of wildfire occurrence under SSP2 is estimated using a weighted interpolation between SSP1 and SSP3, based on their respective temperature differences, as shown in Figure 2.2.2. The weighting factor, α, is calculated as follows:

Equation 9. Weighting factor α

$$\alpha = \frac{T_{SSP3} - T_{SSP2}}{T_{SSP3} - T_{SSP1}}$$

where T_{SSP1}, T_{SSP2}, and T_{SSP3} represent the mean temperatures over Europe for the Distant Future period (2081–2100) under the SSP1, SSP2, and SSP3 scenarios, respectively.

Using the 2081-2100 temperature values from the MPI-ESM1-2-LR model, the weighting factor α is calculated as follows:

Equation 10. Weighting factor α conditional on 2081-2100 temperature

$$\alpha = \frac{281.7 - 280.6}{281.7 - 279.5} = 0.5$$

The scaled probability for SSP2 is then estimated as follows:

Equation 11. SSP2 scaled probability

$$P_{SSP2,2090} = \alpha \cdot P_{SSP1,2090} + (1 - \alpha) \cdot P_{SSP3,2090}$$

where $P_{SSP1,2090}$, $P_{SSP2,2090}$, and $P_{SSP3,2090}$ represent the scaled fire probabilities for year 2090 (representing the Distant Future) under SSP1, SSP2, and SSP3, respectively. Since SSP2 data is not directly available, we estimate $P_{SSP2,2090}$ using a weighted average of $P_{SSP1,2090}$ and $P_{SSP3,2090}$ based on α.

For intermediate horizons such as Mid-Century (2041–2060), the scaled probability is adjusted proportionally to the temperature increase relative to the historical baseline, assuming a linear relationship between temperature rise and fire probability. This is done as well for the other time horizons as follows:

Equation 12. SSP1 scaled probability

$$P_{SSP1,2050} = P_{hist} + \left(P_{SSP1,2090} - P_{hist}\right) * \frac{T_{SSP1,2050} - T_{hist}}{T_{SSP2,2090} - T_{hist}}$$

where $P_{SSP1,2050}$ and $P_{SSP2,2050}$ are the estimated scaled fire probability for SSP1 and SSP2 in 2050, respectively, $P_{SSP2,2090}$ is used as a reference for future fire probability under SSP2, P_{hist} is the historical scaled fire probability, $T_{SSP1,2050}$ is the mean temperature for SSP1 in 2050, and $T_{SSP2,2090}$ is the mean temperature for SSP2 in 2090.

To conduct a final evaluation for an adaptation option, each adaptation option is assessed through several criteria. Table 2.2.3 describes the final evaluation criteria for each adaptation option. The appraisal framework presented in the table adopts a structured approach to evaluating both costs and benefits by integrating qualitative, quantitative, and monetized criteria. In terms of costs, the analysis focuses on operational and investment expenditures, both of which are explicitly captured in monetized form to facilitate economic appraisal and comparability across alternatives. The benefits assessment encompasses both direct impacts and broader co-benefits. Direct benefits include the reduction in expected annual risk damages, which is evaluated through both quantitative indicators and monetized estimates, thereby enabling robust integration into cost–benefit analysis. Additionally, reductions in forest tree loss are assessed quantitatively.

Table 2.2.3: Evaluation criteria used in the cost-benefit analysis of the adaptation options

What appraisal criteria are considered?	How are the criteria measured?		
What costs are considered?	Qualitative	Quantitative	Monetized
- Operational costs	No	No	Yes
- Investment costs	No	No	Yes
What direct benefits are considered?			
- Reduction in expected annual risk damages	No	Yes	Yes
- Reduction in forest tree loss	No	Yes	No
What co-benefits are considered?			
- Economic	No	No	No
- Social	No	No	No
- Environmental	No	Yes	No
Are distributional effects considered? No			

Co-benefits are also considered in quantitative terms, with particular attention to environmental effects in terms of carbon emissions reduction. Although economic and social co-benefits are acknowledged, they are not operationalized within the measurement framework. Importantly, the appraisal does not explicitly consider distributional effects, implying that equity concerns and the distribution of costs and benefits across different social groups remain outside the scope of the evaluation. Overall, the framework prioritizes monetized and quantifiable outcomes while acknowledging the significance of non-monetary dimensions, thereby providing a systematic yet partial basis for decision-making.

5. Results

5.1 Cost-benefit analysis with and without adaptation in the absence of climate change scenarios

Table 2.2.4 presents the results of the forest fire simulation, illustrating how the extent of the area burned varies depending on weather scenarios, such as temperature, precipitation, wind speed, and fuel condition of the study area.

Table 2.2.4: Simulation results of adaptation options

Adaptation option		Burned area (ha)	Avoided burned area (ha)
Creating firebreaks	Option 1	10,86	14,14
	Option 2	0,00	25,00
Reducing tree density		25,00	0,00
Planting fire resistant tree species		16,44	8,56
Prescribed burning		17,52	7,48

The simulation outcomes provide quantitative insights into the relative efficacy of various adaptation options in mitigating wildfire impacts within the privately managed forest, which extends over 25 hectares. The implementation of firebreaks shows the highest effectiveness. Two types of firebreaks are tested: Option 1, a firebreak running diagonally through the stakeholder forest, and Option 2, a firebreak surrounding the stakeholder forest. With Option 1, the burned area is 10,86 ha preventing 14,14 ha of additional forest loss while with Option 2 the burned area is zero, thereby preventing all the property from being burned (25,00 ha). Reducing tree density does not reduce the damage: the burned area is 25 ha, corresponding to an avoided forest loss of zero hectares. In the case of planting new tree species, the strategy limited fire spread to 16,44 ha, corresponding to 8,56 ha of avoided burned forest. Prescribed burning restricted fire damage to 7,48 ha, mitigating the loss by 17,58 ha.

Table 2.2.5 presents the costs and benefits of each adaptation option in monetary terms. Creating firebreaks shows positive adaptation benefits with moderate adaptation costs in both options. The resulting benefits amount to €74.300 and €91.800, respectively. Firebreak Option 2 prevents the entire forest from being burned, as the firebreak surrounds the property and stops the fire from spreading inside the stakeholder's land, thus the damage cost is equal to zero. Planting fire resistant tree species involves relatively low adaptation costs and generates the second highest adaptation benefits among all options. The benefits are estimated €84.300 despite higher damage costs compared to creating firebreaks. It should also be emphasized that planting new tree species has positive spillover effects on the overall forest community because it changes the tree composition of the nearby forest properties protecting them from fire damages. This suggests that the measure is highly effective when large-scale damage can be prevented. Prescribed burning is characterized by low implementation costs, but relatively high damage costs (€137.600). Even so, the option provides positive benefits of €45.100, although they are the smallest among all adaptation options. In contrast, reducing tree density results in a loss (-€17.900). This finding suggests that under the assumptions used in this analysis, thinning is not cost-effective as a stand-alone strategy.

Table 2.2.5: Costs and benefits of adaptation options in monetary values

Adaptation option		(1) Damage costs without adaptation[1]	(2) Adaptation costs[2]	(3) Damage costs with adaptation[3]	(4) Adaptation benefits[4]
Creating firebreaks	Option 1	196.800 €	36.700 €	85.300 €	74.800 €
	Option 2	196.800 €	105.000 €	0 €	91.800 €
Reducing tree density		196.800 €	17.900 €	196.300 €	-17.400 €
Planting fire resistant tree species		196.800 €	17.000 €	95.000 €	84.800 €
Prescribed burning		196.800 €	13.600 €	137.600 €	45.100 €

[1]Without adaptation, the entire stakeholder forest of 25 ha burns, meaning the damage cost without adaptation is the same for all options (See Section 2 of Annex C CS2.2 for the calculation).
[2]The adaptation costs in column 1 consist of expenses of tree felling, transportation of stems and branches, clearing, land preparation, construction, planting, burning and other indirect costs (see Sections 1 and 2 of Annex C CS2.2 for more details).
[3]The damage costs in column 2 are calculated as the burned area multiplied by the average timber volume per hectare and the timber price per cubic meter.
[4]The adaptation benefits in column 3 are the difference between the damage costs under the business-as-usual scenario without adaptation (column 1) and the total adaptation costs, which is the sum of the adaptation costs (column 2) and the damage costs with adaptation (column 3).

In addition to reducing wildfire damages, forest fire adaptation options also bring important environmental co-benefits by reducing carbon emissions. Table 2.2.6 presents the estimated annual carbon sequestration by trees not burned, as well as the avoided carbon emissions from trees not burned for each of the adaptation options. Creating firebreaks and planting fire resistant tree species are the most effective options in reducing carbon emissions.

Table 2.2.6: Co-benefits of adaptation options

Adaptation option		Annual carbon sequestration by trees not burned	Avoided carbon emissions from trees not burned
Creating firebreaks	Option 1	6,50-9,00 tons	2.050-2.262 tons
	Option 2	11,50-16,00 tons	3.625-4.000 tons
Reducing tree density		0,00 tons	0,00 tons
Planting fire resistant tree species		3,90-5,50 tons	1.241-1.370 tons
Prescribed burning		3,40-4,80 tons	1.085-1.197 tons

Notes: The carbon sequestration by trees not burned is calculated as the avoided burned area multiplied by the annual average net carbon sequestration per hectare (see Section 4.1 of Annex C CS2.2 for the calculation). The avoided carbon emissions from trees not burned are calculated as the avoided burned area multiplied by the estimated carbon emission per hectare (see Section 4.2 of Annex C CS2.2 for the calculation).

5.2. Assessment of the expected adaptation benefits under climate change scenarios

The assessment of expected adaptation benefits under climate change scenarios is carried out across three pathways: SSP1-2.6, SSP2-4.5, and SSP3-7.0, and evaluated over five time horizons: Historical (1991-2010), Near Future (2021-2040), Mid Century (2041-2060), Far Future (2061-2080), and Distant Future (2081-2100). As indicated in Equation 1, the inclusion of climate change scenarios incorporates the wildfire risk probability into the assessment of the benefits. The corresponding wildfire risk probability for each scenario and time horizon is summarized in Table 2.2.7.

Table 2.2.7: Wildfire risk probability $\{p\}$

SSP1					
	Historical (1991-2010)	Near Future (2021-2040)	Mid Century (2041-2060)	Far Future (2061-2080)	Distant Future (2081-2100)
Fire risk likelihood > 0.50	0,408	-	-	-	0,438
Temperature (K)	278,7	279,3	279,6	279,7	279,5
Wildfire risk probability $\{p\}$	0,204	0,215	0,221	0,223	0,219
SSP2					
	Historical (1991-2010)	Near Future (2021-2040)	Mid Century (2041-2060)	Far Future (2061-2080)	Distant Future (2081-2100)
Fire risk likelihood > 0.50	0,408	-	-	-	-
Temperature (K)	278,7	279,4	279,9	280,4	280,6
Wildfire risk probability $\{p\}$	0,204	0,216	0,224	0,233	0,236
SSP3					
	Historical (1991-2010)	Near Future (20212040)	Mid Century (2041-2060)	Far Future (2061-2080)	Distant Future (2081-2100)
Fire risk likelihood > 0.50	0,408	-	-	-	0,487
Temperature (K)	278,7	279,5	280,2	280,8	281,7
Wildfire risk probability $\{p\}$	0,204	0,217	0,229	0,239	0,254

For all scenarios, the historical probability of wildfire occurrence is 0.204, corresponding to an average baseline temperature of 278,7 K. Under SSP1, which represents a more sustainable development trajectory, temperatures increase gradually to 279,7 K by the Far Future (2061–2080) before slightly declining to 279,5 K in the Distant Future (2081–2100). The corresponding wildfire risk probability shows only a modest rise, reaching 0,223 before stabilizing at 0,219. In contrast, SSP2, reflecting a 'middle-of-the-road' scenario, demonstrates a more pronounced warming trend, with temperatures rising to 280,6 K by the distant future. This is accompanied by a steady increase in wildfire probability, reaching 0,236 by the end of the century. The most severe trajectory is observed under SSP3, where temperatures escalate to 281,7 K by the distant future, resulting in the highest projected wildfire probability of 0,254. These results indicate that while all scenarios project an increased likelihood of wildfire risk over time, the magnitude of change is strongly dependent on the socioeconomic pathway, with SSP3 posing the greatest long-term threat. A more detailed view of the evolution of these probabilities can be found in Figure 2.2.3.

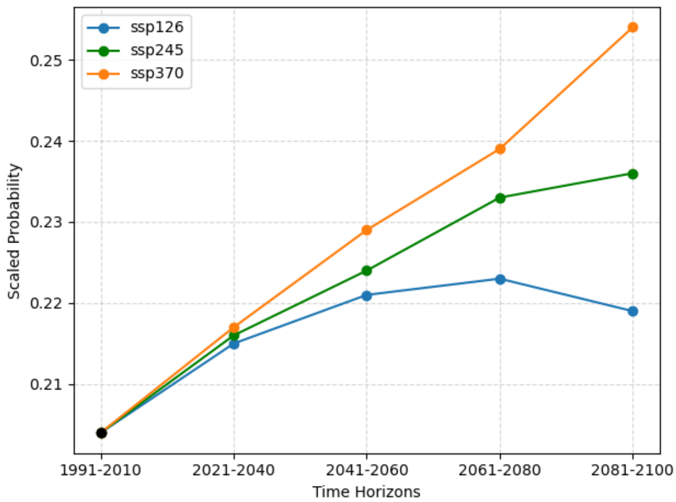


Figure 2.2.3: Wildfire risk probability {p} for different climate scenarios and time horizons. Note: The blue, green, and yellow lines represent climate scenarios SSP1-2.6, SSP2-4.5, and SSP3-7.0, respectively.

Table 2.2.8 reports the expected adaptation benefits, conditional on different wildfire risk probabilities, for the three climate scenarios (SSP1, SSP2, and SSP3), and the time horizons Near Future (2021-2040), Mid Century (2041-2060), Far Future (2061-2080), and Distant Future (2081-2100).

The simulation results indicate that the use of fire-resistant tree species yields the highest monetary value. Furthermore, as the wildfire risk probability increases alongside rising global temperatures, prescribed burning emerges as an additional beneficial adaptation strategy for forest areas in Sweden.

Table 2.2.8: Expected adaptation net-benefits for different climate scenarios and time horizons

SSP1					
Adaptation option		Near Future (2021-2040) $\{p\}$ = 0.215	Mid Century (2041-2060) $\{p\}$ = 0.221	Far Future (2061-2080) $\{p\}$ = 0.223	Distant Future 2081-2100 $\{p\}$ = 0.219
Creating firebreaks	Option 1	-13.000 €	-12.000 €	-12.000 €	-12.400 €
	Option 2	-62.800 €	-62.000 €	-61.200 €	-6.200 €
Reducing tree density		-17.900 €	-17.900 €	-17.900 €	-17.900 €
Planting fire resistant tree species		5.000 €	5.400 €	5.600 €	5.200 €
Prescribed burning		-1.000 €	-630 €	-500 €	-750 €
SSP2					
		Near Future (2021-2040) $\{p\}$ = 0.216	Mid Century (2041-2060) $\{p\}$ = 0.224	Far Future (2061-2080) $\{p\}$ = 0.233	Distant Future 2081-2100 $\{p\}$ = 0.236
Creating firebreaks	Option 1	-12.700 €	-11.800 €	-10.800 €	-10.500 €
	Option 2	-62.600 €	-61.000 €	-60.000 €	-58.700 €
Reducing tree density		-17.900 €	-17.900 €	-17.900 €	-17.900 €
Planting fire resistant tree species		4.900 €	5.700 €	6.600 €	6.900 €
Prescribed burning		-920 €	-450 €	77 €	253 €
SSP3					
		Near Future (2021-2040) $\{p\}$ = 0,217	Mid Century (2041-2060) $\{p\}$ = 0,229	Far Future (2061-2080) $\{p\}$ = 0,239	Distant Future 2081-2100 $\{p\}$ = 0,254
Creating firebreaks	Option 1	-12.600 €	-11.300 €	-10.200 €	-8.500 €
	Option 2	-62.400 €	-60.000 €	-58.000 €	-55.000 €
Reducing tree density		-17.900 €	-17.900 €	-17.900 €	-17.900 €
Planting fire resistant tree species		5.000 €	6.200 €	7.200 €	8.700 €
Prescribed burning		-862 €	-158 €	429 €	1.300 €

6. Barriers and conditions for implementation

The adaptation options discussed in this case study can be categorized in three main adaptation strategies as shown in Table 2.2.9: (i) forest management for damage risk reduction in case of a fire; (ii) fire risk prevention; and (iii) capacity building. Several factors could constrain the implementation of these adaptation strategies. One key barrier is the high cost of forest management, especially given the large forest areas, which require extensive work. Forest management operates on a long-term cycle, where decisions made today can impact outcomes decades into the future. Thus, experimenting with new practices, such as planting different tree species, becomes unappealing in the short term, making traditional practices appear more attractive. Additionally, the fact that not all tree species are suitable for every terrain further complicates the decision. There is also a lack of trained personnel to carry out these adaptation options. Hiring additional staff can be expensive for a forest manager, particularly since they are often required at short notice due to the limited duration of weather forecasts, which influences the number of workers needed for fire prevention. The costs of adding more fireguards, improving infrastructure, or implementing fire prevention options can be significant. Furthermore, awareness of fire risk applications and warning systems is limited, and not everyone is familiar with these tools. The costs of training staff further exacerbate these barriers. Additionally, cultural attitudes may prevent some individuals from changing strategy, viewing it as unnecessary or incompatible with their beliefs. These factors create a complex set of barriers to adopting effective wildfire adaptation options.

Table 2.2.9: Barriers to the implementation of adaptation strategies

Adaptation strategy	Adaptation option	Barriers	Category
(i) Forest management	- Creating firebreaks - Reducing tree density - Planting fire resistant tree species - Prescribed burning	Not all tree species suit all terrains; costly; forest owners may be unaware of options or unwilling due to habits and traditions	K; B; F; S
(ii) Fire risk prevention	Use of fire app with fire risk index	Trained staff unavailability; hiring fireguards costly; fire risk app unawareness	K; H; F; C
(iii) Capacity building	Training programs for firefighters and other stakeholders	Training is costly and time-consuming	F

Note: Barriers to adoption: knowledge, awareness, technology (K); biological (B); financial (F), human capital (H), social and cultural (S).

7. Conclusion

The case study and simulation exercise show that planting fire resistant tree species and creating firebreaks provide the largest monetary benefits among the adaptation options, and that prescribed burning is a valuable complementary adaptation option under warming conditions. By contrast, **reducing tree density** appears economically unfavorable, with costs outweighing the benefits. Collectively, these findings underscore the importance of integrating silvicultural treatments and fuel management practices into community-based forest fire management plans, as they significantly enhance landscape-level resilience to wildfire disturbances. Despite their potential, several barriers hinder implementation, including high management costs, long forestry cycles, and limited personnel. Financial burdens from infrastructure and training further constrain adoption, while low awareness of fire risk tools and cultural attitudes add social challenges. These factors highlight the need to align ecological effectiveness with economic and social feasibility. In conclusion, integrated strategies supported by policy, stakeholder engagement, and long-term planning are essential for effective wildfire adaptation in Sweden.

3 Water-food-biodiversity

Case study 3.1a – Integrated adaptation decisions in managing the water-food nexus in Europe: Thaya river basin (Czech Republic)
Partner: IIASA/Czechglobe
Spatial scale: Thaya river basin scale and country scale – Czech Republic / Austria
Stakeholders: River Basin authorities and Ministry of Agriculture of Czech Republic

1. Decision context

The Thaya River Basin, spanning the southern Czech Republic (83%) and northern Austria (17%), is a critical area for addressing the water-food nexus under increasing water scarcity and climate stress conditions (Fischer et al., 2023). The Thaya River, the longest tributary of the Morava River within the Danube Basin, is heavily influenced by anthropogenic modifications. These include large reservoirs supporting water supply and irrigation. The Thaya River plays a crucial role in supporting regional livelihoods. However, its water resources are heavily utilized for competing needs, including households, industry, energy, and agriculture. These demands become particularly strained during dry years when water usage can consume up to one-third of the river's streamflow (Fischer et al., 2023). One of the central policy questions emerging from these challenges is how to achieve sustainable water resource management while ensuring critical water services, such as drinking water supply and irrigation, under the pressures of climate change. River basin authorities are particularly concerned with improving water management systems to build resilience against climate change impacts, including water scarcity and extreme weather events. Meanwhile, the Ministry of Agriculture emphasizes harmonizing public interests in water protection as an environmental component while ensuring that water resources are sustainably used to support agricultural productivity. Additionally, the forestry and agricultural sectors have expressed an interest in strategies to mitigate climate-induced stresses, such as forest degradation and irrigation challenges, to maintain both ecosystem health and economic viability. The Thaya River Basin presents a compelling case for testing integrated adaptation strategies to manage the water-food nexus under climate change. Stakeholders can harmonize competing interests and secure long-term environmental and economic sustainability by addressing water scarcity, enhancing resilience to extreme events, and promoting sustainable land and forest management. Collaboration among river basin authorities, the Ministry of Agriculture, and local stakeholders will be essential to achieving these outcomes

2. Current and future risk

The Thaya River Basin faces significant present and future risks driven by climate change and environmental pressures. Large reservoirs, vital for water supply and irrigation, have demonstrated vulnerability to extreme droughts, such as those from 2014 to 2019, when drinking water supplies were critically threatened, necessitating restrictive measures and the utilization of all 21 reservoirs in the basin to alleviate scarcity (Fischer et al., 2023). The fertile lowlands, which constitute 66% of the basin's land use, underscore the region's agricultural importance but are highly susceptible to prolonged droughts. These droughts not only reduce water availability but also contribute to ecological challenges, such as a bark-beetle outbreak that affected 30% of coniferous forests during the same period. Hydrologically, the basin is characterized by significant disparities, with high annual precipitation (P) in the upper areas but much lower runoff (RO) coefficients in the lowlands due to elevated evapotranspiration (ETo), leaving the lowland regions particularly vulnerable to water deficits. Projections indicate an increased likelihood of severe agricultural droughts in central Europe, including the Thaya River Basin, with potential long-term soil moisture depletion threatening regional agricultural productivity (Trnka et al., 2022). While central Europe is less prone to hydrological drought compared to southern Europe, the basin's position as a transitional region heightens its vulnerability to shifts in precipitation and evapotranspiration dynamics. Climate models further predict that variations in soil water holding capacity could exacerbate water scarcity under future climate scenarios, emphasizing the urgent need for integrated water management strategies to mitigate these growing risks (Trnka et al., 2022).

3. Identifying adaptation options

The adaptation options identified in the case study for managing the water-food nexus in the Thaya River Basin span grey, green, and soft strategies, reflecting a combination of incremental and transformative approaches. Grey adaptation focuses on the planned and sustainable expansion of irrigation systems, transitioning from rainfed to irrigated management systems, which represents a transformative change in agricultural water use. Green adaptation emphasizes the strategic location of production by optimizing crop shares at the local level, also representing a transformative shift aimed at aligning agricultural practices with environmental conditions. Soft adaptations include measures such as altering trade dynamics by adjusting trading quantities and partners, managing agricultural inputs like fertilizers and irrigation use, and modifying food consumption patterns by changing the quantity and structure of consumption. These soft options primarily involve incremental changes that aim to enhance flexibility and efficiency within existing systems. Furthermore, water demand from domestic and industrial sectors is also evolving, driven by changes in socio-economic pathways (O'Neill et al., 2014) projected for the Thaya River Basin. These shifting demands add an additional layer of complexity to water management and further highlight the need for integrated and forward-looking adaptation strategies. Collectively, these options underscore a holistic approach to address the basin's complex water, food, and socio-economic challenges under climate change

4. Assessment of adaptation options

4.1 Methodology

A robust modeling framework will be employed to assess and implement the Thaya River Basin adaptation strategies, combining the global agro-economic model **GLOBIOM** (Havlík et al., 2014), the global gridded crop model **EPIC-IIASA** (Balkovič et al., 2018), and the global hydrological **CWatM** (Burek et al., 2020) models. This methodology enables the integration of socio-economic and biophysical parameters to evaluate the impacts of climate change and adaptation measures under diverse scenarios in the Thaya River and the Czech Republic. Adaptation options are clustered into three overarching strategies:

- BAU (Business-As-Usual): Reflecting agricultural production based on SSP2 socio-economic development, including unplanned irrigation expansion, improved irrigation efficiency, and gradual increases in international trade. This scenario assumes no constraints on water use or major policy changes, representing an incremental approach.
- HTG (Holding the ground): Focused on maintaining the current level of provision services while leveraging comparative advantages offered by climate change. This strategy incorporates planned irrigation expansion, increased irrigation efficiency, and autonomous crop allocation with higher reliance on trade, representing another incremental approach.
- TBC (The best of climate): Aims for a balanced supply of provisioning, regulating, and cultural ecosystem services through planned and sustainable irrigation expansion, national adaptation strategies, and constraints on irrigation water use. This transformative strategy seeks to decrease imports and meat demand while improving ecosystem service balance.

The evaluation of adaptation strategies in the Thaya River Basin uses a range of indicators to assess economic, social, and environmental impacts. Direct costs, such as production and investment costs, and direct benefits, like increased sustainable agricultural production, are measured quantitatively and monetized. Economic co-benefits include agricultural yield, production, producer prices, and value-added, while social impacts focus on food security. Environmental indicators assess GHG emissions, water availability, and land-use changes. General welfare effects are also considered through distributional impacts and long-term sustainability across multiple time horizons, ensuring a holistic appraisal of outcomes.

Table 3.1a.1: Evaluation criteria used in cascading modelling framework for Thaya River Basin.

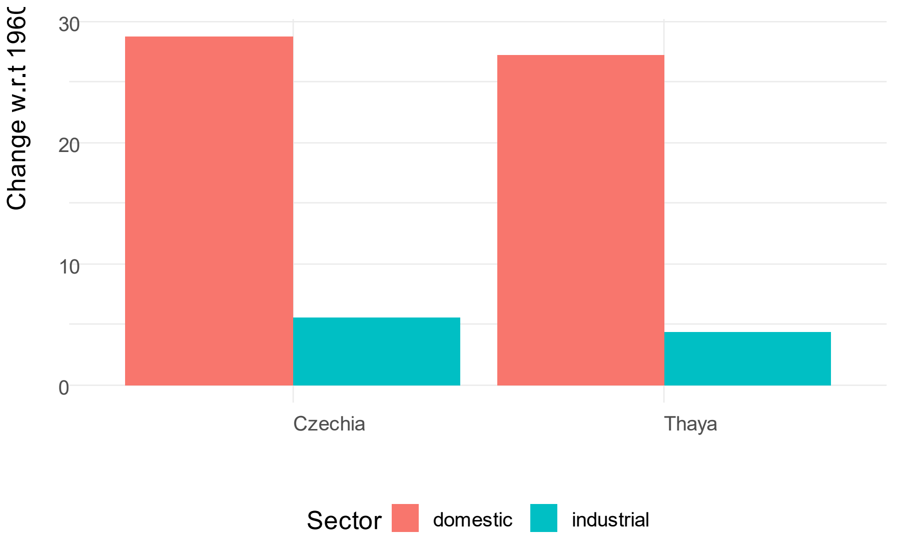
Appraisal criteria (C)

What appraisal criteria are considered?	How are the criteria measured?		
	Qualitative	Quantitative	Monetised
What direct costs are considered?			
• Production cost			X
• Investment cost			X
What direct benefits are considered?			
• Increased sustainable agricultural production		X	
What co-benefits and co-costs are considered?			
Economic			
• Agricultural yield		X	
• Agricultural production		X	
• Agricultural producer prices		X	X
• Agricultural value added		X	X
Social			
• Food security		X	
Environmental			
•GHG emissions		X	
•Water availability and environmental flows		X	
•Land use change		X	
	Distributive	Temporal	Spatial
Are you considering general welfare effects? If so, how? YES/NO	X	X	
• Use multiple time horizons			
• Distributional effects between producers and consumers			

4.2 Results

4.2.1 Water competition with non-agricultural sectors

Figure 3.1a.1 present the projected evolution and relative changes in water withdrawals for the domestic and industrial sectors in Czechia and the Thaya River Basin. The upper panel shows the percentage change in total withdrawals in 2050 relative to the 1960–2020 mean, while the lower panel illustrates the full temporal evolution from 1960 to 2100. Across both regions, domestic water use increases markedly, with values around 30 % above the historical mean by mid-century, reflecting growing household demand and lifestyle changes. In contrast, industrial water use remains relatively stable or declines slightly over the long term, consistent with structural economic transitions and improvements in water-use efficiency. The trajectories reveal that while industrial withdrawals dominated in the late 20th century, their contribution gradually decreases, whereas domestic demand continues to rise and stabilize toward the end of the century. These results highlight a shift in the composition of water demand, emphasizing the increasing importance of the domestic sector and the need for adaptive water management strategies under changing socioeconomic and climatic conditions when irrigation water demand is considered.



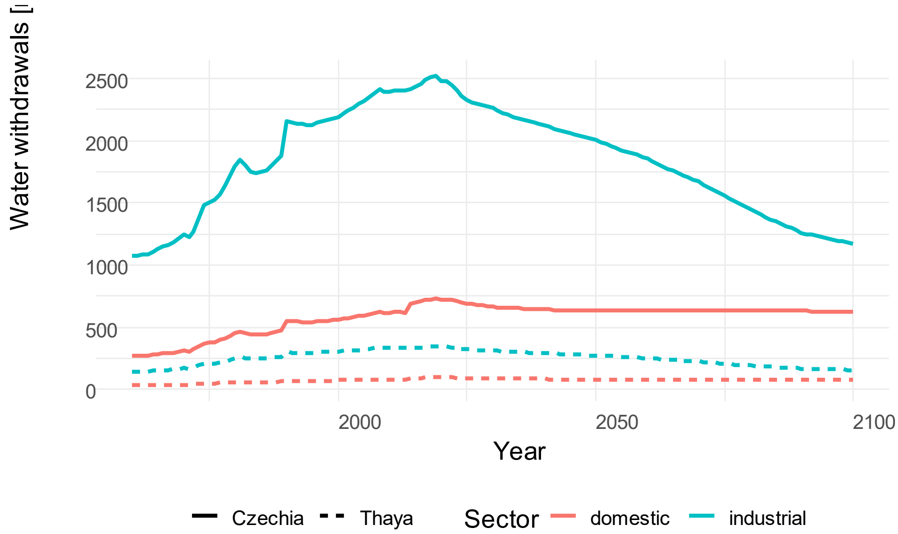


Figure 3.1a.1: Projected changes and long-term evolution of water withdrawals by sector in Czechia and the Thaya River Basin. (a) Percentage change in total water use in 2050 relative to the 1960–2020 mean, showing stronger increases in the domestic sector compared to modest changes in industrial demand. (b) Temporal evolution of water withdrawals (m^3) from 1960 to 2100, with solid lines representing Czechia and dashed lines representing the Thaya River Basin. Colors distinguish domestic and industrial sectors.

4.2.2 Water withdrawals for irrigation

Figure 3.1a.2 projected **irrigation water withdrawals (km^3)** under three adaptation scenarios (BAU, HTG, and TBC) across three Representative Concentration Pathways (RCP 2.6, RCP 4.5, and RCP 7.0) for the year 2050. Across all RCPs, irrigation withdrawals vary moderately among scenarios, reflecting differences in the assumed adaptation strategies and policy interventions. Under **BAU (Business-As-Usual)**, irrigation water use reaches its highest value under **RCP 4.5**, exceeding 0.03 km^3, while RCP 2.6 and RCP 7.0 both show slightly lower withdrawals (~0.019 km^3). This suggests that mid-range climate forcing (RCP 4.5) could lead to relatively higher irrigation demands due to warmer and moderately wetter conditions that sustain both crop productivity and water use intensity.

Under the **HTG (Holding the Ground)** scenario, irrigation withdrawals remain moderate, with RCP 7.0 producing the largest value (~0.027 km^3) and RCP 4.5 the lowest (~0.020 km^3). This reflects the scenario's design — maintaining current provisioning levels with moderate expansion and efficiency gains — where high-emission conditions may intensify irrigation needs, partially offset by adaptation measures.

In the **TBC (The Best of Climate)** scenario, irrigation withdrawals are overall the lowest among all strategies, consistent with its sustainability focus and stricter water-use constraints. Values range between 0.013 km³ (RCP 2.6) and 0.020 km³ (RCP 7.0), indicating that under this transformative approach, both climate mitigation and planned adaptation substantially reduce irrigation demand.
Comparing across both dimensions, **RCP 4.5 and RCP 7.0** generally produce higher irrigation withdrawals than **RCP 2.6**, suggesting that stronger climate forcing elevates water demand even under adaptive management. Meanwhile, **scenario design** exerts a stronger control on absolute values, with BAU > HTG > TBC consistently observed across all RCPs.

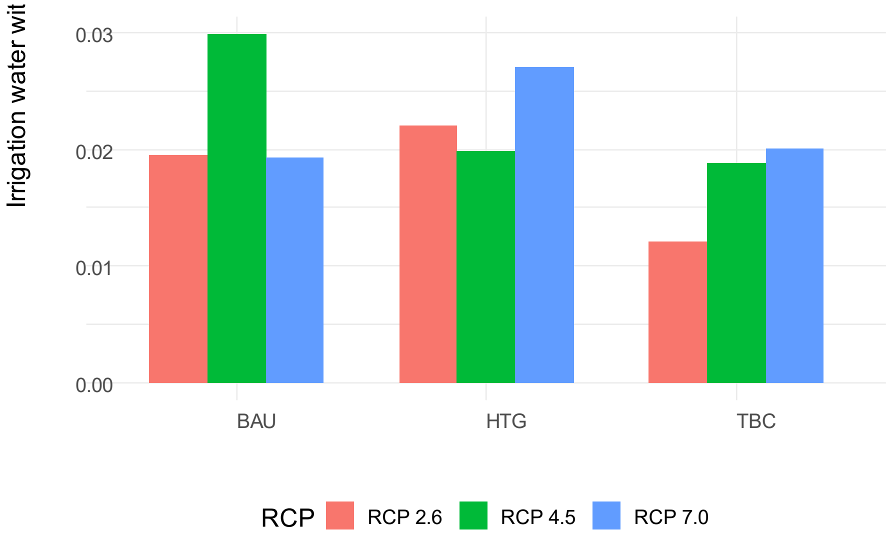


Figure 3.1a.2: Projected irrigation water withdrawals (km³) under three adaptation and socio-economic scenarios—**BAU (Business-As-Usual)**, **HTG (Holding the Ground)**, and **TBC (The Best of Climate)**—and three Representative Concentration Pathways (**RCP 2.6**, **RCP 4.5**, **RCP 7.0**) for the year 2050. Bars represent the **multi-GCM average** of simulated irrigation water use.

4.2.3 Sustainable crop production

Figure 3.1a.3 shows the projected **cropland area (1000 ha)** under three adaptation and socio-economic scenarios—BAU, HTG, and TBC—and three Representative Concentration Pathways (RCP 2.6, RCP 4.5, and RCP 7.0) for the year 2050. Results are presented separately for **irrigated** and **rainfed** cropland, based on the multi-GCM average. Under all scenarios, **rainfed agriculture** remains the dominant land-use type, with total areas one to two orders of magnitude larger than irrigated land. Rainfed cropland shows moderate variability across RCPs and scenarios: the **TBC (The Best of Climate)** scenario yields the largest rainfed area—exceeding 1,600 thousand ha under RCP 4.5 and RCP 7.0—while **HTG (Holding the Ground)** displays the smallest, reflecting higher dependence on irrigation.

By contrast, **irrigated area** expands markedly under climate change conditions but remains relatively small in absolute terms. The **BAU** scenario shows the highest irrigated extent under RCP 4.5 (~24 thousand ha), while **HTG** and **TBC** maintain moderate to lower values, consistent with their more sustainable or balanced management approaches. This pattern indicates that irrigation is increasingly introduced as a **climate adaptation strategy**, especially under warmer and drier RCPs. Importantly, in the **non–climate change baseline (no-impact) simulations**, the **Czech Republic does not feature irrigated cropland**, as irrigation plays a negligible role in current agricultural production. The emergence of irrigated area in these climate impact scenarios thus reflects a **reactive adaptation measure** triggered by projected climate stress, rather than a continuation of present-day practices.

Overall, results demonstrate that while rainfed agriculture will continue to dominate land use, **irrigation emerges as a targeted adaptation strategy** under climate change, particularly in scenarios combining higher emissions and planned adaptation.

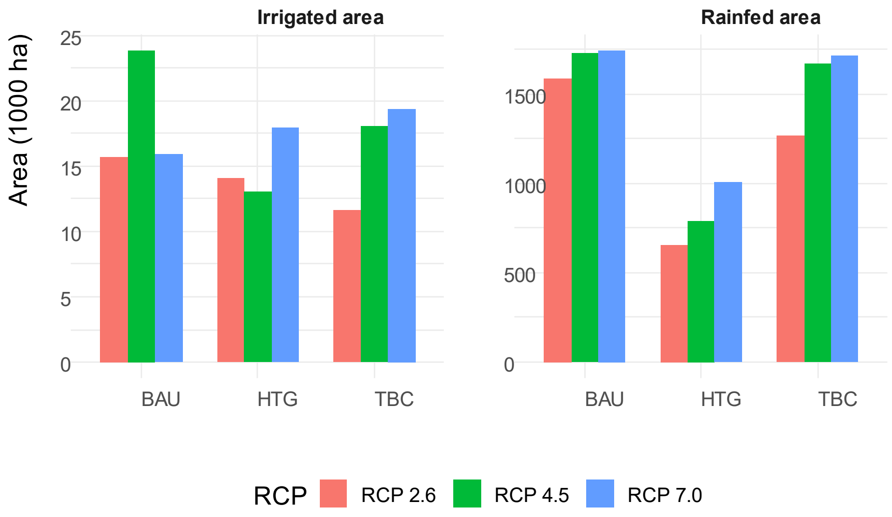


Figure 3.1a.3: Projected cropland area (1000 ha) under three adaptation and socio-economic scenarios (BAU, HTG, TBC) and three Representative Concentration Pathways (RCP 2.6, RCP 4.5, RCP 7.0) for the year 2050. Bars represent the **multi-GCM average**. Panels separate **irrigated** and **rainfed** cropland areas

<u>Co-benefits for the Czech Republic</u>

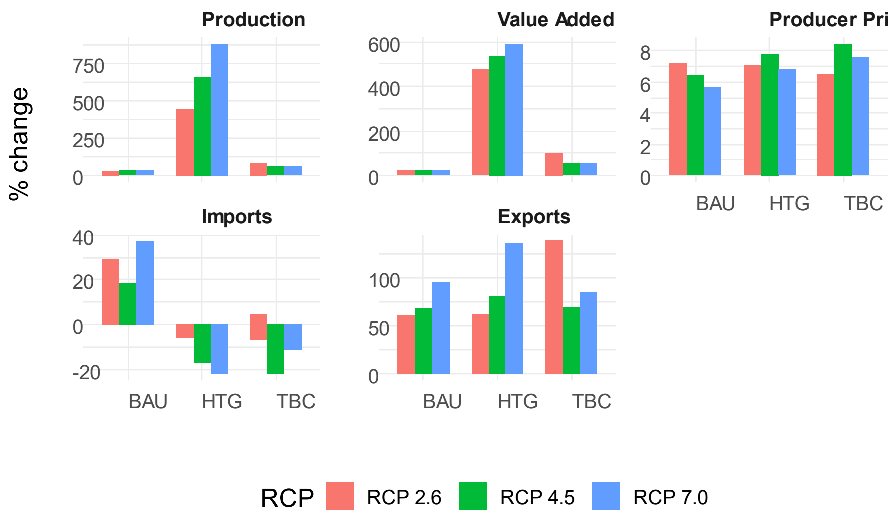


Figure 3.1a.4: Country-level percentage change in key agricultural and trade indicators—production, value added, producer price , imports , and exports —for Czechia in 2050 under three adaptation and socio-economic scenarios (BAU, HTG, TBC) and three Representative Concentration Pathways (RCP 2.6, RCP 4.5, RCP 7.0). Values are expressed as **percentage changes relative to the no–climate change baseline** and represent the **multi-GCM average**

The figure shows the **percentage change** in major agricultural and trade indicators—**production**, **value added**, **producer price**, **imports**, and **exports** —for **Czechia** in 2050 under three adaptation scenarios (BAU, HTG, TBC) and three Representative Concentration Pathways (RCP 2.6, RCP 4.5, RCP 7.0). All values are expressed as **percentage differences relative to the no–climate change baseline**, representing **country-level results averaged across GCMs**.

Across all indicators, climate change induces substantial structural responses in the agricultural sector. **Production** and **value added** exhibit the strongest positive deviations, particularly under **RCP 7.0**, where output increases by up to 800% and value added by over 600% compared to the no-impact baseline. This suggests a strong intensification effect, possibly linked to expanded irrigation and enhanced productivity under adaptation-driven management. In contrast, the **TBC (The Best of**

Climate) scenario shows smaller gains, reflecting its sustainable focus and stricter resource-use constraints.

Producer prices rise modestly (5–8%) across all scenarios and RCPs, consistent with increased demand and higher production costs under climate adaptation. **Imports** display divergent trends: they decrease under HTG and TBC, indicating greater domestic self-sufficiency, while under BAU they rise slightly with warming intensity. **Exports** increase markedly across all conditions—particularly in TBC, where export gains exceed 100%—suggesting a strong trade response to enhanced domestic production potential.

Overall, results highlight that **climate change and adaptation policies can transform Czech agriculture into a more productive and export-oriented system**, with positive economic effects when supported by sustainable management. The magnitude of change, however, remains sensitive to both emission pathway and adaptation strategy, emphasizing the need for balanced policies that maintain economic growth while managing environmental trade-offs.

Environmental impacts of adaptation pathways

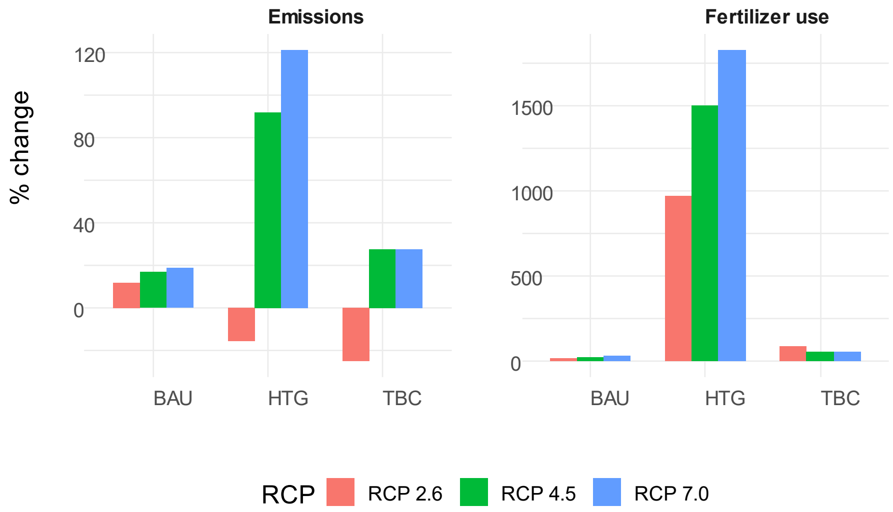


Figure 3.1a.5: Country-level percentage change in agricultural greenhouse gas emissions and fertilizer use in Czechia by 2050 under three adaptation and socio-economic scenarios (BAU, HTG, TBC) and three Representative Concentration Pathways (RCP 2.6, RCP 4.5, RCP 7.0). Values are expressed as **percentage differences relative to the no–climate change baseline**, representing the **multi-GCM average**

Figure 3.1a.5 shows the **percentage change** in **agricultural GHG emissions** and **fertilizer use** in Czechia in 2050, relative to the no–climate change baseline. Results are presented for three adaptation and socio-economic scenarios (BAU, HTG, and TBC) and three Representative Concentration Pathways (RCP 2.6, RCP 4.5, and RCP 7.0), representing the **multi-GCM average**.

Across scenarios, both emissions and fertilizer use exhibit strong sensitivity to the interaction between **climate forcing** and **adaptation intensity**. Under **HTG (Holding the Ground)**, both indicators increase sharply with warming, particularly under **RCP 7.0**, where emissions rise by over **120%** and fertilizer use by more than **1,800%** compared to the no-impact baseline. This reflects a management strategy focused on maintaining production levels through intensified input use and irrigation expansion as adaptive measures.

In contrast, the **BAU (Business-As-Usual)** scenario shows only modest increases in both emissions and fertilizer inputs (typically below 30%), indicating limited adaptation-driven intensification. Meanwhile, the **TBC (The Best of Climate)** scenario exhibits relatively moderate emissions and fertilizer growth—especially under RCP 2.6—consistent with its sustainability-oriented design that constrains water and input use to balance provisioning and regulating ecosystem services.

These results highlight that **climate adaptation can have significant side effects on agricultural emissions**, especially when adaptation relies heavily on input intensification. While such strategies sustain production under climate stress, they also risk amplifying the environmental footprint of agriculture. Hence, integrated adaptation approaches that enhance resilience while minimizing emissions and input dependence will be critical for achieving sustainable outcomes in Czechia's agricultural sector.

5. Barriers and conditions for implementation

The proposed adaptation strategies for the Thaya River Basin face a range of barriers spanning economic, governance, knowledge, and technological challenges (Table 3.1a.2). Economic crises and the need for large investments hinder implementation, while political disparities and advanced governance requirements complicate decision-making. Limited knowledge of effective adaptation measures, coupled with uncertainty in technology, further restricts progress. Physical constraints, such as water competition and limited irrigation resources, exacerbate these challenges. Social resistance, driven by negative perceptions of agriculture's environmental impact, and dependence on market dynamics within the EU, add complexity. Additionally, coordination issues between regional and national governance create significant implementation hurdles. Addressing these barriers requires improved collaboration, knowledge sharing, financial resources, and robust governance frameworks to ensure successful adaptation.

Table 3.1a.2: Barriers for implementation of holistic adaptation strategies for the water-food nexus

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or goverannce and institutional (G).

#	Barriers	Cat
1	1A – Extreme events and economic crisis	E
	1B – Political disparities among stakeholders	G
	1C – Water competition with other sectors	P, E
2	2A - Limited knowledge about sufficient adaptation measures	K
	2B - Bad public opinion about agriculture's impact on the environment	S
	2C - Limited amount of water for irrigation	P
3	3A - Requires advanced governance structures	G
	3B – Can require large investments	F
4	4A- Large uncertainty in technology	K
	4B – Implementation require national and subnational governance	G
	4C – Dependance of Czech comperative advantage in the EU market	E

6. Reflection on holistic supply-demand adaptation strategies for the water-food nexus

The results from the Thaya River Basin and national-level analyses highlight that holistic adaptation strategies—linking water management, land use, and agricultural policy—are essential for balancing productivity gains with environmental sustainability. The proposed scenarios (BAU, HTG, and TBC) demonstrate that climate adaptation has the potential to significantly reshape the water–food nexus by altering irrigation demand, cropland composition, and input intensity. In particular, irrigation emerges as a **reactive adaptation measure**, introduced only under climate impact conditions, as the Czech Republic currently relies almost entirely on rainfed production. The projected expansion of irrigation under high-emission pathways underscores its growing role as a short-term resilience mechanism, but also signals increased pressure on water resources.

From a supply–demand perspective, adaptation strategies that emphasize **input intensification**—such as in the HTG scenario—can sustain production and value added but also amplify greenhouse gas emissions and fertilizer use. Conversely, strategies like TBC demonstrate that **sustainable resource management**, combined with national adaptation planning and trade diversification, can maintain food security with lower environmental costs. This trade-off between productivity and sustainability illustrates the need for integrated decision-making that accounts for both biophysical constraints and socio-economic priorities.

Scaling these strategies beyond the Thaya River Basin requires **context-specific implementation**, recognizing variations in water availability, governance capacity, and agricultural structure. Regions with comparable water stress—such as Southern Europe or semi-arid zones of Asia and Africa—can benefit from similar frameworks if adaptation measures are grounded in robust governance systems and informed by transparent, cross-sectoral coordination. The use of integrated modeling tools such as **GLOBIOM, EPIC-IIASA, and CWatM** enables the quantification of trade-offs and synergies between adaptation options, supporting evidence-based planning. Ultimately, a holistic approach to the water–food nexus requires harmonizing **supply-side measures** (irrigation efficiency, crop optimization) with **demand-side interventions** (diet shifts, trade adjustments, and reduced waste), while ensuring social inclusivity and long-term resilience to climate and economic uncertainties.

7. Conclusion

The analysis of adaptation strategies for the Thaya River Basin reveals that climate change will substantially transform agricultural water use, production patterns, and environmental performance in Czechia. Irrigation, currently absent in the non–climate impact baseline, emerges as a key adaptation strategy to sustain yields under warming conditions. However, scenarios relying heavily on input intensification—such as HTG—lead to significant increases in fertilizer use and agricultural emissions, indicating potential trade-offs between productivity and environmental goals. In contrast, the TBC scenario demonstrates that planned and regulated adaptation, emphasizing sustainability and efficient resource allocation, can balance economic performance with ecological integrity.

These findings underscore the importance of **integrated, multi-sectoral adaptation planning** that bridges water and agricultural policies. While economic and institutional barriers remain, the modeling results provide clear evidence that strategic adaptation—combining grey, green, and soft measures—can enhance resilience while minimizing environmental costs. Replicating such approaches in other regions will require tailored governance frameworks, stakeholder engagement, and continuous monitoring to ensure adaptive flexibility. Ultimately, securing the water–food nexus under future climate conditions will depend on the capacity to adopt **adaptive, inclusive, and sustainability-oriented strategies** that align agricultural productivity with water conservation and climate mitigation objectives.

Case study 3.1b – Integrated adaptation decisions in managing the water-food nexus in Europe – Ebro river basin (Spain)
Partner: IIASA
Spatial scale: EBRO River Basin, Spain
Stakeholder: Ebro Hydrographic Confederation (EHC; River Basin Authority); Scientists (University of Zaragoza, University of Aberdeen)

1. Decision context

This case study focuses on the Ebro River Basin in northeastern Spain. The Ebro is the longest river in Spain (987 km), flowing from north-west to eastern Spain, draining an area of 85,611 km^2. At its outlet to the Mediterranean Sea, the Ebro Delta maintains a rich and important wetland area of 320 km^2. Over 3.2 million people reside within the Ebro River Basin, of which over 600 thousand people live in the city of Saragossa. About 53% is forested, and approximately 45% is agricultural land, of which 15% is irrigated. The annual water abstractions for irrigation, livestock, and aquaculture amount to over 7,310 million m^3, followed by domestic and industrial uses, which amount to 506 and 250 million m^3 year^{-1}, respectively.

Traditionally, cultivation in the Ebro basin focused on winter cereals, yet it has been shifting to water-intensive summer crops since the 1980s. Currently, diverse summer crops (e.g., fruit, maize, and vegetables), fodder, and cereals are grown in the Ebro, concentrated mostly in the northeastern sub-catchments of the river, and supported by multiple reservoirs (Figure 3.1b.1, Haro-Monteagudo et al., 2020). Consequently, water resources management plays a critical role in maintaining sufficient water supply to the multiple water users, including farmers, hydroelectric dams, and aquatic ecosystems (Almazán-Gómez et al., 2018).

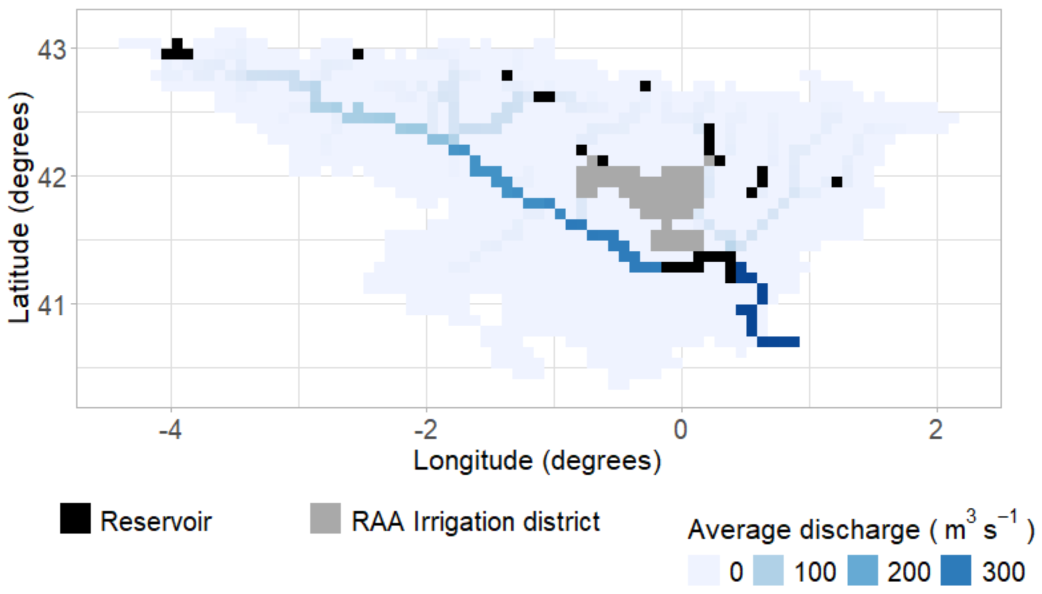


Figure 3.1b.1: Ebro average discharge, RAA irrigation district, and key reservoirs.

Currently, the reservoir storage in the Ebro River Basin amounts to around 8,000 million m^3 (Linés et al., 2018), and is currently close to full capacity (Almazán-Gómez et al., 2018). Additional storage is therefore needed to support the planned expansion of the irrigated agriculture, while balancing the different economic and non-economic water uses, like the mandatory minimal environmental flows. The Ebro River Basin authority (CHE; https://www.chebro.es/) is engaged as a stakeholder in this case study, aiming to assess the potential effectiveness of different adaptation measures in balancing irrigation water use with environmental flows under various climate change scenarios. The overarching policy question for stakeholders is: What are the costs and benefits of adaptive measures in the context of climate change, allowing for the maintenance of water's pivotal role in the regional economy and ecological systems?

This assessment focuses on the Riegos del Alato Aragón (RAA) irrigation district (Figure 3.1b.1), which stretches over 3,762 km^2, and operates through a complex system of reservoirs, canals, and irrigation ditches (see Annex C CS3.1b, section 1a). Irrigation in the RAA relies primarily on water from the Cinca and Gállego Rivers, through the El-Grado reservoir, and Ardisa and Sotonera reservoirs, respectively (see Annex C 3.1b).

2. Current and future risk

Currently, the Ebro River Basin successfully maintains a balance between water use and environmental flows, although its storage capacity to support additional water use is quite limited. Seasonal higher water scarcity often occurs during the dry season (July–September), resulting in a higher occurrence of flows lower than the minimally required environmental flows (Almazán-Gómez et al., 2018; see Figure C.3.1b.13 Annex C). Droughts pose additional risks to the water-dependent economic and natural systems in the Ebro. During drought years (e.g., 2011/2), waterhead reservoir replenishment slows down (Figure C.3.1b.6, Annex C), leading to lower water abstractions (Figure C.3.1b.4, Annex C), reducing the share of irrigation demand supply (Figure C.3.1b.5, Annex C).

Climate change is expected to reduce water supply, where inflows to the headwater reservoirs may be reduced by 9.5% -15.7% in the Gállego River, and 12% -14.6% in the Cinca River (Figure C.3.1b.6, Annex C). Higher evapotranspiration rates imply a future increase in irrigation water demand of 65% - 80% for different climate change scenarios (Representative Concentration Pathways, RCPs; Figure C.3.1b.7, Annex C). These trends will result in increased water scarcity, with lower relative irrigation demand satisfied, where RCP 7.0 presents the most significant decrease (Figure C.3.1b.5, Annex C). Some studies suggest that land abandonment-driven revegetation will increase basin-scale evapotranspiration rates and lead to lower river flows (López-Moreno et al., 2014). Planned irrigation agriculture expansion will introduce additional pressures on the Ebro's water resources, and will further exacerbate water scarcity, especially during the dry season, where downstream uses and ecological systems highly depend on reservoir water releases and irrigation return-flows (Baccour et al., 2024).

Climate change adaptation measures are required to cope with climate change, keep ecosystems intact, and enable economic development in the Ebro River Basin. There are ongoing efforts to modernize the Ebro's irrigation systems, aiming to increase the agricultural productivity and water use efficiency. However, agricultural modernization in the RAA has led to increased seasonal water scarcity due to irrigation expansion and a transition to water-demanding crops (Jlassi et al., 2016). This rebound effect, termed the 'irrigation efficiency paradox' (Grafton et al., 2018), is addressed in the latest River Basin Management plan, which proposes to allocate water savings to planned irrigation expansion (CHE, 2023).

3. Identifying adaptation options

The introduction of efficient irrigation systems is an ongoing grey adaptation measure, which requires complementary management schemes to mitigate potential rebound effects. However, overcoming the current and expected increase in seasonal water scarcity requires additional storage capacity. In fact, the pressures on water resources may be more severe due to planned irrigation expansion.

Due to opposition from environmental organizations and the public against new large dams, the river basin authority considered local storage options—such as on-farm ponds and small off-stream reservoirs—as viable investments. Nevertheless, recent research suggests that local storage may compete with large reservoirs, increase the financial burden put on farmers, and may not serve as an effective measure against droughts (Haro-Monteagudo et al., 2023).

Water users' behavior and water use policies can also act as adaptation measures to reduce water scarcity and drought risk. Well-timed deficit irrigation can be a practical strategy to improve water use efficiency in fruit crops grown in water-scarce regions. Crop selection, e.g., towards water-saving crops, is a soft adaptation strategy that can potentially increase water use efficiency.

4. Assessment of adaptation options

4.1 Methodology

The Ebro five arc minutes (~10 km) hydrological and water resources model was developed based on the global Community Water Model (CWatM; Burek et al., 2020). CWatM is a multi-resolution hydrological model, which includes natural and human components, and simulates key hydrological processes and human interventions in the water cycle, including non-irrigation water consumption, crop-specific irrigation withdrawals, and water storage (see Annex C CS3.1b, Section 1).

The model provides a robust tool to explore climate change impacts and adaptation on the water cycle and on water outcomes (e.g., crop yields). The model setup and calibration focused on river discharge, evaluated using the Kling-Gupta efficiency (KGE), Nash-Sutcliffe efficiency (NSE), and R^2, demonstrating basin-wide good performance (see Figure C.3.1b.3, Annex C). As crop irrigation is a key water user in the Ebro, the model also aimed to capture the water withdrawal quantities and dynamics. The model successfully captures the seasonal dynamics and estimates about 70% of the actual irrigation withdrawals. Model adjustments aiming to represent key features of the Ebro better enhanced the model's performance. These features include reservoir operations (see Annex C CS3.1b, Section 1a), crop-specific water requirements (see Annex C CS3.1b, Section 1b), and irrigation efficiency (see Annex C CS3.1b, Section 1c).

This assessment explores these two adaptation options using CWatM. The Haro-Monteagudo et al. (2020) study inspired the modeling of the local storage adaptation option, which was further developed via stakeholder consultations. The narrative underlying the crop selection adaptation measure relies on the ACCREU D2.2 integrated assessment modeling framework, coupling CWatM and Global Biosphere Management Model (GLOBIOM; Havlík et al., 2018). A detailed description of the implementation of these adaptation options is provided in Annex C CS3.1b (Section 4) and summarised in Table 3.1b.1. With an overall goal to explore the costs and benefits of the different adaptation measures, we quantify the net revenue and irrigation water use efficiency in the RAA for exploring sectoral economic outcomes and the efficient use of water resources (see Annex C CS3.1b).

Table 3.1b.1: Modeling and exploring different adaptation options using CWatM. Adaptation measures in bold were implemented in this assessment.

Adaptation option	Adaptation type	Modeling technique	Questions to address
Increase irrigation efficiency	Grey / Incremental	Changing water irrigation efficiency maps and conducting a sensitivity analysis to assess the response of farmers' and reservoir operations.	How much water can be saved by increasing irrigation efficiency? How much additional cropland could be irrigated using these savings?
Local storage	**Grey / Incremental**	**Setting up grid-cell storage infrastructure as a backup irrigation source.**	**Can local storage buffer against short-term water deficit or droughts?**
Crop selection	**Soft / Transfomative**	**Change the cropping pattern to represent the GLOBIOM narrative.**	**Is crop selection a cost-effective measure for climate change adaptation?**

4.2 Results

Both the local storage and crop selection adaptation measures result in reduced water withdrawals in the RAA under current conditions (2000–2014) and climate change (2015-2060) across RCPs. Climate change increases the water demand without any adaptation, whereas the crop selection adaptation presents a distinct reduction (see Figure C.3.1b.9, Annex C).

Although the adaptation measures reduce the pressures on water resources, they also lead to reduced crop production and lower net revenue at the RAA scale. Due to the low yields of wheat relative to other common crops, like maize and nectarines, the crop selection adaptation results in the lowest production (measured as all crops' production in metric tons). Production according to the local storage adaptation is slightly lower than the baseline (no adaptation), and is showing the highest reduction due to climate change (Figure C.3.1b.10, Annex C). Similarly, the RAA total net revenue (crops' sales minus infrastructure investment) are lower with climate change adaptation compared to the baseline (no adaptation) scenario, and its current (2000–2014) median net revenue is 220 € million, 194.5 € million, and 36.6 € million without adaptation, or with the local storage and crop selection adaptations measures, respectively (Figure C.3.1.b.11, Annex C).

The results indicate an overall decline in RAA economic activity, primarily due to climate change and its subsequent adaptation efforts. Nevertheless, the water use efficiency is higher under the local storage adaptation measure (0.36 € m^{-3}), relative to the baseline (no adaptation; 0.3 € m^{-3}), and the crop selection measure results in the lowest water use efficiency (0.08 € m^{-3}; Figure C.3.1b.12, Annex C).

The effect of climate-change adaptation on environmental flows is complex and changes by river segment as a function of its upstream activities. We compare the monthly simulated and environmental flows in two locations on the main channel of the Ebro: upstream RAA near Saragossa, and midstream RAA near Sástago. The environmental flows exceedance is expressed as the relative number of months in which the average discharge is lower than the required environmental flows. Higher exceedance rates occur mostly between July and September. Adaptation measures reduce the exceedance rates under climate change in the upstream location, but show higher or similar rates of exceedance in the midstream location, depending on the RCP (Figure C.3.1b.13, Annex C).

5. Barriers and conditions for implementation

The analysis of the two climate change adaptation measures yielded conflicting results. Both adaptation measures have reduced water use, though the impact on environmental flows' exceedance remains uncertain. Both measures have decreased the RAA economic activity, yet the local storage adaptation showed a more efficient utilization of the water resources. These results partially represent some of the shortcomings of this analysis, though they also highlight some of the barriers and conditions for implementation.

A. Local storage requires significant investments and a careful design.
   The local storage adaptation measure is designed as a buffer against short-term water deficiency, e.g., due to high demand, exceeding the canal's daily capacity. It means that canal irrigation is prioritized, followed by the local reservoirs. Defining the correct volume for these buffer reservoirs is critical to avoid water shortages (volume is too low) or stored water with no use (volume is too big). Restricting the reservoirs' volume (e.g., by adopting a water quota allocation scheme) will reduce competition between local storage and headwater reservoirs, as well as between different local storage reservoirs. Further, increasing irrigation demand due to climate change (Figure C.3.1b.7, Annex C) may deem installed reservoir capacity too small.

   The timing and rate of reservoir filling are another important parameter of this adaptation measure. In this assessment, we have applied a daily fixed maximum rate, estimated as the reservoir's relative volume multiplied by the canal's daily discharge (Equation 17). However, considering the role of these reservoirs as a backup water source and their plausible sub-optimal design, we acknowledge that other filling strategies should have been explored. One example is to restrict or forbid water transfers during the peak demand period (July–September), which should keep more water at the headwaters available for canal irrigation. Both of these flaws (sub-optimal storage and fixed filling rates) might have affected the results of the local storage adaptation measure simulation, yet it still shows higher water use efficiency.

The local storage adaptation measure poses an economic burden on farmers or farming associations, due to the additional large investments and ongoing maintenance and operation costs (Haro-Monteagudo et al., 2020).

B. Crop selection shall focus on high-value, low-water needs crops and inter-agency cooperation.
The crop selection adaptation measure had the highest water saving outcomes, but it resulted in the lowest benefits (net revenue, water use efficiency), and co-benefits (crop production). The GLOBIOM-inspired narrative that informed this scenario proposed the shift to wheat cultivation as a response to global economic dynamics, including changes in price and trade, that were not fully embedded into the modeling. One shortcoming of the GLOBIOM simulations, within the context of the Ebro River Basin, is that it does not include key high-value crops, such as fruit trees (e.g., nectarines). It follows that switching nectarines, high-yield, high-value crops (like nectarines) with low-yield, low-value crops (like wheat) proves to be an economically inferior strategy. Instead, high-value, low water needs crops may be a more promising adaptation measure.

However, advancing a basin-wide behavioral change can be challenging and will require resources to acquire and communicate new technical and agronomic knowledge, advance cultural transformation, and foster inter-agency cooperation. The latter is crucial, since agricultural policies are fragmented and distributed between different agencies. The Ebro River Basin authority manages the water resource and is involved with allocating irrigation water, but it does not affect crop selection.

6. Reflection on agricultural modernization as an adaptation strategy

Given its feasibility as an adaptation strategy, as assessed, we focus our reflections on agricultural modernization, with special attention to the local storage adaptation measure.

As stated above, the local storage measure already shows slight improvement in water resources efficiency under current and climate change conditions. At the same time, it reduced the overall economic output of the agricultural sector in the RAA. This result may indicate that current water prices are too low. In fact, the current schemes in parts of the RAA set water prices per unit area, providing farmers with an incentive to maximize their yields, regardless of their water use. This market failure may be expressed as maintaining less-efficient irrigation systems and selecting high-yield crops with high water requirements. Setting water prices per unit volume should instead drive farmers to use their water resources more efficiently, which, as indicated, may result in lower total production.

Water use efficiency is particularly important when water is scarce; this is the case in the Ebro's dry season and during drought years. Further, climate change is expected to increase water scarcity and intensify intersectoral trade-offs (Baccour et al., 2024). Adopting a holistic, nexus approach to water planning would allow balancing the water needs of different economic sectors and the environment. If well designed, a local storage adaptation measure could probably support the farmers while minimizing the impact on other sectors of the economy. However, avoiding environmental impacts on downstream riverine ecosystems requires a proactive reservoir management assuring sufficient water releases to satisfy the required environmental flows. In the local storage adaptation measure, lower irrigation volumes have led to reduced return flows and increased the environmental flows. A responsive reservoir management scheme shall increase water releases to secure the downstream environmental flows.

Drought's impact is a fundamental challenge in the Ebro, which remained unaddressed by the local storage adaptation measure. In most years, the Ebro farmers face seasonal water scarcity, which can be resolved by adding sufficient storage capacity. If implemented correctly, the local storage could provide an additional buffer in regulating the seasonal gap between water availability and water demand. However, in drought conditions, the Ebro River Basin experiences a more acute water scarcity, requiring interannual water transfers, which seems to be impossible considering the current storage capacity. The explored implementation of the local storage adaptation measure had not provided a sufficient solution either. Some unexplored complementary demand-side measures may be worth exploring, including scenarios of deficit irrigation, water quotas, reservoir filling strategies, and compensation payments or water markets (e.g., farmers can sell their stored water to the river authority).

7. Conclusion

The Ebro River water resources are intensively utilized for irrigation purposes, using a complex system of reservoirs, ponds, canals, and irrigation ditches. The storage in the Ebro basin has reached its limit, resulting in water scarcity during the dry season and deficit during drought years. Due to objections from environmental groups, the construction of large reservoirs seems impractical. As a response, a combination of small reservoirs, large ponds, and on-farm storage accompanied the modernization of the irrigation systems starting from the 1990s.

Constructing distributed storage systems increases the overall storage in the Ebro basin, leading to reduced water use and crop production, but also to higher water use efficiency, indicating a plausible market failure. A careful design of the local storage adaptation measure, and exploring a variety of proactive irrigation schemes, filling strategies, and reservoirs' releases, may serve as a sufficient climate change adaptation measure, yet additional exploration is required.

Crop selection can also reduce water demand, but its associated economic losses and low water use efficiency deem it impractical. An inter-agency effort to support innovative agricultural practices, identifying and promoting the transition to high-yield, low-water requirement crops, can, however, provide a viable pathway for a crop selection adaptation measure.

A holistic water resources management shall seek a balance between a variety of economic needs and environmental requirements, combining grey and soft adaptation measures.

Case study 3.2 – Integrated species distribution model for estimating potential economic impacts of conservation and impact mitigation preservations (Italy)
Partner: CMCC
Spatial scale: Local, Italy
Stakeholder: WWF

1. Decision context

The case study focuses on a small protected area consisting of coastal dune habitats on the Venetian coast, one of the few remaining examples of this coastal habitat along the Italian Adriatic coast. The area, denominated "Oasi Alberoni", is part of the coastal strip called "Lido di Venezia" which separates the Venice Lagoon from the Adriatic sea (Figure 3.2.1). The area is protected under the Habitat Directive (Directive 92/43/EEC) and is part of the NATURA 2000 network (as one element of four separated areas of the site registered as IT3250023 which is protected both under the Birds and the Habitat directive). The 72 ha of the area are owned by the Venice local authority which gave the concession for the management of the area to the local section of the WWF.

Both dunes and beach are maintained or even growing thanks to sediments from erosion processes taking place at other spots of the coast. Under a prospective of sea level rise, this natural growth process might be interrupted as the natural accretion rate might not take pace with the rate of sea level rise.
Several anthropogenic drivers are furthermore challenging the natural dune conservation/regeneration processes which would allow the dunes to adapt to sea level rise.

1. The area is situated between a small settlement, a golf court and some dispersed urbanization on the western side the Adriatic sea in the east, and the lagoon inlet with the hard structures of the MOSE mobile dike which protects the lagoon from high floods. Opportunities for dune migration towards the inland as a natural answer to rising sea levels are thus hindered (coastal squeeze).
2. The area is interested, especially in summertime, by (mainly local) beach tourism. Dune structures and vegetation are damaged by beach tourists walking across the dune areas without any limitation, introducing plant species which disturb the dune habitat.
3. In correspondence to the beach establishments, the dune ridges have been interrupted (access to bars, restaurant), drivers which create, alongside with alien species, the main challenge for the conservation of the area, reducing the protection function of the dune ridges for the settlement.

In addition, climate change related impacts are challenging the conservation of the dune habitat:

4. Alien species are invading the dune area, displacing key species of habitat which are crucial for dune maintenance and regeneration.
5. Changes in seasonality of storm surges make such events more frequent during the nesting time of the iconic bird species, the Kentish Plower, putting at risk of inundation the nesting sites which are situated on the margin between beach and foredune vegetation.

The main stakeholder, WWF who oversees the management of the area, is engaged in ensuring the conservation of the area. Other actors are the regional authority which is managing the forested part of the dune system, and the local authority which has delegated the management of the dunes on the basis of pluriannual contracts to the WWF and which is in charge of control of planning and control of urbanization as well as of emission and management of concessions for commercial beach management.

Policy question: *How to conserve the dune system so to allow for its adaptation to the risk of rising sea levels and extreme events? Specifically: how to best manage a coastal natural area (site of the "Habitat" Directive 92/43/EEC), in a way that biodiversity of the site and its capacity to adapt to rising sea levels are conserved while allowing for touristic activities and for flood protection of the areas behind the dunes.*

Figure 3.2.1: Map of the Protected Area (source: https://www.comune.venezia.it/sites/comune.venezia.it/files/page/files/Mappa%20ZSC%20Alberoni.pdf

1.1 Pressures and conflicts in the area

The area is heavily frequented by beach tourists during summertime, mainly by local residents of the municipality of Venice and the hinterland of the lagoon, yet the also the pressure of tourism investing the city of Venice contributes with raising real estate prices, which have an impact also on the less densely urbanized area at the southern end of the Lido generating requests for new urbanization at the margins of the protected area.

The high frequency of beach visitors creates two types of specific pressures within the area, one regards the nesting sites of the most important protected bird species, the Kentish plover, which breed directly on the beach and are thus difficult to protect, and the second regards trampling in the area of dunes where vegetation is damaged, preventing the natural development and conservation of dunes. Further pressures take origin from invasive species invading the area of the dunes, and of pine trees, planted for decorative reasons some decades ago substituting the natural forest habitat.

Access to the beaches and structures providing services have been created, for this reason, the dune ridge has been interrupted in one point for an area of approx. 250 m and substituted by an asphalt surface. In the northern part of the area, dunes have been eliminated for the construction of further beach establishments which are in disuse. Access to the entire dune area for pedestrians is actually not limited by any measure and tourists are free to circulate in the whole protected area. The only exception is presented by the delimitation of nesting areas on the beaches to protect the Kentish Plover.

The main stakeholder, WWF, surveys the nesting are in the periods of major access to beaches, and organizes dissemination activities (guided tours, beach cleaning campaigns, information tables) to increase awareness of visitors about the habitat.

2. Current and future risks

The conservation status of the Oasis is threatened by human activities within the dune areas. Expected impacts from climate change relevant for the area of Alberoni include impacts from sea level rise and storm surges which will shorten the beach front of the dunes and intensify the impact of storm surges on the dune system. While stable dunes can benefit from storm-surges because they are able to capture sediments delivered in these occasions, thanks to their specific structure, fragmented dunes with few vegetation would be less able to withstand the impacts of waves during storm surges.

2.1 Sea level risk & inundation risk

Climate-only sea level rise (SLR) is the projected increase in sea level due to climate factors and does not account for local factors that may influence *relative* ('actual') SLR in the area. Climate-only SLR data are inputted into the DIVA model (Global Climate Forum, 2024), from which the *relative* SLR for the area is projected. **For this study, there is no difference between climate only and predicted relative SLR for the Lido Island area** (Figure 3.2.2). Such findings imply that local factors (e.g., subsidence, longshore drift, sediment accretion, human disturbances) have little to no impact on the *relative* SLR and that projected SLR is attributed solely to climate-driven factors. However, these results should be conservatively interpreted, given the nature of the DIVA model. The DIVA model projects relative SLR at the floodplain level, and thus it is not possible to incorporate local factors at the study site that may impact relative SLR. Previous research has shown that the Alberoni shoreline area is heavily affected by, among others, land subsidence (Tosi et al., 2018), longshore sediment transport, storm surges, and human engineering interventions (Molinaroli et al., 2023). Further research and model development are required for precise relative SLR due to interactions between projected sea level rise and local factors. Thus, the reported relative SLR for this area should be interpreted as a coarse estimate in the absence of further information.

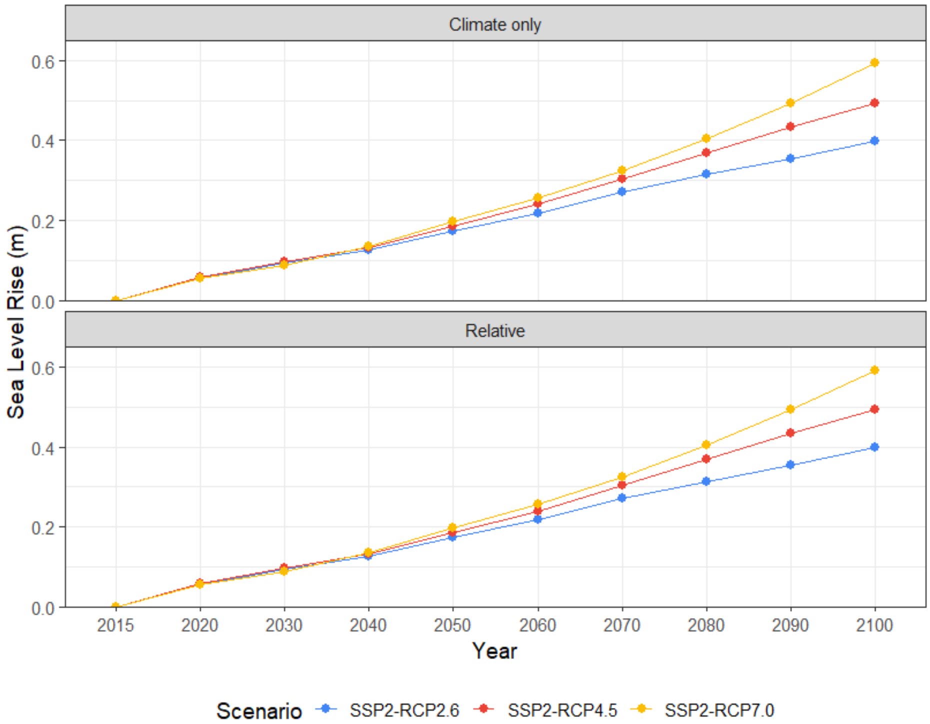


Figure 3.2.2: DIVA model inputs of climate-only sea level rise (m) and outputs of projected elative sea level rise (m) for Lido Island (Location ID 70944) under SSP2 RCP2.6, RCP4.5, and RCP7 scenarios from 2015-2100.

Using the DIVA-derived projected relative SLR, and a contemporary digital elevation map, we found that inundation risk areas within the Alberoni Oasis protected area are projected to increase steadily until 2100 for all SSP2-RCP scenarios (Figure 3.2.3, Figure 3.2.4). The largest inundation risk for all years is projected under scenario SSP2-RCP7. Under this scenario, the area at risk for inundation in Alberoni Oasis (all habitats and non-habitats combined) will increase from 12.78 % in 2030 (9.26 ha inundated) to 18.29 % (13.25 ha inundated) in 2100.

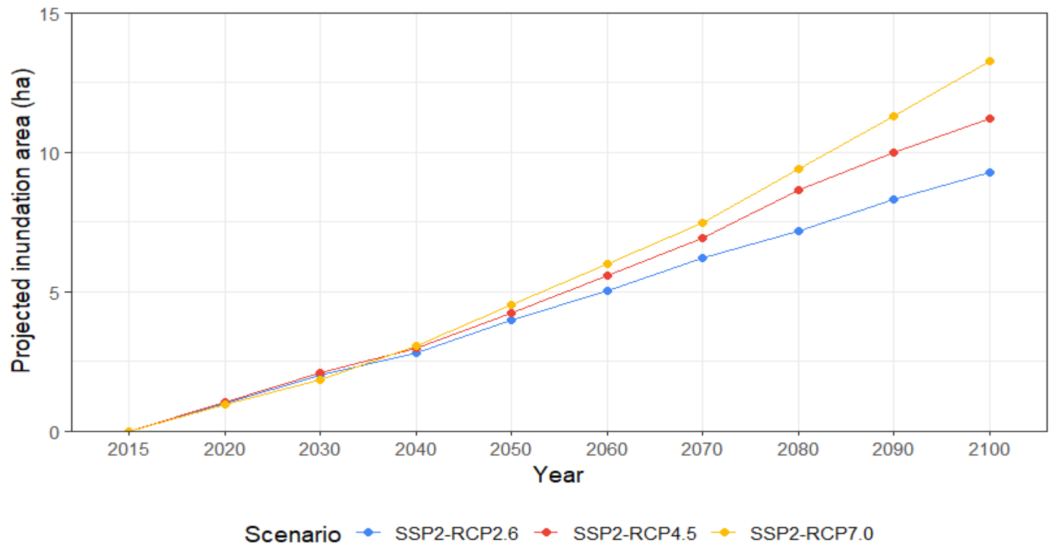


Figure 3.2.3: Total projected inundation risk area (ha) over time for the Alberoni site for 2015-2100, under SSP2 and RCP 2.6, 4.5, and 7.0.

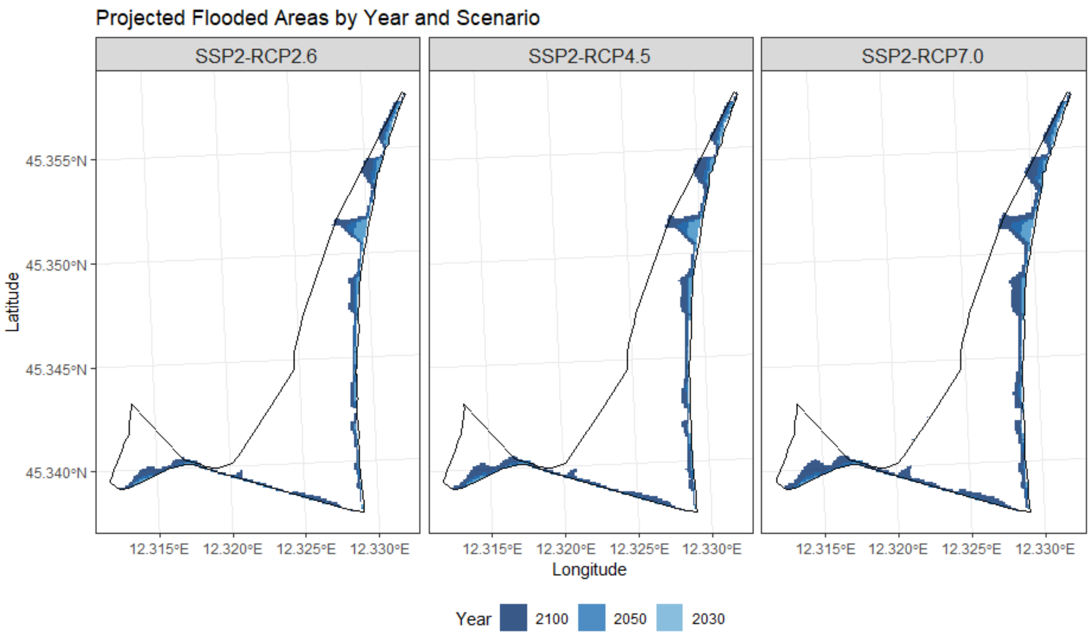


Figure 3.2.4: Projected inundation risk areas due to relative sea level rise in Alberoni for 2030, 2050, and 2100. Calculated from a digital elevation model and DIVA-derived relative sea level rise projections (m).

Figure 3.2.5: Vegetation habitat map of Alberoni Oasis within the "Lido di Venezia: biotopi litoranei" Natura2000 protected area (75.67 ha). Of the total area, coded habitat types cover 50.58 ha, and exclude Mosaic habitat types, Populus alba community habitat, and non-habitat areas.

Table 3.2.1: Habitat types and codes of habitats present within Alberoni Oasis (part of Natura2000 Site IT3250023 Lido di Venezia: coastal biotopes").

Habitat Type	Habitat Code	Represented in habitat map?
Annual vegetation of drift lines	1210#	Yes
Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)	1420	Yes
Embryonic shifting dunes	2110#	No
Shifting dunes of the shoreline with *Ammophila arenaria* (white dunes)	2120#	Yes
Fixed coastal dunes with herbaceous vegetation (grey dunes)	2130*	Yes
Interdune wet depressions	2190	No
Malcolmietalia dune grasslands	2230	Yes
Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*	2270*	Yes
Mediterranean tall humid grasslands of the Molinio-Holoschoenion	6420	Yes
*Priority habitat from Directive 92/43/EEC #Kentish Plover potential nesting sites		

2.2 Sea level rise impacts on habitats

For all mapped vegetation habitat types of interest in the Alberoni Oasis (Table 3.2.1), the total area is projected to decrease due to SLR inundation under all SSP2-RCP scenarios. (Figure 3.2.6, Figure 3.2.7 Panel "All Habitats"). Of the total mapped habitat areas, there is projected 'shrinkage' in the total area available for terrestrial species. By 2100, the total available habitat area is projected to decrease to 54.76 ha under SSP2-RCP2.6 (9.41 % loss), 53.14 ha under SSP2-RCP4.5 (12.09 %), with the largest loss under SSP2-RCP7.0 (51.37 ha, 15.02 % decrease). Per habitat type, a similar pattern of loss due to SLR inundation is observed (smallest under SSP2-RCP2.6, largest under SSP2-RCP7.0) but varies according to habitat type (Figure 3.2.6, Figure 3.2.7). Below we discuss the results and implications of SLR impacts on each of these habitats as they relate to biodiversity and ecosystem services. For reporting purposes, we focus on animal species of interest and loss of dune vegetation as they relate to their associated ecosystem services (dune stabilization and potential increased flooding).

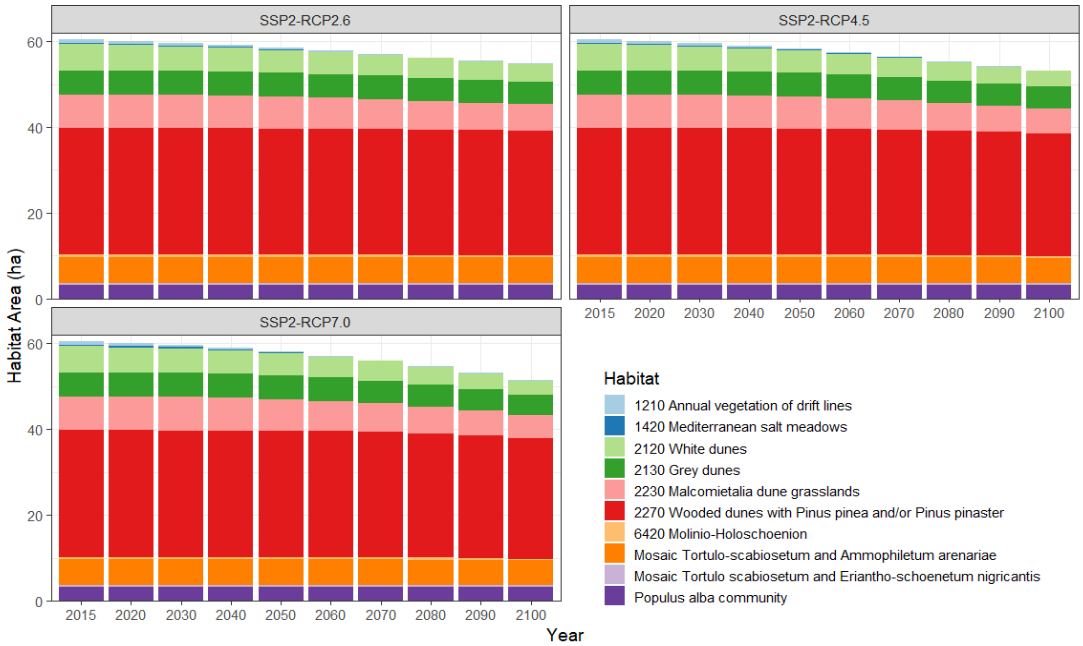


Figure 3.2.6: Actual habitat area (ha), per habitat type, in the Alberoni Oasis under sea level projections SSP2 RCP2.6, RCP4.5, and RCP7.0. Habitat numbers correspond to the WWF habitat types.

The foredune habitats, closely associated with Kentish Plover nesting sites (1210 and 2120; Table 3.2.1), show a large reduction in available habitat area over time relative to 2015 (Figure 3.2.7). Habitat 1210 (Annual vegetation of drift lines) shows an almost complete loss in relative available habitat by 2100 due to SLR for all three SSP2-RCP scenarios (RCP2.6 91.14%; RCP4.5 93.67 %; RCP7.0 93.67 %). Habitat type 2120 (shifting dunes of the shoreline with *Ammophila arenaria* i.e., white dunes) is projected to decrease by 31.32 % under RCP2.6, 39.64 % under RCP4.5, and by almost half (46.82 %) under RCP7.0. As the Kentish Plover nests behind the tide line and forages on the shore, SLR will severely impact this species due to loss of nesting and foraging habitat unless shore habitats 'retreat' and replace the dune habitats in the future.

In addition to their importance as nesting habitats for Kentish Plovers, the **foredunes** are critical for protecting and maintaining the back dune priority habitats 2130 (grey dunes) and 2270 (Dunes with *Pinus pinea* and/or *Pinus pinaster* forests) under Habitats Directive 92/43/EEC. Habitats 2130 and 2270 currently cover a large area of the Alberoni Oasis protected area (wooded dunes = 29.55 ha, grey dunes = 5.6 ha). Such vegetated dunes are important natural barriers protecting often urbanized areas behind the dunes from SLR and associated storm surges. Our results show that these habitat types remain remarkably intact for all SLR scenarios, with only small declines in available habitat by 2100 (Figure 3.2.7). For all SSP2-RCP scenarios, at least 86% of habitat 2130 (grey dunes) area remain intact by 2100, and 95 % of habitat 2270 (wooded dunes with pine forests). This may be due to the higher elevation of these habitats providing some protection from SLR than lower-lying habitats (e.g., white dunes, shoreline).

However, these results do not consider that habitats 2130 and 2270 only exist due to the protective function of foreshore habitats in front of them (1210 and 2120). According to the EU Habitats Directive, the foredune habitats (those close to the sea) 1210 and 2120 are critical for protecting back dune habitats 2130 and 2270. Foreshore habitats absorb the impact of waves and wind, thereby reducing erosion and preventing saltwater intrusion into the areas behind them. The protective function of the foreshore habitats creates a stable environment for the development and maintenance of the diverse plant communities and habitats of the grey (2130) and wooded dune (2270) behind them. With the estimated loss of the foredune habitats under sea level rise (Section 3.2.1), it is difficult to assume that the two habitats (2130 and 2270) adapted to less extreme environmental factors than those present towards the sea, can exist without the protection of the foredune habitats.

The current high proportional area of the two priority habitats (2130, 2270) implies that these habitat areas could be a useful nature-based defence against coastal flooding in the future if managed correctly. However, the maintenance of these habitats is also dependent on the maintenance of the foredune habitats (1210 and 2120). Thus, further work is required on dune succession and responses to projected sea level rise, from which we could derive helpful management tools to maintain or improve the condition of priority habitats (2130, 2270) *and* the protecting **foredune habitats (1210 and 2120), in turn maintaining the natural flood protection ecosystem service benefit**.

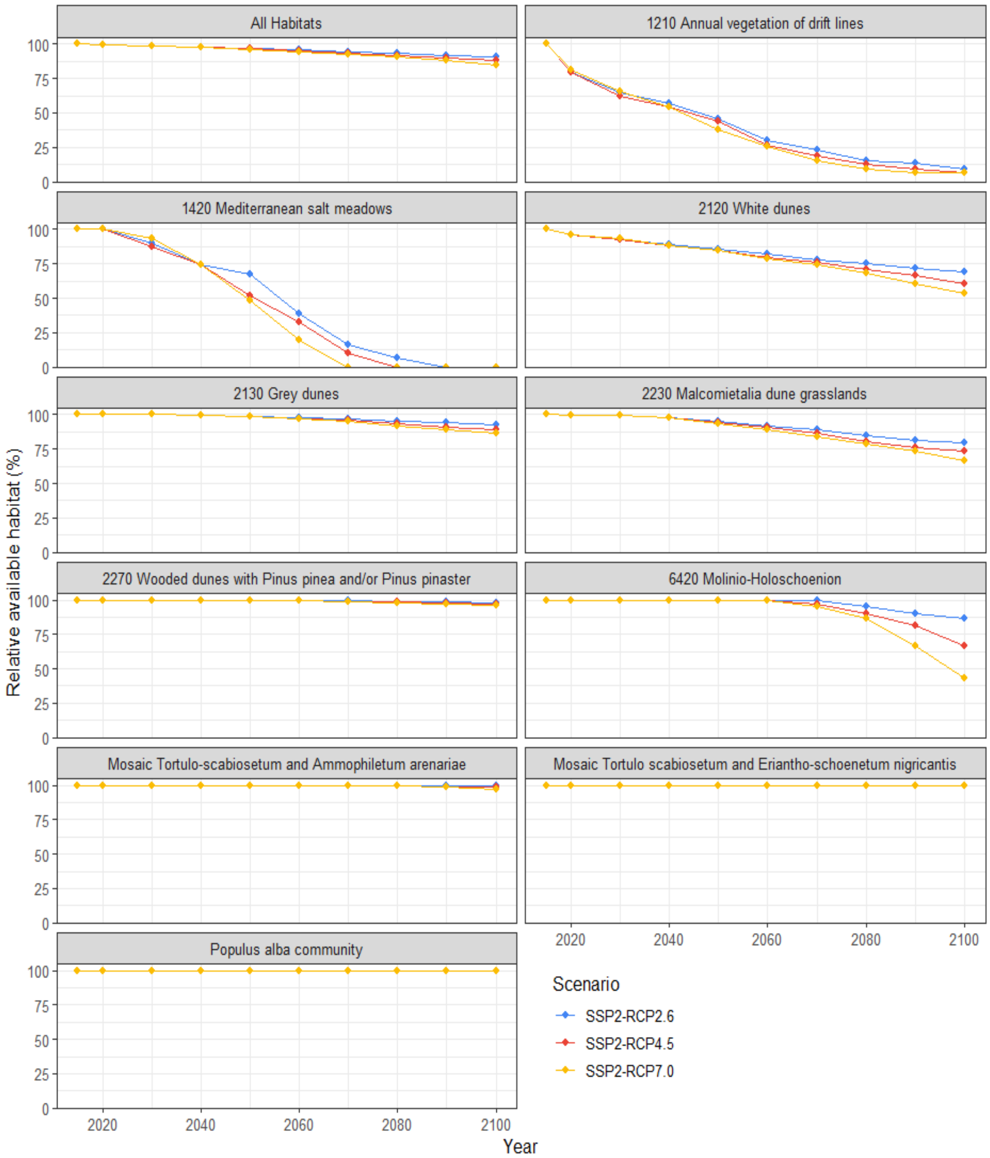


Figure 3.2.7: Relative available terrestrial habitat type area (%) under sea level rise projections.

3. Identifying adaptation options

The protection of biodiversity, and in particular of the dune system in the Alberoni Oasis, depends on the reduction of anthropogenic pressures, including the reduction of coastal squeeze, and a correct management of the beach and the dune area. Measures envisaged for adaptation focus on the reduction of anthropogenic impacts on the dune system include (Table 3.2.2):

Table 3.2.2: Adaptation options.

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy
1	Forest management (regional forest agency)	Conversion of the pine-wood into autochtonous mixed dune forest (reduction of fire risk, protection of the dune system, implemented by the regional forest agency)
2	Dune protection and management (WWF)	a) Delimitation of pathways crossing dune areas channel the accessibility of the beach area for tourists. Installation of fences, and wooden pathways). b) Intensification of awareness rising among residents and visitors and stronger surveillance of visitors' behaviours c) Surveillance of nesting areas and emergency interventions during storm surges, thinning and elimination of invasive vegetation
3	Dune reconstruction (Lagoon authority, Local authority)	a) Reconstruction and revegetation of missing parts of the dune system (recreation of parts of the dune habitat). b) (1) cancellation of unused concession (2) closure of existing establishments at expiry of existing concessions
4	Reduce urbanization (local authority)	Closure of roads accessing to the beaches, creating space for dunes (demolition of buildings and other sealed surfaces)
5	Governance	Competences for actions are split between different authorities, coordination needed

1. Forest Management
   The pine wood covering parts of the furthest dune ridges is gradually being transformed into a forest composition based on local species (ash, holm oak and downy oak) to re-establish a local dune habitat and reduce risk of forest fire. This process is managed and financed by the regional forestry department as a management of natural substitution of trees.
2. Protection and rehabilitation of dune habitats
   The protected area is actually delimited by fences and signposts, while within the area, access to the more vulnerable parts of the dunes is not limited. To reduce damages to the dune vegetation, fenced corridors or pathways can channel the accessibility of the beach area for tourists. This requires investments in fences, combined with wooden pathways and the maintenance of these structures.
   Intensification of awareness raising among residents and visitors and stronger surveillance of visitors' behaviours active surveillance of dune access by WWF and public authorities who are able to enforce respect of rules. Awareness rising activities include guided tours and beach cleaning campaigns are currently guaranteed by WWF volunteers.
   During the nesting period of the Kentish plover, volunteers of the WWF delimit the nesting areas and survey the nests during the days of major touristic presence. During storm surge events which would put the nests at risk of being flooded, they transport the nests to higher areas as an emergency intervention, thinning and elimination of invasive vegetation.
3. Dune Reconstruction
   In correspondence of the major beach establishment, a part of dunes has been eliminated to create a parking lot and bus stop which provides direct access to the beach area and the beach establishments. Also in the northern part of the protected area, dune areas have been flattened to make place for beach establishments which are no longer in use, although beach concessions have not been extinguished. The dune ridge should be reconstructed and revegetated to strengthen and recreate biodiversity of the dune system and provide protection to the settlement situated behind the dunes.
   Review of concession for beach establishments: the local authority would need to immediately stop the emission of new beach concessions within the protected area. A successive step should be the (1) cancellation of unused concessions (2) closure of existing establishments at expiry of existing concessions.

4. Reduce urbanization/coastal squeeze
   Further to buildings and artefacts to be eliminated to allow dune reconstruction, also building ruins, tarmac, etc. in the area behind the dunes could be eliminated and areas re-naturated, to reduce the coastal squeeze and create space for dune migration.
5. Governance
   Governance competences for the area are split between different authorities (region, local urban planning and environmental services), a better coordination and alignment of objectives would be beneficial.

4. Assessment of adaptation options

4.1 Methodology

Considering the main objective of the adaptation measures, the conservation of biodiversity in a typical coastal ecosystem, no CBA has been envisaged. The only monetization could regard the protection effect of dune reconstruction, closing the interruption of the dune belt. Actually, this breach in the natural protection belt increases the exposure of the settlement behind the Oasis to storm surges.

Table 3.2.3: Assessment strategy: Appraisal Criteria

What appraisal criteria are considered?		How are the criteria measured?		
	Who benefits?	Qualitative	Quantitative	Monetised
What direct costs are considered? Costs for enforcing surveillance, installation (opportunity costs for foregone beach uses/installation of beach establishments)	Local authority		x	x
What direct benefits are considered? Increase of biodiversity, conservation of a rare habitat and species	society	x		
What co-benefits and co-costs are considered? Economic: ecosystem services: carbon sequestration of dune vegetation	Whole society		X	
Flood protection for the residential area	Residents and establishments in Alberoni,		x	x
Social: • biodiversity (cultural, recreation)	Lido/Venice residents tourists	X		x
Environmental: • Value of biodiversity and coastal habitats	society	x		
Are you considering general welfare effects? If so, how?		Distributive	Temporal	Spatial
no				

Co-effects

The consolidation and conservation of habitats by reducing anthropogenic pressures is expected to allow for the adaptation of the habitat at least for the medium term (until 2050). All options selected are directly supporting natural processes and biodiversity conservation and reducing anthropogenic impacts by non-invasive physical interventions and changes in management and governance of the whole area.

Costs of measures

Overall (not discounted) costs of the envisaged measures are of €13.453.700 over 25 years. See Table 3.2.4 for costs per measure.

Table 3.2.4: Schematic overview of adaptation measures and (undiscounted) costs:

	Operational costs/losses of revenue	Actor	Investment (€)	2025–2050 (25yrs)	Source
1. Forest management 2023	2.646,90€/ha for 26ha	Regional Forest agency	€70.000		Prezzario Regionale Agroforestale 2022
2. Dune protection					
a) fences walkwaysfor 2000m	€52/m €100/m for 2000m	Local authority	€4,104.000		Regione Veneto, Prezzario Regionale Agroforestale 2022
b) awareness raising	€80.000 per year	WWF		2.000.000	Management costs WWF Venezia (personal communication by the stakeholder)
c). Nesting protection, thinning/elimination of invasive vegetation	€30.000 per year	WWF		750.000	
3) Dune reconstruction					
a).Physical reconstruction of missing dune ridge (9200m2; per 1,3m, 11,960m^3)	€74/m3 for 11,960 m^3	local authority, lagoon authority	€1.021.200,00		https://adriadapt.eu/adaptation-options/dune-construction-and-strengthening/
b) cancellation of unused beach concessions, loss of public revenues	€ 9800 per yr	Local authority		€245.000	https://dati.mit.gov.it/catalog/dataset/concessioni-demaniali-marittime-a-maggio-2021
Closure of existing establishments and cancellation of concessions after expiry in 2033	€30.100/yr	Local authority		€662.200	
4. Reduction of coastal squeeze: demolition of existing artefacts		Local authority			
Total			€ 5.195.200	€ 3.657.200	€ 8.852.400

1 Prezzario Regionale Prezzario Regionale Agroforestale 2022
2.a Regione Veneto, Prezzario Regionale Agroforestale 2022
2 b,c Management costs WWF Venezia
3 a https://adriadapt.eu/adaptation-options/dune-construction-and-strengthening/
3 b, c https://dati.mit.gov.it/catalog/dataset/concessioni-demaniali-marittime-a-maggio-2021

4.2 Results

While costs of measures have been quantified at an indicative level (see table 3.2.4), no overall quantification of benefits has been envisaged. A qualitative description of benefits for biodiversity has been provided by IIASA, based on information on biodiversity distribution from IIASA. Benefits for residents and owners of premises in Alberoni would arise from a reduction of reduction of flood risk thanks to the closure of the dune belt. See Table 3.2.5.

Table 3.2.5: Scorecard

Criteria/ Strategy description	Reversibility	Costs	Social benefits	Economic benefits	Ecologic benefits	Resilience
Forest management (Regional Forest agency)	**0**	+	+	+	+	++
Dune protection and management (WWF)	++	+	++	**0**	+++	+++
Dune reconstruction (Lagoon authority, Local authority)	**-**	++	++	+	++	+++
Reduce urbanization (Local authority)	**-**	++	**0**	**0**	++	+++
Governance	+	**0**	+	**0**	**0**	++

Legend: -, -- negative or strong negative impact, 0 neutral or no impact, +, ++ positive or strong positive impact.

5. Barriers and conditions for implementation

Forestry

This activity is actually on-going as part of a general forestry strategy of the Region which aims at managing forest habitats in a close to nature manner. The strategy generates benefits in relation to reduced fire risk and to the re-establishment of typical local habitats of dune areas in the northern Adriatic.

Dune protection

The implementation of dune protection measures depends heavily on public awareness, to be translated into political will for active policies in favour of the protection of the dune habitat. This would, inter alia, require an increase of funding for surveillance and management of the area by the local authority, inverting a trend of the past 10 years which saw a reduction of the compensations paid by the local authority to WWF for the management of the site, further to an investment in physical infrastructures (fences etc. to limit trampling in the dune area).

Dune Reconstruction

The reconstruction of the missing part of the dune ridge represents a major intervention with relatively high costs, as it might require the use of sand to be transported as the distance of the part to be reconstructed is too far for natural beach growth processes. Further to planting of the new surfaces and creation of additional infrastructures to protect the area, and allow access to the beach (included in the gross cost estimates for the dune reconstruction).

Except for the dune reconstruction, measures foreseen are reversible, except the demolition of (derelict) buildings. These building, which are located in the northern part of the area, are unused since some time. Revoking unused beach concessions would cause a loss of income to the local authority, which would theoretically be reversible, but might also have some political implications due to resistance from concession holders who would need to renounce on potential future economic exploitation.

Potential social and cultural and political barriers can arise on the side of beach users who would oppose a closure of the beach services, and by economic actors who would like to exploit the location offering services to beach visitors. For this reason, the existing beach establishment could be conserved at least for the duration of the concession (actually until 2033), revising the access crossing the newly created part the dune belt. This establishment could be combined with a small visitors centre and a permanent office for WWF staff.

Beach concessions in the central part of the area are related to buildings in use or even only recently built and the management of the beach. The closure of active beach concession of active beach concessions (services and management of the beach) would entail an economic loss for the local authority, further to political opposition by the holders of the concession and beach users not willing to renounce on the amenities offered by the beach services (restaurant, showers and bathrooms, etc.)

<u>Reduction of urbanization and coastal squeeze</u>
The reduction of urbanization and demolition of artefacts on the back of the dune area (streets, etc) would require a rethinking of the local urbanization strategy towards a more protection-oriented, long-term vision for the whole area, further to important costs for demolition an indemnisation, while providing benefits for the resilience of the dune habitat and the ecosystem services ensured by a vital dune system.

<u>Governance</u>
Increasing multi-level governance and co-ordination for a joint management of the dune habitat would potentially create synergies and promote coherent policies, with benefits for the management of the protected area and the resilience of the dune system, channelling different financial resources into joint activities.

Table 3.2.6: Assessment strategy: Barriers for implementation.

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governance and institutional (G).

#	Barriers	Cat.
1 Forests	Forest management is on-going as a slow transformation process, forest surface is limited by urbanization	P/B
2 Dune protection	(a) Costs of physical infrastructures for dune protection (b) Costs of surveillance and awareness raising (c) Manpower for protecting hatching sites from flooding during storm surges	P/F/G
3 dune reconstruction	Public opposition to limitation of new concessions, eventual indenisations High costs of dune reconstruction	B
4 urbanization	Public opposition to limits to urbanization, costs of demolition and indenisation of owners	S
5 governance	The split of competences between urban planning, beach and forest management and nature conservation would require some coordination.	G
		…

6. Conclusion

The major benefits of a strategy for protection of the coastal habitats of the Alberoni Dunes are in terms of Resilience due to decrease of flood risk for the Alberoni settlement and of decreased fire risk in the area close to the pinewood. This comes at costs in terms of foregone income from concession fees for the Local Authority, from further urbanization and touristic exploitation of the area at expense of the coastal dune habitats. Other costs to be borne by society are caused by dune reconstruction, activities for the management of the area and biodiversity conservation.

The conservation of the area furthermore provides benefits to the entire society due to the existence of its biodiversity, and its carbon sequestration capacities, while visitors and beach users can benefit from its cultural and recreational values.

The creation and conservation of these values require a strong political will and dedicated action (planning, surveillance) to protect the area and avoid further urbanization.

4 Health & justice

Case study 4.1 – Adaptation policy assessment, focus on health and distributional aspects (Spain)
Partner: BC3
Spatial scale: Regional (Basque Autonomous Community, NUTS2)
Stakeholder: Basque Environmental Agency (Ihobe)

1. Decision context

This case study focuses on the Basque Country, a region located in the north of the Iberian Peninsula, with a 209 km coastline stretching along the Cantabrian Sea. With an area of 7,234 km^2, the population was 2,175,000 inhabitants in 2017, resulting in a population density of 300 inhabitants/km^2. It is the fifth largest economy in Spain, with a per capita income of €35,800, above the national average.

Regional governments play a crucial role in developing and implementing climate adaptation policies (Setzer et al., 2020). This is particularly relevant in Spain's context, as it is not a federal state yet has a high degree of decentralisation. The Autonomous Community of the Basque Country has historical rights that have enabled it to develop a high degree of self-government since the transition, together with Navarre. Like many other regional governments, the Basque Country has the authority to act in areas key to public adaptation policies, such as finance, land use, disaster management, natural resources, education, and health (Galarraga et al., 2011).

The Basque Climate Change Strategy (Klima 2050), which was approved in 2015, and the Energy Transition and Climate Change Act, which was adopted by all parties in the Basque Parliament in January 2024, are currently the key climate policies for adaptation. The Basque Government also has an Energy Transition and Climate Change Plan for 2021–2024, which is currently being updated. From a sectoral perspective, the Basque Government has a Health Plan 2030, which provides a framework for all health-related policies and annual heat prevention plans.

In this context, the following research questions arise in both case studies: 1) What are the economic and financial implications of climate risks for the health sector? 2) What are the differential effects and social justice dimensions of adaptation options for different groups? 3) What are the costs and co-benefits of socially-just adaptation options?

2. Current and future risk

According to regionalised scenarios for the Basque Country, there has been a trend since 1971 towards fewer cold-dry days and an increase in the average daily temperature of more than 1.0°C. All indicators calculated from maximum temperatures that are statistically significant show a positive trend. These trends are projected to continue in future climate scenarios, with increases in minimum and maximum temperatures, as well as in the number of summer days and days above the 35°C threshold. This is likely to result in an increase in the frequency and duration of heat waves (Ihobe, 2019).

The expected health impacts of climate change are primarily related to increased temperatures, worsening air quality, and increased flooding and landslides. These factors will lead to higher morbidity and mortality rates, an increase in diseases (e.g., respiratory, skin, and vector-borne, etc.) and a deterioration in human comfort (Ihobe, 2019).

3. Identifying adaptation options

Planning for adaptation to climate change in the health sector is more dispersed in the case of the Basque Country. Table 4.1.1 lists the measures identified in the main planning documents.

Table 4.1.1: List of the main health-related adaptation options included in the Basque public policies.

Type of measure			Measure	Plan or strategy
Grey	Green	Soft		
x	x	x	Ensuring the resilience of the built environment and critical infrastructures (energy, water, food, health and ICTs) in the face of extreme events	Basque Climate Change Strategy (Klima 2050) Energy Transition and Climate Change Plan 2021-2024
x			Promotion of energy efficiency and rehabilitation of the urban building stock.	Basque Urban Agenda (Bultzatu 2050)
		x	Early warning systems	Health Plan Euskadi 2030 Klima 2050
		x	Improve emergency management	Energy Transition and Climate Change Plan 2021-2024
		x	One health approach to identifying, monitoring and evaluating health risks	Health Plan Euskadi 2030
	x	x	Promoting a resilient urban infrastructure by developing green infrastructures and NBS	Health Plan Euskadi 2030
		x	Mainstreaming vulnerability analysis and climate change adaptation into land planning	Health Plan Euskadi 2030
		x	Explore the co-benefits of environmental (and climate) policies.	Basque Urban Agenda (Bultzatu 2050)
		x	Governance: inter-institutional coordination and collaboration	All
		x	Promoting healthy lifestyles in cities (e.g. inclusive and safe urban planning, promoting walking and cycling…)	Basque Urban Agenda (Bultzatu 2050)
		x	Heat information / awareness-raising	Heat Plan 2024
		x	Preventive measures during heat waves (these include actions for local authorities, health and social services, companies and occupational health officers)	Heat Plan 2024

We found no reference to transformational adaptation options or adaptation of health services. There were no mentions of climate shelters, but some local projects are already in place. Planning documents barely mention the non-temperature-related health effects of climate change.

4. Assessment of adaptation options

4.1 Methodology

The assessment methodology for this case study consists of two main parts: 1) A qualitative social justice assessment of the Heat Action Plan focusing on the consideration of vulnerable groups in the plan's measures and 2) a cost-benefit analysis (CBA) of socially-just adaptation options

4.1.1 Social justice assessment

The social justice assessment developed in the Basque Country has been limited by the strategic characteristics of the adaptation planning documents in force. The methodology follows the the Adaptation Justice Index (AJI) defined by Juhola et al. (2022). The AJI was developed to operationalise the four dimensions of justice (recognition, distribution, participation and restorative justice), providing a comprehensive view of the justice of adaptation plans from a climate justice perspective (see Table 4.1.2). AJI uses an ordinal scale to compare the extent to which justice is integrated into the documents. The resulting scores aim to reflect the comprehensiveness and ambition with which the various justice-related issues are addressed in the policy documents. However, climate justice criteria have only recently been incorporated into adaptation planning, so rather than obtaining a score, we have opted to carry out a qualitative analysis.

Table 4.1.2: Dimensions considered in the assessment

1. Recognitional justice
1.1. The strategy acknowledges that adaptation needs are different across groups in society
1.2. The strategy acknowledges the impact of existing societal structures on vulnerable groups in adapting to the impacts of climate change
1.3. The strategy acknowledges adaptation as a way to secure basic rights
2. Distributive justice
2.1. A risk mapping/assessment is conducted
2.2. Vulnerability assessment is conducted and there is a process for identifying vulnerable groups
2.3. There is a process that assesses the distribution of benefits from adaptation
2.4. There is a process that assesses how costs of adaptation are divided
2.5. The strategy identifies the possibility of the distribution of negative impacts, i.e., maladaptation, of adaptation measures
3. Procedural justice
3.1. Adaptation plan details who participates in the strategy process
3.2. The adaptation strategy has involved participation during different phases of the process
3.3. The strategy allocates responsibilities related to adaptation
3.4. The adaptation strategy has a structured plan for participation in the implementation.
3.5. The adaptation strategy has a plan for updating and evaluating the strategy
4. Restorative justice
4.1. The strategy acknowledges the need to compensate for the diverging impacts of climate change
4.2. The strategy has compensation measures to deal with maladaptation
4.3. The unequal distribution of resources for adaptation is compensated by redistribution

For each of the indicators presented in Table 4.1.2, Juhola et al. (2022) provide a scoring system that allows for some consistency in the evaluation process. An example is provided in Table 4.1.3, which shows the suggested scores for the recognitional justice dimension. As mentioned earlier, the values shown in Table 4.1.3 were not used in the assessment to produce a single score but to provide an indication of the level of commitment to and ambition for the inclusion of equity criteria in adaptation planning.

Table 4.1.3: Detailed criteria for evaluation as defined by Juhola et al. (2022).

Dimension	Indicator	Scale	Value
Recognitional justice	1.1. The strategy acknowledges that adaptation needs are different across groups in society	No	0
		The strategy states that adaptation needs are different	1
		The strategy takes into account different adaptation needs based on expert review	2
		The strategy is built on different groups identifying their adaptation needs	3
	1.2. The strategy acknowledges the impact of existing societal structures on vulnerable groups in adapting to the impacts of climate change	No	0
		The existence of structures is mentioned in general manner	1
		There are measures to decrease the impact of structures	2
		There is a structured plan to assess the impact of societal structures on vulnerability	3
	1.3. The strategy acknowledges adaptation as a way to secure basic rights	No	0
		Adaptation as a way to secure basic rights is mentioned	1
		The strategy describes how adaptation can secure basic rights in general	2
		The strategy has measures to secure basic rights	3

4.1.2 Assessment of costs and benefits

The assessment of costs and benefits seeks to answer policy question *1) What are the economic and financial implications of climate risks for the health sector?* and policy question *3) What are the costs and co-benefits of socially-just adaptation options?* Based on the work developed in WP2, we have an estimate at the NUTS3 scale of the costs of climate change in terms of heat-related mortality and morbidity. These data are available for a combination of RCPs and SSPs (see ACCREU Deliverable 2.3). Furthermore, the costs of adaptation measures foreseen in the above-mentioned planning instruments have been estimated. Based on the literature, an estimate of the potential effectiveness of these measures will be made, allowing us to calculate the avoided costs.

Table 4.1.4: Evaluation criteria used in the cost-benefit analysis.

Appraisal criteria (C)

What appraisal criteria are considered?	How are the criteria measured?		
	Qualitative	Quantitative	Monetised
What direct costs are considered?			
- Cost of mortality		X	X
- Cost of morbidity		X	X
- Cost of health and adaptation options	X	X	X
What direct benefits are considered?			
- Avoided mortality and morbidity		X	X
- Reduced healthcare costs		X	X
- Reduced social inequality	X		
What co-benefits and co-costs are considered?			
Economic: • Effects on productivity		(X)	
Social: • Social justice	X		
Social: • Well-being	X		
Environmental: • Biodiversity	X	(X)	
	Distributive	Temporal	Spatial
Are you considering general welfare effects? If so, how? Yes We will consider the distributional and wider social justice effects of heat impacts and how this is integrated in adaptation policy and related measures with relevance for the health sector. This includes analysis of vulnerable groups' residence, work context and access to health services.	X	X	X

4.2 Results

4.2.1 Social justice assessment

This assessment draws primarily on the Basque Country's long-term framework Klima 2050 (Basque Government, 2015) and complements it with the subsequent Energy Transition and Climate Change Plan, PTECC 2021–2024 (Basque Government, 2021), given the strategy's time horizon.

<u>Dimension 1: Recognitional justice</u>

Although the term 'recognitional justice' is not explicitly used in Klima 2050, the strategy recognises that the impact of climate change is uneven and place specific. Vulnerability and the resulting impact depend on the physical, biological, ecological, economic, and social characteristics of each territory. The expert prioritisation process consistently states that, under the equity criterion, most sectors foresee unequal impacts, thereby reinforcing the idea of differentiated effects across society. In recognising intra-societal differences, the public health section (Annex V) explicitly calls for further work on group-specific and gender-differentiated vulnerability. It acknowledges the heterogeneity among "different social groups and between men and women".

Regarding structures that shape vulnerability, the strategy identifies non-climatic structural drivers—e.g., urban form/structure/functions, deficient sanitation systems, and sociodemographic change—as key determinants of exposure and impacts in cities, and routes responses through territorial and urban planning instruments. The PTECC integrates vulnerability/adaptation criteria in critical infrastructures (energy, water, health, education, ICTs, transport, industry), but without a focus on social vulnerable groups. Finally, while Klima 2050 does not frame adaptation as securing basic rights in explicit rights language, some lines of action do underpin essential services, such as guaranteeing water supply.

<u>Dimension 2: Distributional justice</u>
Klima 2050 lays important groundwork for the spatial distribution of climate risks by integrating climate criteria into territorial/urban planning. However, it falls short of assessing who within society bears those risks or who benefits from adaptation measures. The PTECC moves forward and explicitly flags a "just transition" and energy-poverty mitigation; yet it still does not offer a comprehensive analysis of the distribution of benefits and costs of adaptation across groups or territories.

Concerning risk assessments (indicator 2.1), Klima 2050 requires identifying, analysing and monitoring the zones and critical infrastructures most exposed to climate hazards, and includes a dedicated line of action (Line 17 under Objective 7). The PTECC builds on by funding municipal planning tools, calls for adaptation/mitigation project grants in municipalities and counties, and pilots under LIFE IP Urban Klima 2050, thereby operationalising risk work where impacts are felt. Its monitoring system also tracks municipalities with adaptation plans, linking risk work to coverage across the territory rather than social or vulnerable groups.

Klima 2050 embeds vulnerability analysis (indicator 2.2) in planning (DOT, PTP, PTS, PGOU) and, in the annexes, makes equity a cross-cutting criterion, noting that most sectors foresee unequal impacts, recognising that vulnerability is not uniformly distributed. It also details non-climatic structural drivers that shape exposure (e.g., urban form). Once more, the strategy's vulnerability framing is largely sectoral/territorial, rather than group-specific. The PTECC makes distributional concern more explicit through Line of Action 8 for a just transition, including Measure 24 to provide technical and financial support to avoid energy poverty and to sustain social cohesion.

Neither document offers a systematic appraisal of who benefits from each adaptation measure by income, gender, age, or municipality (indicator 2.3) or who bears the cost (indicator 2.4). Klima 2050 prioritises risk hotspots and critical systems, which implicitly concentrates benefits where exposure is greatest. The PTECC allocates funds to support local initiatives and to building rehabilitation and retrofitting, and underlines the need to guarantee a "just transition". There is clear resourcing of potentially pro-equity measures, but it lacks a formal benefit-distribution analysis.

With regards to maladaptation (indicator 2.5), the PTECC explicitly warns against it in the context of developing mitigation–adaptation–energy policies. Klima 2050 minimises this risk via planning integration and attention to critical infrastructures; however, neither document assesses who could be potentially affected.

<u>Dimension 3: Procedural justice</u>
This is likely the dimension in which the Basque framework performs stronger. Both planning documents have been developed through broad participatory processes, multilevel coordination, explicit responsibilities, and structured monitoring. Some remaining gaps exist in relation to enabling the participation of vulnerable groups. While the PTECC defines a monitoring, evaluation and reporting (MER) system including detailed indicators and reporting, it is less explicit about how stakeholders engage in this process.

Klima 2050 has a strong procedural basis. In its development, participation was opened up to a range of stakeholders, including a dedicated Udalsarea 21 forum involving municipalities and local organisations, a public Social Forum, and an open consultation on Irekia[5]. These were all used to inform long-term strategies and adjust action plans. While this widened access at the agenda-setting stage, the text does not spell out bespoke mechanisms to specifically include vulnerable groups in decision-making processes.

Participation extended across the phases of the plan, with several participatory sessions happening during the development process (indicator 3.2) and into the monitoring and updating phases (indicator 3.5). Klima 2050 committed to producing follow-up reports every two years from 2017 onwards, as well as intermediate evaluations in 2020, 2030, and 2040. The first evaluation report was published in January 2022[6]. These provisions are complemented by capacity-building and coordination enablers, such as training for public servants and public information (lines 20–21) and inter-institutional coordination (line 23). These measures aim to sustain multilevel engagement over time. Responsibilities during follow-up and evaluation (indicator 3.3) are assigned to the general administration, with coordination assigned to the Directorate for the Natural Environment and Environmental Planning.

The PTECC 2021–2024 specifies a clearer governance model, led by the Department of Economic Development, Sustainability and Environment and a technical–political commission (EVE, Ihobe) tasked with coordination and evaluation (indicator 3.3). It also establishes a MER system with a department responsible for each action line (indicators 3.2, 3.5).

For participation in implementation (indicator 3.4), there are measures to support municipalities and counties, including tools and methodologies to integrate climate into local planning, indicator support via Udalsarea 2030, working groups, grant calls for adaptation/mitigation projects, and a LIFE project Urban Klima 2050 pilots designed for transfer across the territory.

<u>Dimension 4: Restorative justice</u>

In line with Juhola et al.'s (2022) findings, restorative justice is the least developed dimension in the Basque Country's adaptation framework. Neither Klima 2050 nor the PTECC specifies compensatory mechanisms for uneven climate harms, provides ex post remedies for maladaptation, or sets explicit rules to redistribute adaptation resources toward low-capacity groups or municipalities. The PTECC does advance a just transition framing and anti-energy-poverty support, but these instruments sit adjacent to adaptation redistribution rather than constituting compensation for climate harms.

4.2.2 Assessment of costs and benefits

<u>Effectiveness of Heat Action Plans</u>

In the absence of direct data on the implementation of the Heat-Health Action Plans (HHAP), we turned to the literature to obtain an estimate of the benefits that these plans can have in terms of avoided impacts, both in terms of mortality and morbidity.

Following the 2003 heatwave, which marked a turning point in Europe, HHAPs have increased significantly, and today there are numerous plans at national, regional, and even municipal levels (Martinez et al., 2019). However, Dwyer et al. (2022) argue that, considering the number of heat plans currently in place, the number of studies assessing their effectiveness in the literature remains relatively low. This is more so in relation to morbidity outcomes.

A study of the benefits of heat alerts in 20 US cities found no association with lower mortality, except for Philadelphia, where heat alerts were associated with 4.4% lower mortality rates (Weinberger et al., 2018). Mixed results were also found in a systematic literature review of HHAP evaluations (Dwyer et al., 2022). Among 11 evaluations of heat action plans assessed, only one reported an overall mortality

[5] Irekia is the Open Government platform: https://www.irekia.euskadi.eus/en/site/tos?label=about&requirements%5Blabel%5D=%28%3F-mix%3A%5Cw%2B%29

[6] https://www.ihobe.eus/es/publicaciones/primera-evaluacion-estrategia-cambio-climatico-pais-vasco-klima-2050-2

reduction; two of three morbidity evaluations found reductions; and one multi-city study observed a protective effect in a single city only. Overall, positive signals are limited and context-specific.

In Spain, after the HHAP[1] was introduced, the extreme-heat mortality fraction decreased (from 0.67% to 0.56%, a relative reduction of 16%), but this was offset by an increase in the moderate-heat mortality fraction (from 0.38% to 1.21%), so the total heat-attributable mortality increased. On plan-activation days, the attributable fraction was reduced. Interestingly, those provinces with more actions being implemented within their HAPs showed higher decreases in mortality attributable to extreme heat (Martínez-Solanas and Basagaña, 2019).

In Italy, de'Donato et al. (2018) found that among adults over 65 years, the heat-attributable mortality fraction for extreme temperatures fell from 6.3% to 4.1% across 23 cities (35% relative decline), after the introduction of the national HHAPs.

Feldbusch et al. (2025) analysed the effectiveness of the national heat and health warning system in 15 German cities using a difference-in-differences approach. After adjusting for city characteristics, heat alerts were associated with 15% lower all-cause mortality on alert days (RR = 0.85; 95% CI 0.75–0.97). When city characteristics were not considered, no protective effect was found (RR = 1.00; 0.98–1.01). City-level reductions were statistically significant in Berlin (RR = 0.95), Frankfurt (0.94), and Hamburg (0.95).

On balance, the evidence of a reduction in mortality is stronger than the evidence for no effect or an opposite effect.

<u>Estimating the benefits of heat-related adaptation measures in the Basque Country</u>
The benefits of adaptation measures aimed at reducing the effects of heat on human health are usually measured in terms of avoided mortality and morbidity. As done in the case of Bremen, we adopt (i) a central effectiveness of 15% of the Basque Country's heat adaptation measures for all-cause mortality (Feldbusch et al., 2025). As a sensitivity analysis, a lower bound of 5% (Weinberger et al., 2018), and an upper bound of 30% (e.g., de'Donato et al., 2018) could also be applied. For the effects on morbidity, we follow the approach applied by Markandya et al. (2025) that relates heat-related mortality and morbidity based on data from Adelaïde et al. (2022). Mortality data (referred to adults over 65) is taken from Loroño et al. (2025) and morbidity from Markandya et al. (2025).

Given that the Basque Country's assessment relies heavily on the heat emergency plan and this has been in place since 2006, no maturity ramp has been considered.

<u>The cost of heat-related adaptation measures in the Basque Country</u>
The measures considered in this CBA are drawn from multiple Basque planning frameworks and are therefore heterogeneous in scope, maturity, and budgeting. They span strategic directions in KLIMA 2050 (umbrella adaptation strategy), sectoral initiatives in the Energy Transition and Climate Change Plan (PTECC), urban actions in the Basque Urban Agenda (Bultzatu 2050), and health-system responses (Basque Health Plan 2030). These plans emphasise resilient cities and green infrastructure, preparedness and governance, and the need to align health, environment, and urban policy; however, itemised heat-specific budgets are not always provided.

To develop the CBA, we have grouped the identified adaptation options (Table 4.1.1) as follows:

i. Strategic measures. High level objectives that lack a heat-specific package or budget in the short term (e.g., ensuring the resilience of the built environment and critical infrastructure). They are excluded from the CBA due to the difficulty of measuring their cost, as well as to avoid misattribution and double-counting.
ii. Preparedness and emergency response. Heat plan or health system measures and include early warning communications, targeted outreach to vulnerable groups, clinical and occupational protocols, and monitoring and evaluation. These measures are operational and can be costed following previous studies from the literature (e.g., Hunt et al., 2016).

iii. Urban cooling and green/grey infrastructure. Actions such as urban greening, green/cool roofs and pavements, unsealing, and broader rehabilitation that appear in the Urban Agenda–Bultzatu 2050 and PTECC as programmatic lines, rather than heat-mitigation projects. They are multi-hazard, multi-benefit, and currently lack heat-specific packages and specific budgets attributable to the Heat Plan[7].
iv. Cross-cutting governance measures, including inter-institutional coordination, preparedness and routine surveillance of the impacts of heat. These measures are considered when costs are available (e.g., estimates of fixed annual costs).

The CBA includes group (ii) and those items in group (iv) with clear, heat-related costs. We exclude (i) strategic and (iii) urban cooling/green-grey items from quantification at this stage because they were not defined as heat-specific packages and/or assigned specific budgets. This makes our results conservative for both costs and benefits.

The first action involves an annual programme cost, which covers the planning, oversight, coordination, and reporting of the identified adaptation measures. This cost is estimated at a conservative 0.5% share of the public health programme developed in the Health Plan 2030 (€150,000), given that the Plan's objectives are not broken down into specific budget lines for heat. The cost of all activity-driven effort is allocated to each operational measure. We budget for monitoring and evaluation as a small, fixed cost. On heat-warning days, we allocate an additional budget to cover alert notifications, increased outreach activity, overflowing helplines, and other minor expenses (Table 4.1.5).

Table 4.1.5: Detailed criteria for evaluation as defined by Juhola et al. (2022).

Measure group	Planning documents	Cost per year (€)
Governance and coordination	Public Health Plan 2030 HAP Action 1. Implementation and coordination	150,000
Heat portal / web info	HAP Action 2. Information and awareness;	20,000
General public awareness campaign	HAP Action 2. Información y sensibilización	40,000
Attention to vulnerable groups: preventive measures and information	HAP Action 2. Information and awareness; HAP Action 4.2 Preventive measures	20,000
Training	HAP Action 4.2 Preventive measures	20,000
Occupational heat protection (high-exposure jobs)	HAP Action 4.2 Preventive measures	10,000
Monitoring & evaluation	HAP Action 5. Monitoring the health effects of heat	34,000
Alert activation-day budget *(10 heat-days per year)*	HAP Action 3. Forecasting and assessment system HAP Action 4.1 Communications by risk level	100,000
Total (per year)	—	394,000

These estimates are conservative yet consistent with those of previous studies. A previous cost-benefit assessment in the Basque Country modelled HHAP spending using a fixed component and a variable per-alert term based on assumptions about staff time (Chiabai and Sainz de Murieta, 2017). The resource-based costing for heat-health programmes follows the methodology of Hunt et al. (2016). A recent European synthesis reports costs of around €7,800 per heat day for warning operations alone and between €9,261 and €14,000 per heat day when health action components are included. It also notes cases involving an additional fixed annual contract/dissemination cost of around €200,000 (Hunt et al., 2016; Rao et al., 2025). Historical evidence from Philadelphia also puts direct per-warning-day cash costs at around $10,000, which supports the idea that the activation costs we assume are typical of alert-and-response models (Ebi et al., 2004).

[7] Some initiatives in the PTECC have headline budgets (e.g., the municipal NBS programme has a budget of €4.7 M in the 2021-2024 period) but they are not heat-specific. Therefore, do not allocate them to this CBA unless a heat-targeted package is specified.

Comparing costs and benefits

Over 2025–2030 the Basque Heat Plan yields very large benefits relative to its cost. Using our central effectiveness prior and valuing mortality with a VSL of €1.3 million (morbidity contributes only marginally), total benefits are about €49 m in 2025 (partial first year) and ~€121 m per year from 2026, across emission scenarios. With the programme cost set at €394,000 per year (fixed €294,000 plus an activation envelope consistent with 10 heat-days), the present value of benefits is €656–764 m at 0% and €587–690 m at 3%, while the present value of costs is €2.364 m (0%) and €2.134 m (3%). This produces BCRs of 277–323 at 0% and 275–323 at 3%, and NPVs around €585–€688 m at 3% depending on the SSP. Results are robust to discounting and to scenario choice; the dominant driver is avoided mortality, with the first-year ramp explaining the lower 2025 benefit. These totals also align with the cost architecture used in prior evaluations (fixed governance and standing capacity plus a per-heat-day operational envelope), while remaining conservative because broader structural adaptation investments are excluded from this CBA.

As in the Bremen case (see case study 4.2), the headline results are driven by the way in which mortality is valued. We use a VSL of €1.3 million and a central 15% effectiveness. With these parameters, the Basque programme would prevent over 90 deaths per year from 2025 to 2030 across SSPs. Given the programme's annual cost of €394,000, that implies an expenditure of approximately €4,200 per death avoided. Even if higher or lower mortality valuations are used, the benefits vastly exceed the costs.

This is without taking co-benefits into account, as these they are not included in Basque adaptation policies. However, research shows that the willingness to pay for climate policies increases when the co-benefits of these policies can bring are considered (e.g., Rodríguez-Entrena et al., 2014). The literature on this topic has grown in recent years, particularly in the context of climate change adaptation (Sainz de Murieta, 2020; Surminski and Tanner, 2016), also within the health sector (e.g., Sharifi et al., 2021). Including these benefits in calculations can enhance the legitimacy of such policies (Krook Riekkola et al., 2011) and could be an effective means of addressing climate scepticism or lack of concern (Bain et al., 2016).

5. Barriers and conditions for implementation

The Basque planning framework has already identified several factors that facilitate adaptation to heat. KLIMA 2050 committed to strengthening early warning and monitoring systems, developing a public portal, and investing in training and communication. The initiative also promotes interdepartmental and inter-institutional coordination.

The 2023 Environmental Profile Report highlighted specific information gaps in heat-health work. It recommended systematically linking environmental information with health data, upgrading information systems to measure environmental stressors and population exposure, and ensuring that territorial diversity and axes of vulnerability are explicitly included in estimates. Until these gaps are closed, attribution and equity-focused targeting will remain limited.

Monitoring, evaluation, reporting, and learning (MERL) are often areas for improvement in adaptation. The annual Heat Emergency plan combines weather warnings with public health surveillance of mortality, but the effectiveness of the implemented policies and measures is not evaluated.

The Basque Health Plan 2030 makes reducing health inequalities a cross-cutting objective and requires all objectives and lines of action to reflect diversity and incorporate axes of vulnerability (including age, gender, social class, education, origin/ethnicity, and territory). This clearly mandates the integration of equity criteria into the planning, delivery and monitoring of health-related actions.

6. Conclusions

The Basque Country has an annual heat emergency plan and solid strategic framework including plans for climate, health and urban development. However, it does not yet have a dedicated programme on health and heat with its own budget and implementation tools that would allow for more in-depth monitoring and evaluation of policies. Some social justice elements are present. There is recognition of uneven risk, coordination procedures, and some distributional targeting via guidance and messaging to older adults, care settings, and social care users. The plan focuses on distributing information and short-term protections, but would benefit from addressing structural drivers of vulnerability, such as heat-unsafe housing. Within the Heat Action Plan, meteorological and mortality (impact) indicators are tracked, but Monitoring is present than in many contexts — the system tracks— it still needs to be disaggregated by place and population to show who benefits, who is missed and where course corrections are needed after each season.

The socioeconomic appraisal indicates that the programme is highly cost-effective, even under conservative assumptions. A modest fixed annual budget, plus an operational envelope for each heat day, generates benefits primarily in the form of avoided mortality. However, the estimates are based on uncertain effectiveness assumptions and on the programme's ability to reach those at risk on activation days, both of which require ongoing scrutiny. The totals are also limited: structural cooling investments and most co-benefits are excluded from both costs and benefits.

If the Basque Country were to transition from seasonal arrangements to a comprehensive heat-health programme, three key areas would enhance both equity and value for money: (i) formalising a dedicated heat budget with clear allocations and equity-focused monitoring; (ii) ensuring distributional impact checks and equity criteria are required; and (iii) publishing disaggregated, post-season evaluations that inform next year's targeting and spending.

Case study 4.2 – Qualitative assessment of social justice dimensions of climate policy (Germany)
Partner: Ecologic; BC3
Spatial scale: Bremen City (NUTS 3) and Federal (City) State (Bremen and Bremerhaven) (NUTS 2)
Stakeholder: Ministry for Environment, Climate and Science of the Free Hanseatic City of Bremen – Directorate for Climate Adaptation (Landeszentrale Klimaanpassung), in coordination with Ministry for Health, Women and Consumer Protection of the Hanseatic City of Bremen and the Health Authority ("Gesundheitsamt").

1. Decision context

This case study focuses on the State of Bremen (pop. 684,000) which comprises the cities of Bremen (pop. 570,00) and Bremerhaven (114,000). The State of Bremen faces socioeconomic disparities, indicated by relatively high unemployment and poverty rates in parts of the city (Senatorin für Soziales, Jugend, Integration und Sport, 2021). In addition, Bremen has the highest share of migrants of all German Bundesländer (Federal States) and a relatively low life expectancy, ranking 14 out of 16 Federal States (Bund-Länder Demografie Portal, 2025). At the same time, Bremen is, as many other regions, confronted with increasing temperatures and prolonged heat spells, which are expected to become more severe in the future (Senatorin für Umwelt, Klima und Wissenschaft, 2024). In 2018, the State of Bremen adopted a Climate Adaptation Strategy, which was revised with a new Strategy published in July 2025. In 2024, a specific Heat Action Plan (HAP) was also adopted, setting out further measures to protect the State's inhabitants to better meet the heat-related climate impacts. The Ministry for Environment, Climate and Science is responsible for planning and monitoring, developing and implementing the state-level Adaptation Strategy, mapping of climate impacts including areas with higher social vulnerability or heat stress. The Ministry also led the design and development phase for the HAP. Responsibilities for measures are distributed across relevant actors in the administration with some roles allocated to the Health Ministry. Key policy questions for the Federal State of Bremen are to understand how heat impacts are distributed i.e. to understand which areas are affected by heat and how, and to understand how this transects with differential vulnerabilities within different groups in the population. This leads to the following specific questions:

1) What are the economic and financial implications of climate risks for the health sector?
2) What are the differential effects and social justice dimensions of adaptation options for different groups?
3) What are the costs and co-benefits of socially-just adaptation options?

2. Current and future risk

Although adaptation to heat has been increasing, heat events remain an important threat to human health in Germany. The years 2018-2020 were significant in this regard, with 2018 being the second hottest year since 1881 and registering 8700 heat-related deaths (Winklmayr et al. 2022). Regionally, in the period 1881-2023, average annual temperatures in the State of Bremen have increased by 1.6°C (DWD 2024). There has also been a notable increase in the number of hot days ($T_{max} \geq 30$ °C) from the period 1971–2000 (23 days in Bremen, 14 days in Bremerhaven) to the period 1991–2020 (30 days in Bremen, 21 days in Bremerhaven) (Senatorin für Umwelt, Klima und Wissenschaft, 2024). This trend is expected to continue and for individual hot days to be associated with prolonged periods of heat. In Bremen daytime temperatures tend to be higher than in Bremerhaven, while warmer nighttime temperatures affect Bremerhaven more strongly than Bremen (Senatorin für Umwelt, Klima und Wissenschaft, 2024). During years with extreme heat, as witnessed in 1994, there was an observable regional difference in the number of tropical nights ($T_{min} > 20$ °C). In 1994, 10 tropical nights were registered in Bremerhaven while only one was registered in neighbouring Bremen (DWD 2013; DWD 2016).

By the end of the century (2071–2100) there is an expected increase of between +0.6°C and +6°C in average summer temperatures for the north German metropolitan region of Bremen-Oldenburg (of which the Bremen region is part) as compared to 1961–1990 levels (Norddeutscher Klimaatlas).[8] With regards to other temperature-related changes in this region, there is presently only low-level agreement between different climate models. The range for the mean number of summer days (Tmax >= 25 °C) varies between -1 and +40 days, while both the mean number of hot days (Tmax >= 30 °C) and number of tropical nights (Tmin > 20 °C) range from 0–27 days.

3. Identifying adaptation options

The Bremen Heat Action Plan (HAP) (see Section 1 above) identifies adaptation measures that fall into five categories: A) Structure and coordination; B) Risk communication, information and awareness-raising; C) Extreme event management; D) Climate-adapted urban development; and E) Measures for Monitoring and Evaluation.

Categories A and E are primarily administrative, while measures in categories B–D are focused on the implementation of practical adaptation measures. A full overview of the measures is visible in the assessment in Section 4.2.1. Among the specific measures included in the Heat Action Plan are a number of grey, green and soft interventions. These include for example:

Grey

- Cooling in health sector infrastructure / buildings
- Identification of potential rooms that provide cooling
- Drinking water provision either through wells or through water bottles, esp. for vulnerable groups in focus areas
- Provide seasonal shading

Green

- Nature-based transformation of public spaces (long-term)
- Planting and maintenance of city trees and green spaces
- Provide seasonal shading options through trees

Soft

- Heat information / awareness-raising of vulnerable groups
- Creation of an online portal on heat
- Training of staff in social facilities
- Exchange and networking on climate adaptation at state level
- Communication regarding options for cooling

4. Assessment of adaptation options

4.1 Methodology

The assessment methodology for the Bremen case study consists of two main parts, each answering different elements of policy questions identified in Section 1 Decision Context.

1) A qualitative social justice assessment of the Heat Action Plan focusing on the consideration of vulnerable groups in the plan's measures (Policy question 2);
2) Cost-benefit analysis (CBA) of socially-just adaptation options (Policy questions 1 and 3)

These two components will be taken together to consider the economic costs of risks of heat to the health sector and how these risks and their costs are distributed across society and what the benefits of a more socially just form of adaptation could be.

4.1.1 Social justice assessment

The qualitative social justice assessment focuses on policy question 2) *What are the differential effects and social justice dimensions of adaptation options for different groups?* The assessment is based on

[8] The North German Climate Atlas uses A1B ARPEGE RM 5.1 to show possible mean change, but there are other scenarios and RCPs that can be applied for other results https://www.norddeutscher-klimaatlas.de/klimaatlas/2071-2100/sommer/durchschnittliche-temperatur/metropolregion-bremen-oldenburg/mittlereanderung.html

three recent frameworks developed for the evaluation of the justice dimensions of climate adaptation policies (Juhola et al., 2022; Heyen 2023; Brousseau et al., 2024). The assessment comprises three major steps (see Figure 4.2.1). The evaluation criteria and scoring system were developed by the case study team in close collaboration with the local lead stakeholder. The evaluation of the strategy and measures were conducted by three members of the project team, first individually and then through discussion to reach consensus. The evaluation approach was then discussed with the local lead stakeholder in Bremen.

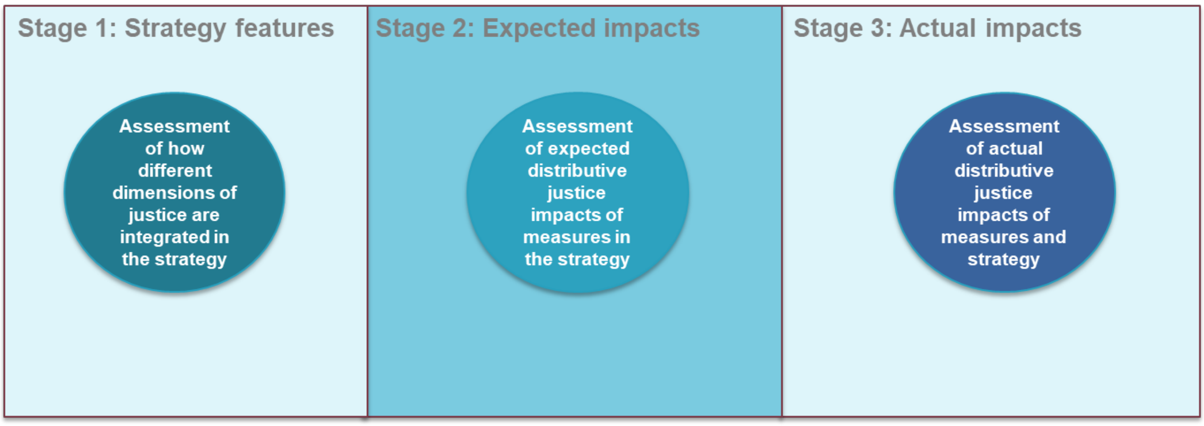


Figure 4.2.1: Conceptual framework for social justice assessment

In a first step, different dimensions of justice (recognition, distribution, participation and restorative justice) are assessed for their level of integration in the policy. For each of these dimensions, specific features have been identified (see Table 4.2.1).

Table 4.2.1: Dimensions considered in strategy assessment (Step 1)

Recognition
1.1 There is a process for identifying vulnerable groups
1.2 Consideration of climate impacts on marginalised and/or vulnerable groups
1.3 Consideration of differential adaptation needs of marginalised and/or vulnerable groups
1.4 Consideration of impacts of adaptation interventions on marginalised and/or vulnerable groups
1.5 Consideration of impacts of societal structures and existing injustices on marginalised and/or vulnerable groups
Distribution
2.1 There is a process to map and assess the distribution of risks from climate impacts
2.2 There is a process that assesses the distribution of benefits from adaptation across the population
2.3 There is a process that assesses how positive or negative effects of the strategy are spatially distributed
2.4 There is a process that assesses of how positive or negative effects of the strategy are temporally distributed
Participation
3.1 The creation of the strategy involved participation of relevant stakeholders (e.g. expert groups, private actors) during different phases of the process
3.2 The creation of the strategy involved participation of the general public during different phases of the process
3.3 The strategy has a structured plan for participation in the implementation
3.4 The strategy has a structured plan for participation of vulnerable and marginalised groups in the implementation
3.5 The adaptation strategy has a participatory process for monitoring, evaluation and learning (MEL)
Restorative justice
4.1 The strategy acknowledges and addresses the roots of marginalisation and vulnerability
4.2 The strategy acknowledges the need to compensate for the diverging impacts of climate change

In a second step, the measures of the strategies/plans are examined more closely ex-ante, focusing on their expected distributive justice impacts (Table 4.2.2).

Table 4.2.2: Framework for ex-ante distributive justice assessment of measures (Step 2)

Name of measure:		
Total score (out of 8):		
Distributive justice impact	**Evaluation scale**	**Score**
1. Training and employment Measure enhances capacities of workforce to support marginalised / vulnerable groups or supports these groups directly	0: Not addressed / not relevant 1: General description: Describes in general how capacities of workforce will be inreased to address marginalisation / vulnerability 2: Detailed description: Describes in detail how employment/training will be implemented to reduce marginalisation / vulnerability, such as funding, activities and target groups	
2. Assets, buildings, transport Measure enhances access of marginalised / vulnerable groups to housing and other community buildings, public transport infrastructure equipped to deal with climate impacts	0: Not addressed / not relevant 1: General description: Describes in general how public access to climate resilient buildings and transport will be enhanced 2: Detailed description: Describes detailed actions to enhance vulnerable / marginalised groups' access to climate resilient buildings and transport through specific funding, activities and targeted objects and locations.	
3. Public health and safety Measure enhances access of marginalised / vulnerable groups to public health resources and emergency support before, during, and after extreme events	0: Not addressed / not relevant 1: General description: Describes in general how public access to public health resources and emergency support will be enhanced 2: Detailed description: Describes detailed actions to enhance vulnerable / marginalised groups' access to public health resources and emergency support through specific funding, activities and targeted objects and locations.	
4. Blue and green infrastructure, mental health, leisure Measure enhances access of marginalised / vulnerable groups to public blue and green infrastructure (parks, canopy coverage, water) and/or enhances access to health infrastructure to compensate for mental stress and provides access to leisure activities	0: Not addressed / not relevant 1: General description: Describes in general how public access to green and mental health infrastructure and leisure activities will be enhanced. 2: Detailed description: Describes detailed actions to enhance vulnerable / marginalised groups' access to green and mental health infrastructure and leisure activities through specific funding, activities and targeted objects and locations.	

In a third and final step, actual distributive impacts can be assessed ex-post implementation, using process and outcome-based indicators. A framework for evaluation is suggested (Table 4.2.3) but for time reasons, this will not be assessed in the lifetime of the ACCREU project.

Table 4.2.3: Framework for monitoring and evaluation of distributive impacts of measures (Step 3)

Impact on distributive justice	Indicators to measure progress towards impact	Score and rationale
1. Training and employment Measure enhances capacities of workforce to support marginalised / vulnerable groups or supports these groups directly		
2. Assets, buildings, transport Measure enhances access of marginalised / vulnerable groups to housing and other community buildings, public transport infrastructure equipped to deal with climate impacts		
3. Public health and safety Measure enhances access of marginalised / vulnerable groups to public health resources and emergency support before, during, and after extreme events		
4. Blue and green infrastructure, mental health, leisure Measure enhances access of marginalised / vulnerable groups to public blue and green infrastructure (parks, canopy coverage, water) and/or enhances access to health infrastructure to compensate for mental stress and provides access to leisure activities		

4.1.2 Assessment of costs and benefits

The assessment of costs and benefits seeks to answer policy question *1) What are the economic and financial implications of climate risks for the health sector?* and policy question *3) What are the costs and co-benefits of socially-just adaptation options?* Based on the work developed in WP2, we have an estimate at the NUTS 3 scale of the costs of climate change in terms of heat-related mortality and morbidity. These data are available for a combination of RCPs and SSPs (see deliverable 2.3). Furthermore, the costs of adaptation measures foreseen in the above-mentioned planning instruments will be estimated. Based on the literature, an estimate of the potential effectiveness of these measures will be made, allowing us to calculate the avoided costs.

Research shows that the willingness to pay for climate policies increases when the co-benefits of climate policies are taken into account (e.g. Rodríguez-Entrena et al., 2014). The literature in this area has grown considerably in recent years in the context of climate change adaptation (Sainz de Murieta, 2020), including in the health sector (e.g. Sharifi et al., 2021). Accounting for these benefits can promote the legitimacy of these policies (Krook Riekkola et al., 2011) and could be a powerful tool to overcome climate scepticism or lack of concern (Bain et al., 2016). For this reason, the assessment includes a qualitative assessment of co-benefits of climate change adaptation. We also explore the potential costs of adaptation options in health services, to which the literature has paid little attention so far.

4.2 Results

4.2.1 Social justice assessment

The Bremen HAP consists of a main document and 30 ‘Fiches’, one per planned measure. In the first step, the social justice assessment was conducted for the HAP main document, looking at the intentions of the strategy as a whole. The results are presented in Table 4.2.4.

Table 4.2.4: Social justice assessment of the overall aspects of the Bremen Heat Action Plan (Step 1)

1. RECOGNITION		
Strategy feature	**Evaluation scale**	**Score and rationale**
1.1 There is a process for identifying vulnerable groups	0: No process 1: Marginalised and/or vulnerable groups are identified 2: There is an existing assessment process that will be adapted. 3: The assessment of marginalised and/or vulnerable groups is clear and connected to adaptation planning and monitoring	3 – The assessment and results are shown in the HAP. Definitions are defined and clearly followed and based on this vulnerable groups are indicated.
1.2 Consideration of climate impacts on marginalised and/or vulnerable groups	0: The strategy does not identify marginalised and/or vulnerable groups 1: The strategy identifies a link between climate impacts and marginalised and/or vulnerable groups 2: The strategy identifies that marginalised and/or vulnerable groups are disproportionately affected by climate change 3: The strategy identifies *how* marginalised and/or vulnerable groups are disproportionately affected by climate change	3 – The assessment of heat impacts on vulnerable groups are shown in the HAP. Definitions are defined and clearly followed and based on this, vulnerable groups are indicated. In the maps also the intensity of heat days, night temperatures is linked to different criteria, such as age, socio-economic indicators, etc.
1.3 Consideration of differential adaptation needs of marginalised and/or vulnerable groups	0: The strategy does not identify marginalised and/or vulnerable groups 1: The strategy identifies that marginalised and/or vulnerable groups may have differential adaptation needs 2: The strategy identifies what these differential needs are 3: The strategy identifies *measures to* address the differential adaptation needs of marginalised and/or vulnerable groups	3 – The measures have the aim to address different vulnerable groups and their needs, e.g. specific measures for pregnant women, parents, babies, elderly, socially-isolated, people working outside, etc. (partially via multiplicators, e.g. schools/teachers, doctors, social volunteers)
1.4 Consideration of impacts of adaptation interventions on marginalised and/or vulnerable groups	0: The strategy does not identify marginalised and/or vulnerable groups 1: The strategy identifies that adaptation interventions can have negative impacts marginalised and/or vulnerable groups 2: The strategy identifies what these negative impacts on marginalised and/or vulnerable groups are 3: The strategy identifies *how* it will mitigate these negative impacts.	1–The HAP mentions in general that negative impacts of measures should be avoided.
1.5 Consideration of impacts of societal structures and existing injustices on marginalised and/or vulnerable groups	0: No acknowledgement 1: The existence of structural injustices is mentioned in a general manner 2: There are measures that tackle some structural injustices 3: There is a detailed plan to consider the impacts of structural injustices on marginalised and/or vulnerable groups as part of the strategic approach to adaptation	1 – Structural injustices are mentioned. The measures focus mainly on information and behaviour during an heat event but do not address structural changes, such as heat insulation in buildings.
2. DISTRIBUTION		
Strategy feature	**Evaluation scale**	**Score and rationale**
2.1 There is a process to map and assess the distribution of risks from climate impacts	0: No risk assessment process 1: Process for risk assessment is part of the strategy but does not consider differential aspects 2: Process for differential risk assessment is included 3: Process for risk assessment is implemented, risks are prioritized and	2 – A process for risk assessment is in place, definition of indicators and mapping has been implemented

	measures are identified to address differential distribution of risks	
2.2 There is a process that assesses the distribution of benefits from adaptation across the population	0: No process for assessing benefits 1: Process for identifying benefits of adaptation measures in general 2: Process for assessing distribution of benefits across the population is included 3: Distribution of benefits across the population is understood in detail and informs measures to address inequalities	2 – Benefits are described for targeted groups in qualitative terms
2.3 There is a process that assesses how positive or negative effects of strategy are spatially distributed	0: No process to consider spatial effects of strategy 1: Spatial dimensions of adaptation are considered 2: Process for assessing the distribution of the strategy's effects across different spatial areas is included 3: Spatial distribution is mapped in detail e.g. according to proportional socio-structural, economic and socio-spatial criteria and is used to inform measures to address inequalities.	0 – Spatial effects are mentioned but no process is described for taking these effects into account
2.4 There is a process that assesses how positive or negative effects of strategy are temporally distributed	0: No process to consider temporal dimensions of strategy 1: Temporal dimensions of adaptation are considered 2: Process for assessing the different effects of the strategy for different generations is included 3: Temporal distribution is understood in detail and is used to inform measures to address the inter- and intragenerational dimensions of adaptation costs and benefits	1 – Temporal dimension is considered in general, e.g. via measures for children
3. PARTICIPATION		
Strategy feature	**Evaluation scale**	**Score and rationale**
3.1 The creation of the strategy involved participation of relevant stakeholders (e.g. expert groups, private actors) during different phases of the process	0: No participation 1: The strategy process has involved information provision about adaptation (at least once during the process before the final output publication) 2: The strategy process has involved consultation. 3: The participation in the strategy process has been collaborative and continuous	2 – The strategy was developed with participation of relevant stakeholders from the social and health sectors. Several meetings aimed to include their knowledge and preferences in the process, in order to define the measures and to ensure consistency with ongoing activities.
3.2 The creation of the strategy involved participation of the general public during different phases of the process	0: No participation 1: The strategy process has involved information provision about adaptation (at least once during the process before the final output publication) 2: The strategy process has involved consultation. 3: The participation in the strategy process has been collaborative and continuous	1 – Several public presentations were held around the development of the HAP including the university, local councils and the parliament. The public was not involved in the development of the strategy. However, to a limited extent, their input may have been included via the inclusion of interest groups (see 3.1.)
3.3 The strategy has a structured plan for participation in its implementation	0: No participation in the plan for implementation 1: The implementation plan involves informing different stakeholders 2: The implementation plan involves stakeholder consultation	2 – The plan does not provide a structured plan for participation. However, it does refer to citizen participation in the description of several measures. While not yet incorporated in a structured way, the plan is for the Actors Network to be a key way to deliver on this point.

	3: The implementation plan involves stakeholder participation in a collaborative and continuous manner	
3.4 The strategy has a structured plan for participation of vulnerable and marginalised groups in the implementation	0: The adaptation strategy is implemented by public bodies without participation of vulnerable and marginalised groups 1: Marginalised and vulnerable groups are targeted by and informed about implementation activities in the adaptation strategy 2: Marginalised and vulnerable groups are invited to participate in adaptation activities 3: Marginalised and vulnerable groups are engaged directly and can take appropriate levels of responsibility for adaptation activities.	2 – The plan explicitly addressing vulnerable groups in its measures as recipients, e.g. through information campaigns. Vulnerable groups will be represented through the active participation of their representatives (health and social workers)-
3.5 The adaptation strategy has a participatory process for monitoring, evaluation and learning (MEL)	0: No plan 1: The strategy involves a plan for MEL but this is done by the authorities 2: The strategy involves a plan for MEL that includes external inputs and feedback from stakeholders 3: The strategy has a detailed plan for stakeholder involvement in MEL throughout its implementation.	2 – The strategy aims to develop a plan for MEL that includes external inputs and feedback from the Steuerungskreis (Steering group) and Akteursnetzwerk (actor network) as stakeholders. The Plan is, however, not yet available and will only be developed in the future.
4. RESTORATIVE JUSTICE		
Strategy feature	**Evaluation scale**	**Score and rationale**
4.1 The strategy acknowledges and addresses the roots of marginalisation and vulnerability	0: No acknowledgement of past harms or injustices 1: Past harms and injustices are mentioned 2: The impact of past harms on current experiences of marginalisation, vulnerability or injustice is recognised 3: Action is taken to repair and restore past harms through recognition or redistribution	0 – No acknowledgement of past harms or injustices
4.2 The strategy acknowledges the need to compensate for the diverging impacts of climate change	0: No acknowledgement 1: The strategy acknowledges a need for compensatory action on climate change impacts for certain individuals or communities 2: The strategy foresees procedures for defining compensatory action. 3: The strategy has a plan for addressing and compensating for the impacts of climate change	1 – In some of its measures, the strategy acknowledges a need to address social inequalities, however, without explicitly calling for compensatory actions.

The HAP shows a clear awareness of the differential effects of heat for groups in the population. It identifies vulnerable groups and the effects of heat on these groups. Maps have been developed to show the distribution of heat impacts such as number of hot days or tropical nights, linked to different socio-economic indicators. These have identified the unequal distribution of climate risks for vulnerable populations. To this end, measures have been defined to target different vulnerable groups and their needs in relation to heat. This includes specific measures for pregnant women, parents, babies, elderly, drug-users, the socially-isolated, people without housing and people working outside. This is done primarily in partnership with existing multipliers such as schools, social and health care facilities, neighbourhood outreach centres and volunteering initiatives. Despite identifying these vulnerabilities and strategies to support groups, the measures focus mainly on information campaigns to support adaptive behaviour during heat events. There is little to indicate that broader structural action is being taken to address these vulnerabilities at their root. At the same time, this is in part because it is beyond the scope of a HAP; many of the root causes such as structural economic disadvantage cannot be tackled at the level of the state or municipality. While the distribution of risks has been mapped in detail, how the benefits of adaptation are distributed across the population is only briefly considered. Temporal dimensions, such as intergenerational effects of impacts or adaptation are not considered.

Concerning procedural justice, the strategy was developed with participation of relevant stakeholders from the social and health sectors. Several meetings aimed to include their knowledge and preferences in the process of defining measures and to connect with ongoing activities. However, general members of the public were not involved in the development of the strategy. Only where they belonged to a particular interest group or vulnerable group, were they included via third party representatives. The HAP primarily foresees interactions with the public through communication and awareness raising. Whether citizens will be invited to participate in the implementation of measures is unclear. Nevertheless, there are processes planned for ongoing MEL to accompany the implementation of the HAP. These have not yet been established, but there will be a process of ongoing feedback through the Steuerungskreis (Steering group) and Akteursnetzwerk (actor network). Restorative justice is, as yet, a very niche area of justice considerations in climate adaptation strategies. While it has been included in the assessment framework for theoretical completeness, there are no indications that Bremen or any other of the strategies analysed for the ADT are considering this issue through, for example, compensatory measures.

The second step of the assessment examined the individual measures of the HAP for their expected distributive justice impacts.[9] Each measure was allocated a score of 0 (for no mention or relevance), 1 (for general reference) or 2 (with specific details) of how the measure considered distributional justice issues. Drawing on Heyen et al. 2023, we developed four clusters in which distributional justice concerns might be taken up: 1. Training and employment; 2. Assets, buildings and transport; 3. Public health and safety; and 4. Blue and green infrastructure, mental health and leisure.

The results reveal that scores in the third cluster on public health and safety were around double the scores in the other categories. This means that while distributional justice issues were considered in other activity areas, the primary way in which marginalised and vulnerable groups are considered is in relation to public health resources and emergency support before, during, and after extreme events. Less attention is paid in the consideration of these groups in urban planning, although for urban renewal projects, the participation of vulnerable groups is an integral part. Looking at the five action areas identified by the Bremen government (see page 2), we see a focus on B) Risk communication, information and awareness-raising measures and C) Extreme event management measures. Activities to address distributional justice are less present in A) Internal management and organization; D) Measures for climate-adapted city planning; and E) Measures for Monitoring and Evaluation. An overview of the evaluation is presented in Table 4.2.5, with high scoring areas highlighted in bold and purple. Individual high scores (where measures scored '2') are highlighted in dark blue. Particularly high scoring were measures that focused directly on vulnerable groups and developed targeted measures to support these groups through infrastructure such as cooling provision or undertaking capacity building of multipliers to inform and support these groups (e.g. measures C4, C5, C7, C8).

[9] All measures can be found in detail on pp 33-83 of the Bremen Heat Action Plan available in German at https://www.klimaanpassung.bremen.de/sixcms/media.php/13/Hitzeaktionsplan.pdf.

Table 4.2.5: Social justice assessment of individual measures in the Bremen Heat Action Plan (Step 2)

Measure number (brackets show corresponding measures in Bremen/ Bremerhaven)	Measure name	1. Training and employ-ment	2. Assets, buildings, transport	**3. Public health and safety**	4. Blue and green infra-structure, mental health, leisure	Overall score
A1	Coordination bureau	1	0	1	0	2
A2	Coordination group	0	0	0	0	0
A3	Heat Action Plan Stakeholder Network	1	1	1	0	3
B1	Warning and information plan	0	0	1	0	1
B2	Heat Portal for the Federal State of Bremen	0	0	1	1	2
B3	General awareness raising campaign	0	0	1	0	1
B4	Information and awareness raising for vulnerable groups	1	0	2	0	3
B5	**Training and further education for professional groups working with vulnerable people**	2	0	2	0	4
B6	**Further training for family carers and voluntary support workers**	2	0	2	0	4
B7	**Heat protection for particularly exposed employees**	2	0	2	0	4
C1	Distribution of heat alerts from the German weather service	0	0	1	0	1
C2	**Heat protection plans for mobile healthcare services, stationary care facilities and hospitals**	0	2	2	0	4
C3	**Mobilisation and support for pediatric facilities and midwives**	2	0	2	1	4
C4	**Neighbourhood support pilot project (heat buddies, heat hotline)**	2	1	2	1	6
C5	**Preparation and communication about public cool spaces**	0	2	2	2	6
C6	Call to action for GPs and pharmacists to check medication plans	1	0	2	0	3
C7	**Provision for unhoused and substance-using citizens in public spaces**	1	2	2	2	7
C8	**Heat protection in school playgrounds and outdoor areas of nurseries**	2	2	2	0	6
C9	**Drinking water in public spaces**	0	2	2	0	4
D1 (D5)	Climate adapted management of green spaces (Bremen)	0	0	0	1	1
D2 (D6)	Urban Trees Action concept 2.0 (Bremen)	0	0	0	1	1
D3 (D7)	Pilot, nature-based reconfiguration of public spaces (Bremen)	0	1	0	2	3
D4	Adaptation of public buildings (Bremen)	0	2	0	0	2
D5	Adapted management of green spaces in urban areas (Bremerhaven)	0	0	0	1	1
D6	Urban Trees Action concept 2.0 (Bremerhaven)	0	0	0	1	1
D7	Pilot, nature-based reconfiguration of public spaces (Bremerhaven)	0	1	0	2	3
D8	Concept for summer heat protection for public and social facilities (Bremerhaven)	0	2	0	0	2
D9	Climate adaptation of existing industrial zones (Bremerhaven)	0	0	0	0	0
E1	Monitoring of implementation of measures	0	0	0	0	0

E2	Monitoring of morbidity and mortality during heat periods	0	0	2	0	2
		Total	Total	Total	Total	
		17	18	32	15	

In Step 3 (Table 4.2.6), indicators are suggested for the monitoring, evaluation and learning around the distributive impact of the measures discussed in Step 2. These will not be used for assessment in the ACCREU project due to the longer timeframe in which the Bremen HAP will be implemented. However, some initial ideas are proposed and can be adapted according to individual measures and data availability.

Table 4.2.6: Suggested indicators for monitoring, evaluation and learning on distributive justice (Step 3)

Impact on distributive justice	Aim / Definition / Category	Suggested proxy indicators	Source
1. Training and employment	1. Measure enhances capacities of workforce to support marginalised / vulnerable groups or supports these groups directly	Training and continuing education for professional groups who deal with vulnerable people: Percentage of employees reached through qualification measures	HAP Bremen (B.5)*
		Continuing education for family carers and volunteers: Number of at home carers and volunteers reached through qualification measures	HAP Bremen (B.6)
		Heat protection plans for health and care facilities: Creation of guidelines, proportion of facilities with a specific heat protection plan, monitoring of heat-related illness burden	HAP Bremen (C.2)
		Activation and support of paediatric practices and midwives: Proportion of participating practices and midwives, feedback/interviews with participating practices	HAP Bremen (C.3)
		Climate adaptation in existing industrial/commerical areas: Continuous updating of the industrial zones recorded with regard to the need for action and the measures implemented.	HAP Bremen (D.9)
2. Assets, buildings & transport	Measure enhances access of marginalised / vulnerable groups to housing and other community buildings, public transport infrastructure equipped to deal with climate impacts	Percentage of social buildings (housing, nurseries, elderly homes, shelters) with active or passive cooling or green infrastructure (green roofs, shading, ventilation) elements.	EI*
		Number of publicly accessible cooling centers (libraries, community halls, senior centers) per 10.000 residents.	EI
		Accessibility to cooling centers with public transport (e.g. stops close to cooling centers / average travel time for vulnerable groups).	EI
		Public transport (density)	EI
		Percentage of public transport fleet that is air conditioned	EI
		Provision for homeless, homeless and addicted/mentally ill people in public spaces:Frequency of use of the services	HAP Bremen (C.7)
		Concept for summer heat protection for public and social facilities:Percentage of heat resilient buildings.	HAP Bremen (D.8)
		Heat protection in school playgrounds and daycare centre playgrounds: proportion of facilities with shaded outdoor areas.	HAP Bremen (C.8)
3. Public health and safety	Measure enhances access of marginalised / vulnerable groups to public health resources	Proportion of residents reached by the early warning system	Tuomimaa et al. 2023
		Number of hospital beds per district per km2	EI
		Number of physicians per district per km2	EI

	and emergency support before, during, and after extreme events	Access to water/Water fountain concentrations (n=xx/% coverage)	EI
		Number of interactions between support workers and vulnerable groups in preparation for extreme heat events	EI
		Awareness of cooling spaces and of physical effects of heat	EI
		Downloads / distributed print outs of cooling spaces maps	EI
		Drinking water in public spaces: number of drinking fountains installed or participating shops as refill stations per km2	HAP Bremen (C.9)
4. Green Infrastructure & leisure	Measure enhances access of marginalised / vulnerable groups to public blue and green infrastructure (parks, canopy coverage, water) and/or enhances access to health infrastructure to compensate for mental stress and provides access to leisure activities	Green area per inhabitant in the city	Catalan Climate Adaptation Plan (S2)
		Availability and equitable distribution of blue-green space (Unit: map) availability of green space and indicators	EU 2021. "Evaluating the impact of NbS" (19.6)
		Accessibility to (public) green spaces (e.g. measure through distance of public transport stations from green spaces)	Böhme et al. 2023
		Urban tree index / Tree survival rate / Tree cover per capita	EI
		Time spent outdoors in summer months	EI
		Indoor and outdoor swimming pools, lakes, rivers and sea (right to health)	Catalan Climate Adaptation Plan (JC7)

* HAP Bremen (indicator mentioned directly in the Heat Action Plan); EI (Ecologic Institute)

4.2.2 Assessment of costs and benefits

Effectiveness of Heat Action Plans

In the absence of direct data on the implementation of the Heat-Health Action Plans (HHAP), we turned to the literature to obtain an estimate of the benefits that these plans can have in terms of avoided impacts, both in terms of mortality and morbidity.

Following the 2003 heatwave, which marked a turning point in Europe, HHAPs have increased significantly, and today there are numerous plans at national, regional, and even municipal levels (Martinez et al., 2019). However, Dwyer et al. (2022) argue that, considering the number of heat plans currently in place, the number of studies assessing their effectiveness in the literature remains relatively low. This is more so in relation to morbidity outcomes.

A study of the benefits of heat alerts in 20 US cities found no association with lower mortality, except for Philadelphia, where heat alerts were associated with 4.4% lower mortality rates (Weinberger et al., 2018). Mixed results were also found in a systematic literature review of HHAP evaluations (Dwyer et al., 2022). Among 11 evaluations of heat action plans assessed, only one reported an overall mortality reduction; two of three morbidity evaluations found reductions; and one multi-city study observed a protective effect in a single city only. Overall, positive signals are limited and context-specific.

In Spain, after the HHAP[10] was introduced, the extreme-heat mortality fraction decreased (from 0.67% to 0.56%, a relative reduction of 16%), but this was offset by an increase in the moderate-heat mortality fraction (from 0.38% to 1.21%), so the total heat-attributable mortality increased. On plan-activation days, the attributable fraction was reduced. Interestingly, those provinces with more actions being implemented

[10] This plan is framed as a Heat-Health Prevention Plan (HHPP), but we continue with the HAP (Heat Action Plan) notation for every heat and health-related plan.

within their HAPs showed higher decreases in mortality attributable to extreme heat (Martínez-Solanas and Basagaña, 2019).

In Italy, de'Donato et al. (2018) found that among adults over 65 years, the heat-attributable mortality fraction for extreme temperatures fell from 6.3% to 4.1% across 23 cities (35% relative decline), after the introduction of the national HHAPs.

Feldbusch et al. (2025) analysed the effectiveness of the national heat and health warning system in 15 German cities using a difference-in-differences approach. After adjusting for city characteristics, heat alerts were associated with 15% lower all-cause mortality on alert days (RR = 0.85; 95% CI 0.75–0.97). When city characteristics were not considered, no protective effect was found (RR = 1.00; 0.98–1.01). City-level reductions were statistically significant in Berlin (RR = 0.95), Frankfurt (0.94), and Hamburg (0.95), while Bremen's estimate was not significant.

On balance, we can say that the evidence of a reduction in mortality is stronger than the evidence for no effect or an opposite effect.

Estimating the benefits of Bremen's Heat Action Plan

We measure the benefits of the implementation of Bremen's HAP in terms of the reduction of health impacts (mortality and morbidity). Given the heterogeneity in the literature, we adopt a central effectiveness of 15% of Bremen's HAP for all-cause mortality, in line with the pooled protective effect found by Feldbusch et al. (2025), once city characteristics were considered. While they did not find a significant reduction for Bremen, it should be noted that they evaluated the national heat-health warning system rather than full regional or municipal HAPs. Secondly, the newly adopted HAP for Bremen was developed with a strong focus on the region's characteristics and vulnerabilities, so it is reasonable to assume this level of effectiveness as an ex-ante portfolio assumption.

To account for uncertainty, we also use lower and upper bounds of effectiveness. The lower bound is 5%, in line with Weinberger et al. (2018), and the upper bound is 30%, in line with the higher effectiveness estimates (e.g., de'Donato et al., 2018).

Bremen's HAP anticipates annual implementation reviews and post-summer health evaluations, and several structural measures have a multi-year setup. For this reason, we assume a maturity ramp that assumes a partial effect in 2025 (40%), near-full effect in 2026 (75%), and a full protective effect from 2027 to 2030. To estimate effects on morbidity, we follow the approach applied by Markandya et al. (2025) that relates heat-related mortality and morbidity based on data from Adelaïde et al. (2022). Mortality data (for adults over 65) is taken from Loroño et al. (2025) and morbidity from Markandya et al. (2025).

Finally, although Bremen's HAP includes specific measures (B7) to reduce health impacts and productivity losses experienced by workers particularly exposed to heat, we were unable to assess the economic effects as the impact has not yet been quantified.

The cost of Bremen's Heat Action Plan

As noted in Section 1, the measures in Bremen's HAP are divided into five fields of action: A) Structure and coordination; B) Risk communication, information and awareness-raising; C) Extreme event management; D) Climate-adapted urban development; and E) Measures for Monitoring and Evaluation.

We treat the Coordination bureau (A1) as a fixed annual programme cost, covering planning, oversight, and coordination (central estimate €250,000 within the HAP's €230,000–270,000 range). Therefore, these costs do not vary with the number of alerts/heat-wave days. Any activity-driven effort is costed under each relevant measure (e.g., outreach, training). A2–A3 tasks, in-kind staff time with only minor event expenses (room/catering), are assumed to be included in A1. Considering about 80% of the coordination costs are salary costs, we have assumed that nominal these will increase by 2.5% per year, which is likely a conservative assumption given recent wage growth trends in Germany.

For measures in group B, related to communications, information, and awareness, we made the following calculations. Costs are obtained using resource-based costing (Hunt et al., 2016): task hours times the Eurostat whole-economy hourly labour cost[11] for Germany in 2024 (€45/hour), plus non-labour items, estimated based on observed average market costs. The central annual budget sums to €120,000, which we find consistent with a communications-heavy package. We have assumed that the first year of implementation will incur additional expenses that will not be necessary in subsequent years, such as web design, training packs or information guides.

We budget Group C on considering consumption supplies (materials, printing, media/placements, small outsourced tasks, supplies/equipment), keeping internal staff time under A1.

Concerning structural measures linked to the adaptation strategy (Group D), we opted to consider the city's strategy-funded investments (e.g., greening, shading, building upgrades) as baseline and therefore exclude their full costs from the cost-benefit analysis of Bremen HAP to avoid double-counting.

We cost E-group measures using the same resource-based approach as above but assume that the bulk of monitoring/analytics hours are delivered by the A1 Coordination Centre and Group E's budget only covers minor office items associated with the monitoring process (e.g., software/data access if needed, annual review meetings, etc.). On this basis, the cost is €12,000/year for outsourced item costs. Table 4.2.7 shows the summary of the HAP costs.

Table 4.2.7: Cost of Bremen HAP, by areas of action.

Measures	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Group A	250,000	255,000	260,100	265,302	270,608	276,020
Group B	120,000	96,000	96,000	96,000	96,000	96,000
Group C	174,500	147,500	147,500	147,500	147,500	147,500
Group D	-	-	-	-	-	-
Group E	12,000	12,000	12,000	12,000	12,000	12,000
HAP cost	556,500	510,500	515,600	520,802	526,108	531,520

Comparing costs and benefits

Over the analysis period, 2025-2030, the benefits are dominated by avoided mortality, which is valued using the value of a statistical life (VSL) of €1.3 million (Szewczyk et al., 2018). Avoided morbidity values are taken from Markandya et al. (2025), but they contribute a very small share (less than 1%) of monetised benefits. In the central scenario (considering an effectiveness of 15%), annual benefits range from €50–55 million, depending on the climate scenario considered, while programme costs total €510,000 – 556,000 per year.

Using a 3% discount rate and end-of-year timing, the present value of benefits is €268-300 million, and the present value of costs is €2.8 million. This yields a benefit-to-cost ratio (BCR) of 94-105. The results are robust to discounting (BCR remains essentially unchanged between 0 and 3%), and even with substantially lower effectiveness (e.g., one-third of the central scenario), the ratio remains well above 1.

[11] Eurostat: Labour cost levels by NACE Rev. 2 activity. Available at: https://ec.europa.eu/eurostat/databrowser/view/lc_lci_lev/default/table?lang=en&category=labour.lc.lcan

When considering a maturity ramp where efficiency gradually increases from 40% in 2025 to 60% in 2026, 75% in 2027, before reaching 100% in 2028, the results vary slightly. Nevertheless, the programme continues to deliver substantial benefits between 2025 and 2030. Using this maturity curve and a discount rate of 3%, the present value of the benefits ranges from €209 million to €234 million, depending on the emissions scenario. The present value of costs remains at €2.9 million, resulting in an NPV of between €206 million and €231 million, and a cost-benefit ratio of between 73 and 82.

The outcome of the CBA carried out depends largely on the method used to calculate the value of a human life. Here, the value of a statistical life (VSL) of €1.3 million was used, which some might consider too high, despite higher values also being found in the literature (e.g., OECD, 2012; Alberini and Ščasný, 2024). Assuming a 15% effectiveness, this would mean avoiding 40-45 deaths per year thanks to the plan. Given that the plan incurs an annual cost of €529,500, this equates to an investment of €11,770-€12,900 per life saved.

5. Barriers and conditions for implementation

The HAP takes clear account of the differential impacts on vulnerable groups and has integrated this as an important dimension of the strategy. However, whether adaptation measures will truly target and benefit these groups remains to be seen. This will depend on overcoming potential barriers listed below. There appear to be systems in place, particularly after the Covid-19 pandemic that can be mobilised to reach vulnerable groups in neighbourhoods. However, whether and how this can be deployed for heat and health remains to be seen and will depend on adequate funding and human resources. Furthermore, actions that provide wider benefits to the public but from which vulnerable groups can benefit such as increasing green infrastructure in public spaces relies on being able to recruit appropriately trained personnel to take care of the planting. Some of the initial barriers identified by the stakeholders in Bremen with regards to implementation are listed in Table 4.2.8.

Table 4.2.8: Measures in the HAP and their barriers to implementation

Measures	Barriers	Type of barrier
Communication campaigns	• Lack of long-term funding to implement strategies • Difficulties to reach specific vulnerable groups (e.g. due to technical barriers or cultural ones, limited accessibility via different media) • Lack of staff in social care and high workload of existing ones	• Financial • Social and cultural • Human capital
Management of extreme events	• Lack of long-term funding to implement strategies • Lack of ability to induce behavioural change among vulnerable groups e.g. homeless people • Governance of cross-sectoral measures given sectoral organisation of Senate	• Financial • Social and cultural • Governance
Long-term resilience building strategy for heat events	• Lack of long-term funding to implement strategies • Low support from relevant stakeholders in planning, implementation and maintenance of measures • Vulnerable groups not prioritised despite higher impacts • Lack of training time to skill up personnel or lack of trained personnel	• Financial • Governance • Social and cultural • Human capital

6. Conclusions and reflections on socially just adaptation to heat impacts on health

The HAP was developed by the State Ministry for Environment, Climate and Science, which has also been in charge of developing the climate adaptation strategy (KAS) in parallel. The HAP takes a targeted approach to addressing the heat impacts of climate change for health. The HAP is interpreted as the policy through which the more 'social' components of the KAS are implemented and includes clear attempts to address the distributional and social justice dimensions of heat. This has included the strategic development with partners from across the regional administration, engaging with representatives from civil society organisations. However, it means that while somewhat mentioned, these issues are not dealt with in as much detail in broader adaptation activities being conducted through the KAS. The assessment of the HAP indicates that there is some level of justice as recognition, procedure and distribution being considered in terms of impacts, but that restorative justice is rather ambitious for the sub-national level, being a criterion that would need longer consideration and/or embedding at the national level. The focus of these actions is primarily on the distribution of heat impacts across the population who have already been identified as vulnerable rather than addressing the underlying causes of vulnerability. The HAP is intended to be the first of many iterations and will be monitored in an online portal to make progress transparent. A number of possible indicators have been proposed in this case study which could be used to specifically account for the social justice dimensions of the HAP.

The assessment of the distributional justice of the HAP measures conducted in Step 2 suggests that it is predominantly through risk communication and sensitisation of the population at large that distributional justice is accounted for. There is some promising consideration of differential needs of those who are physically vulnerable and/or marginalised owing to their socio-economic circumstances. The HAP foresees soft adaptation measures that aim to inform and protect vulnerable and marginalised groups either directly or through support workers and representatives. There are also a range of green and grey measures, such as improving green areas and shading. However, the distributional dimensions of budget allocations for greening are not yet taken account of in a systematic way. Without this being factored in, investments may end up being captured by higher income groups and/or implemented in locations where the need for greening is not as high from a social or environmental perspective. The mapping that accompanies the HAP has been used to develop spatially differentiated planning of measures that account for distributional inequalities, which in the best-case scenario are expected to be taken up in public urban planning. In the private sector on the other hand there is no requirement to consider the differential impacts of urban development. This is thus a blind spot in understanding the full extent of the distributional effects of investment and planning decisions on climate adapted urban development.

As elsewhere, the economic benefits associated with health and heat protection measures in Bremen are expected to exceed a benefit-to-cost ratio well above 1, even where substantially lower effectiveness is accounted for. However, the measures of the HAP will not reach their full protective effect until the period 2027–30. At the same time, funding of adaptation measures is on a shorter-term, rolling basis. The lack of investment certainty can affect retention of human resources which have high startup costs for recruitment and training meaning that the efficiencies to be gained from retention of staff with appropriate skills and capacities may not be reached. Well-trained and locally engaged staff can support action that is sensitive to differential and complex needs and vulnerabilities in different locations. Long term planning and investment coupled with retention of staff with targeted skill sets is thus an important factor in delivering on socially just forms of adaptation.

5 Finance and private sector

Case study 5.1 – Adaptation options for enhancing financial stability (Netherlands)

Partner: Deltares
Spatial scale: National, Netherlands
Stakeholder: Dutch Central Bank

1. Decision context

De Nederlandsche Bank (DNB) is the central bank of The Netherlands. DNB's mission is to safeguard financial stability and thus contribute to sustainable prosperity in the Netherlands. Among its objectives are: safeguarding price stability and balanced macroeconomic development; ensuring a shock-resilient financial system; and ensuring sound and ethical financial institutions. In addition, they are an economic policy advisor to the Dutch government[12].

In the context of the ACCREU project, the primary focus is on financial stability monitoring, with possible additional considerations for macroprudential policy. Without adaptation, flood risk and other climate hazards might possibly develop into risks with substantial adverse impacts on the stability of the financial system, in particular for banks, that have exposures in assets that are vulnerable to climate risks.

The overarching policy question of DNB in this project is: do climate hazards pose a substantial threat to financial stability in The Netherlands and what are the possible implications for macroprudential policy? Some related questions are: through what transmission channels may climate hazards impact the financial stability of banks and other financial institutions? What are the possible adaptation options to reduce these vulnerabilities? How would adaptation to climate hazards interact with macroprudential policy considerations?

In terms of scope, we have focused on flood-related risks and banks' mortgage exposures, for which real estate serves as collateral.

The wider decision-making context is that many central banks and international organizations are starting to work on climate-related financial risks (CRFR). This work is ultimately aimed to ensure that financial institutions support, rather than hinder, a timely and orderly climate transition, given their pivotal role in the economy. At the European level, the European Central Bank (ECB) has conducted a climate-related stress test exercise in 2022 (EBA, 2023), and several national central banks are working on CRFR as well. In The Netherlands, the choice to start with flood risk is natural, given the large exposure to floods in the country.

2. Current and future risk

The strengthening of dikes and other flood protection infrastructure is not the first focus point of DNB, but rather of institutions like the Ministry of Infrastructure and Water, and the 21 waterboards in The Netherlands. At the same time, the success of the national flood risk adaptation strategy is highly relevant for the research questions of DNB. Therefore, we will briefly describe the Dutch flood risk adaptation strategy and it's expected impact on future risk, before describing the approach that was taken in the ACCREU-research.

The largest-scale flood events in The Netherlands are caused by flooding from the sea, inland lakes and the large rivers. The main climate drivers for these flood types are the rising sea level, and the expected increase of extreme peak discharge in the rivers. Another important reason for focusing on river and coastal flooding

[12] https://www.dnb.nl/en/about-us/mission-and-tasks/, accessed 7 Jan. 2025.

is that unlike other flood types (such as pluvial flooding, breaches in regional water systems) these are typically not covered by Dutch insurance.

Flood protection standards in The Netherlands are derived from Cost-Benefit Analysis (CBA), which seeks the optimum between flood protection costs compared to flood risk reduction benefits. In 2017, new CBA-optimal protection standards became formally in place (Kind et al., 2014). By then, in many locations the flood protection in place did not meet the new standards. Therefore, large scale reinforcement projects were started, and to date these are still going on. By 2050, all flood protection structures need to meet the new standards.

This flood protection strategy has the paradoxical consequence that the flood risk in 2050 is projected to be substantially lower than at present. In other words, till 2050, successful adaptation would reduce the risk faster than climate change is increasing the risk[13].

The macroprudential policy perspective is somewhat different from a classical flood risk management perspective. Instead of looking at flood risk in each individual location, the focus is on extreme but physically plausible events that may induce a considerable magnitude of damage and may have implications on a macro-financial scale. Hence, our emphasis has been on calculating the (financial) system-wide impact of extreme and catastrophic flood-related shocks. The event selection process has been carried out as part of ACCREU Task 2.5 'Extremes, catastrophic events & supply chains', and has been described in the corresponding ACCREU milestone M2.2 ('Flood damage'), and will be delivered as a separate ACCREU deliverable D2.5.

3. Considered adaptation options/strategies

We have done no quantitative analysis of the adaptation options and strategies (except for credit restrictions, see section 5). Instead we have focused on the question that comes prior to that: what would be the impact of flood risk on financial stability in The Netherlands? The results of this analysis (section 4), are the starting point for further (qualitative) reflection on the adaptation options and strategies which will be elaborated here.

We have identified three overarching strategies:

1. <u>Fully relying on (physical) flood risk adaptation options (mainly grey options)</u>

The essence of the first strategy is that flood risk adaptation is strongly focused (and limited) to the physical domain: the strengthening of dikes, storm surge barriers and other flood protection structures. The role of (soft non-physical) financial adaptation instruments to reduce risk is limited to a minimum. Also, there is no active land use policy in place that aims to reduce the exposure of real estate and economic activities to flood risk. In this strategy, managing flood risk remains the domain of engineering: through technical means the flood risk is kept within tolerable levels.

In this strategy, a possible role from a financial stability perspective could be to regularly stress test the macro-financial impact of flooding. By assessment of this impact and the probability of occurrence, the stress test can serve as the basis for an advice to the Dutch government on the sufficiency of the physical flood risk adaptation measures that have been planned. If needed, this could lead to a recommendation to take more technical measures to make sure the risk remains within tolerable levels.

[13] Compare for example the "overstromingsrisico norm 2050" with the "overstromingsrisico actueel" maps on https://basisinformatie-overstromingen.nl.

The adaptation options that fit this strategy bear the most resemblance to the status quo. The strategy means that adaptation options are focused on the technical/physical engineering domain. In the Netherlands it is not possible (or very uncommon) to take insurance against large scale coastal and river flooding. Instead, the Dutch government promises a form of financial compensation of individual real estate owners through national law[14]. There is no large-scale land use policy through which developments in the hazard zone are discouraged or forbidden (with the exception of some highly exposed unprotected areas).

2. Active steering with financial adaptation instruments (mainly soft non-physical options)

The essence of the second strategy is that the physical measures are complemented with a range of financial instruments through which (systemic) financial risks are mitigated. So-called 'risk transformation' already is one of the textbook tasks of a financial system (e.g. Boonstra & Van Goor, 2021). The novelty of this strategy is that it would be actively extended to the domain of climate-related financial risks.

Both within the central banking community and academia there is quite some discussion on the extent to which climate-related risks are, and should be, within the mandate of central banks (e.g. Bolton et al., 2020; ESRD, 2016; ECB and ESRB, 2023). When describing adaptation options here, we take no position in this debate, we simply seek to sketch some possible directions of thought.

Some typical adaptation options that lie within the financial domain are:

- Flood insurance. This adaptation option is addressed in case study 5.2.
- Differentiating loan pricing or lending standards, based on the degree to which a collateral is at risk from floods. In Endendijk et al. (2024, under review) we have done some pioneering modelling work on the benefits of reduced lending standards, which will be discussed in section 5.
- Make portfolio diversification compulsory: i.e. force banks to include climate-related considerations in their risk management practices to complement the hazard-prone part of their portfolio with assets that are not or less exposed to flood risk (or that cannot be affected during the same event)
- Induce risk reduction, segmentation and transfer by making the risk tradeable, i.e. securitize at-risk loans.
- Establish a real estate flood risk label in The Netherlands to increase risk awareness and transparency and contribute to incorporating flood risks in real estate prices. This can be a separate option, but also is a building block for most of the other options that were mentioned above.
- Macroprudential options for containing systemic risk. Some options that have been discussed in this context include climate-specific capital surcharges (e.g. buffers or risk-weight floors), concentration limits, or borrower-based measures[15].

Arguably, opting for this strategy would involve a large role of financial stability policymakers compared to the first and third strategy. Because these adaptation options have a stronger overlap with the mandate of the central bank.

3. Active steering on land use planning (mainly green options)

The essence of the third approach is that the national spatial planning policy would actively seek to decrease the exposure of real estate (and economic activities) to flood hazard. Real estate development in flood-prone areas would be discouraged, whereas developments on safer grounds would be encouraged.

Though more located in other policy domains, this approach may have some benefits from a financial stability perspective. Quantifying the financial stability benefits associated to certain spatial policies and

[14] Wet tegemoetkoming schade bij rampen. http://wetten.overheid.nl/jci1.3:c:BWBR0009637

[15] For further discussion, see ECB/ESRB (2023)

warn about the risks connected to the underlying transition are examples of tasks that could be fulfilled within the advisory role of the central bank even if the land use planning task itself would not be part of the central bank mandate.

4. Method and results

Having described the decision-making context, and the range of adaptation options and strategies, we now turn to describing our quantification of risks.

The method and results of this analysis have been extensively described in a working paper by De Nederlandsche Bank (Caloia et al., 2023) and (with more focus on the flood risk dimension) in a Dutch water magazine (van Ginkel et al., 2023). The process of scenario selection has been described as part of ACCREU T2.5 (D2.5 and M2.2). Here, the method, results and recommendations for further research are briefly summarized.

The objective of the study was to investigate financial stability risks through real-estate exposures in The Netherlands, in case of large-scale flooding from the river and/or sea. The results were expressed in terms of CET-1 capital depletions of major lenders.

4.1 Method

As described in M2.2, 32 scenario's for individual dike breaches were selected. Out of 1800 scenarios, the ones with the largest damage to residential and commercial real estate were selected. Aiming at a good geographical spread, scenarios in different parts of the country were identified. In addition, 6 Worst Credible Flood scenarios were examined, where dike breaches occurred at multiple locations at the same time. These should be seen as very low probability, yet physically plausible flood scenarios.

For each scenario, the real estate damage was calculated with the SSM (SSM stands for damage and casualties method, in Dutch) standard method (Slager and Wagenaar, 2017) for calculating flood damage in The Netherlands.

These damages were connected to a model tracing out how flood-related damages impact credit risks for major lenders. Real estate damage was reflected as a reduction in real estate value, and therefore as an increase in Loan-To-Value (LTV) ratio of the mortgage. The first channel through which this affects credit risk is an increase of the Loss-Given-Default (LGD). The second channel were increased risk weights in the calculation of the CET-1 ratio. The third channel, which played a minor role, was the increase in the Probability-of-Default (PD) of the mortgage. All these three channels lead to a decrease in the CET-1 indicator, which is a key indicator for monitoring the financial resilience of a bank. For a detailed description of these procedures, we refer to Caloia et al., 2023.

4.2 Results

Figure 5.1.1 shows the property damage and capital depletion under 38 flood scenarios. Capital depletions mostly are in the range of 30–50 basis points. The third and second Worst Credible Flood scenarios are substantially higher: 75 basis points, whereas the most extreme scenario leads to a depletion of 110 basis points.

This amount of capital depletion seems manageable, also given the level of existing capital buffers of banks in The Netherlands. For example, the most extreme scenario represents a capital depletion (CET-1 ratio) from 15% to 14%. This depletion is substantially smaller than the impact of a severe economic shock, which was estimated at 459 basis points in a 2023 banking stress test of the European Banking Authority (EBA, 2023). The outcomes of this EBA stress test did not lead to large concerns about the stability of European Banks.

At the same time, these results should be interpreted with caution. After all, we only examined one transmission channel: how the flood damage (repair costs) on residential and commercial real estate would impact the balance sheets of banks. Even within this transmission channel, there is some indication that we might have underestimated the real estate damage. For example, there is new evidence that the real estate flood damage curves give a significant underestimation of the flood risk in The Netherlands (De Moel et al., 2025). More importantly, there are several other transmission channels through which financial stability may also be impaired in the aftermath of a big flood. For example, business interruption may cause a decline in economic output and impact corporate loans directly and indirectly.

These scenarios are derived given the present climate conditions (i.e. hydraulic boundary conditions such as river discharge and sea level). However, because they represent very extreme, that is: very unlikely circumstances, they are still representative for moderate degrees of climate change. For example, in the year 2050, these boundary conditions are still extreme, they only have become somewhat more likely. At the same time, dikes are expected to be strengthened by then, so that the actual risk might even decrease by 2050. In the most unfavorable yet still highly uncertain scenarios (e.g. Bamber et al., 2019), a large acceleration of sea level rise might occur after 2050. This would also change the hydraulic boundary conditions to such a degree that they may be no longer representative. For that reason, one of our recommendations for further research is to explore the sensitivity of the results for a substantial degree of (high-end, accelerated) sea level rise.

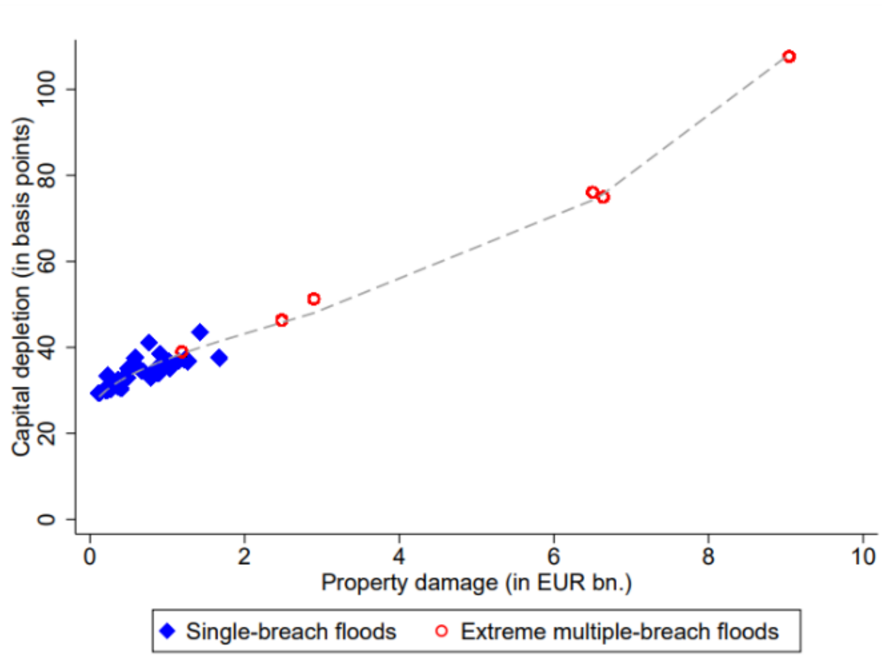


Figure 5.1.1: Property damage and capital depletion under 38 flood scenarios, from Caloia et al. (2023).

5. Adaptation: reducing lending to 90% of taxation value

5.1 Benefits

Endendijk et al. (2024, under review)[16] have done pioneering modelling work on the benefits of reduced lending standards. Their study presents a novel framework 'for evaluating both direct and indirect flood-related risks to residential and commercial mortgage and real estate portfolios'. The methodological setup of this study differs from the study by Caloia et al., that we discussed above. Caloia et al. examine the real

[16] On behalf of Deltares, Kees van Ginkel contributed to this paper using ACCREU-funding, which is acknowledged in the publication.

estate portfolios of multiple large lenders in The Netherlands, with real-world data. Moreover, Caloia et al. take a system-wide financial stability perspective. In contrast, Endendijk et al. examine the (hypothetical) portfolio of a single mortgage provider or real estate investor. Thus, Endendijk et al. take the perspective of a single financial institution instead of a system-wide perspective. This stylized approach allows for the inclusion of more transmission channels, and allows for exploring the effect of adaptation measures.

Endendijk et al. model the effect of a reduced lending standard for properties exposed to flooding, as a financial adaptation option. Before 2018, The Netherlands allowed mortgages to exceed the taxation value of the real estate (under some conditions). This means that under some conditions, the loan-to-value (LTV) ratio could exceed 100%. Since 2018, the LTV ratio has been capped to 100%, meaning that the mortgage value would at maximum equal the real estate taxation value. The essence of the adaptation measure considered here, is that for flood-prone properties, this cap would be further lowered, from 100% to 90%. This means that households in flood-prone areas can only finance 90% of the value through a mortgage, and would need to fund the other 10% through other means, for example from their savings.

First, Endendijk et al. examine how much the credit risk for the financial institution would be reduced by capping the LTV, in the case of *risk-based pricing*. They find that capping the LTV to 90% will cause a substantial reduction in mortgage credit risk. They apply the cap to four hypothetical portfolio's. For three portfolio's, the cap will completely absorb the credit risk. For one portfolio, the measure causes some risk reduction, but cannot fully absorb the risk.

Second, Endendijk et al. also examine how much the credit risk would be reduced by capping the LTV, in the case of *event-based pricing.* Again, they find that the capping the LTV to 90% causes a substantial reduction in mortgage credit risk. The LTV cap even reduces the credit risk more than it increases due to the flood event.

In conclusion, this study finds that capping the LTV to 90% proves to be a very effective measure to reduce the credit risk of a real estate investor or mortgage lender.

5.2 Limits, barriers and distributional impacts

If an LTV-cap is such an effective adaptation measure, why would one not simply implement it? First of all, one must be aware that it mainly is effective in reducing the risk for the *mortgage provider*. This is because the LTV-cap reduces the maximum exposure of the lender, relative to the collateral value pledged. A lower LTV usually means a lower monthly payment obligation as well, which also reduces the likelihood of a borrower default.

Moreover, an important effect of this measure is that less households will be able to afford a house, if 10% of the value needs to be funded from their personal savings. This will have a strong distributional effect: households with less wealth (savings) will have reduced access to living in flood-prone areas, whereas wealthier households gain a relative advantage over them. Very practically, it will for example become much harder for younger people (first-time homebuyers that have not yet accumulated capital) to buy a house in these areas.

A second order effect of the measure, is that reduced market accessibility may decrease the total demand for houses in flood-prone areas, which may reduce the house price in flood-prone areas. In turn, the price of houses without flood risk, outside the hazard zone, may increase. Rent prices would likely be impacted too, given the shifts in demand and the reduced accessibility in the owner-occupied segment.

In summary, the barriers and distributional impacts of imposing a credit constraint are:

- It may reduce the accessibility of the housing market for younger and less wealthy people. For financial institutions, this in turn may have implications for credit growth (less loans, smaller loans).
- Hence it may cause a distributional effect across generations and between wealthier and less wealthy households;
- It may reduce house prices in flood-prone areas (and increase prices in areas without flood risk). This may be deemed desirable or undesirable, depending on the nation-wide spatial policies, but would induce wealth losses for some homeowners.
- While it may reduce the risk for financial institutions, it does not necessarily so for an individual homeowner.

The effects that we describe here for the concrete adaptation measure of credit constraints, exemplify principles that go beyond this single measure. Policy instruments, such as LTV-caps, serve many different objectives, which do not necessarily align with the climate adaptation objectives. In this case, one of the objectives is accessibility of the housing market, which has been an increasingly prominent political issue in recent years. A credit constraint may have climate adaptation benefits, but at the same time reduce the accessibility to the housing and credit market. In the adaptation decision type report, we will see that this kind of considerations also play a role for the other macroprudential policy adaptation options.

6. Recommendations and conclusion

Within this case study, we have been doing pioneering work on calculating the impact of large scale flooding on financial stability through a credit risk channel (Caloia et al., 2023). At this point, this risk seems manageable. However, this study rather provides one puzzle piece (credit risk channel real estate exposures) than that it gives a complete picture of all impacts of flooding on financial stability that may result from various transmission channels. Also, there are several uncertainties that require further investigation. We therefore give the following recommendations:

- For the real estate transmission channel: investigate the uncertainty in the real estate damage curves and the consequence of a sudden capitalization of risk in the real estate price (for all properties in the hazard zone, and not only for the ones affected by one particular flood).
- Expand the analysis to other transmission channels that may also affect banks, e.g. credit risk on corporate loans or market risk on sovereign and corporate bonds.
- Investigate the other macroeconomic impacts of such large scale flood scenarios
- Investigate whether sea level rise and climate adaptation could lead to a substantially different flood risk profile (when the Randstad area would be exposed to larger water depths)

Although we concluded in Caloia et al. (2023) that the risk seems manageable, we have nevertheless explored the effect of one adaptation measure: imposing a credit constraint by reducing lending to 90% of the taxation value (Endendijk et al., 2024). The results show that this is a very effective measure for reducing the credit risk of the lender, mainly because it reduces the risk for the lender by imposing a downpayment constraint to the household. A main barrier for this adaptation measure is that it would reduce the accessibility of the housing market, and would likely have a very strong distributional effect: favouring wealthier households over first-time buyers.

Case study 5.2 – Stimulation of private sector adaptation through insurance arrangements (Netherlands)

Partner: VU
Spatial scale: NUTS3 regions and national scale in the Netherlands
Stakeholder: Dutch Association of Insurers

1. Decision context

Flood events cause large disruptions to society by causing both direct and indirect damage (Dottori et al., 2018; Kreibich et al., 2014), which will be further exacerbated by climate change and socioeconomic development (IPCC, 2023). In comparison with households, businesses can experience business interruption damages alongside direct impacts due to flooding (Botzen et al., 2019; Kreibich et al., 2014). Moreover, when businesses are not operational because of flood damage, this can have far-reaching economic consequences (Gertz et al., 2019; Koks et al., 2019; Taguchi et al., 2022). Insurance is a tool to spread this risk across space and time, thereby softening the impact of a flood event. The Netherlands currently maintains an insurance system run by private insurance firms, where households and businesses are free to decide whether to purchase insurance or not.

Furthermore, insurance can be used to increase policyholder adaptation effort, thereby decreasing the total flood risk. Evidence for this has been found in studies concerning household-level insurance and adaptation (Hudson et al., 2016, 2019). A comparable analysis has not been carried out for business-level insurance. Furthermore, the Dutch Association of Insurers is involved in this case study as a stakeholder. The policy question of the stakeholder revolves around the possibility of stimulating private sector adaptation through insurance arrangements. Therefore, in case study 5.2, it is assessed in what capacity insurance incentives can increase policyholder adaptation effort in the private sector in the Netherlands. To aid in this question, the Dutch Association of Insurers has actively been involved in this research through discussions on how to shape the insurance market for businesses in the model we will be using to carry out this research, and by acquiring data on the availability of flood insurance for businesses in the Netherlands.

2. Current and future risk

This case study considers impacts from both riverine and coastal floods and follows the classification of flood events by Landelijk Informatiesysteem Water en Overstromingen (LIWO). LIWO classifies flood risk in the Netherlands into four types: Type A, floods in unembanked areas; Type B, floods resulting from the failure of a primary flood defense; Type C, floods caused by the failure of a secondary flood defense; and Type D, floods originating from regional water bodies. In the current situation, impacts resulting from a Type A and Type B flood are considered uninsurable. Therefore, in this case study, we consider two scenarios: one in which we look at the effect of insurance incentives on private sector adaptation effort using the risk resulting only from Type C and Type D floods, and one in which we look at the effect of insurance incentives on private sector adaptation effort using the extended risk (all flood types together).

Risk is operationalized as Expected Annual Damage (EAD) to facilitate the calculation of insurance premiums at a later stage. To calculate the EAD, the 'Slachtoffer en Schade Module' (SSM) (Slager & Wagenaar, 2017), version 2023, is used. Future risk in the Netherlands is projected to increase. In this case study, the GLOFRIS model (Ward et al., 2017; Winsemius et al., 2016) is used to estimate the EAD for future periods. Using the SSP2 scenario in combination with RCP4.5 scenario, the EAD is expected to double in 2050 and more than triple in 2080 compared to the current EAD.

3. Adaptation options

The main adaptation options of this case study are building-level adaptation measures for businesses. Insurance as such can also be considered an adaptation option, but the focus of this case study is how insurance incentives can promote the adoption of building-level adaptation measures. Policyholder adaptation measures come in the form of dry-proofing (preventing water from entering the building), and wet-proofing (minimizing the damage when water does enter the building), with the aim of minimizing damage when a flood event occurs (Aerts, 2018). Incentives for these adaptation measures are given in the form of insurance premium discounts, where policyholders receive a discount on their annual premium equal to the amount of risk reduced by the applied measure.

4. Assessment of adaptation options

4.1 Method

Building-level floodproofing measures can be incentivized by an insurance system due to the risk signal and by providing premium discounts when adaptation measures are taken (Hudson et al., 2016, 2019; Unterberger et al., 2019). We assess four stylized insurance market forms using the 'Dynamic Integrated Flood Insurance' (DIFI) model, adapted from Hudson et al. (2019) and Tesselaar et al. (2020a). The insurance market forms investigated start from the baseline situation in which only Type C and Type D floods are eligible for insurance and reinsurance is organized by private reinsurers. The next market form is a scenario in which the coverage is expanded from Type C and Type D to also include Type A and Type B floodings, and reinsurance is organized by private reinsurers. The last two insurance market forms replace the private reinsurers in the first two scenarios with a public reinsurance system in which the government plays a larger role. Assessing these four scenarios, we gain insights into how the insurance incentive to stimulate building-level floodproofing measures behaves under different insurance market situations.

The DIFI model is a partial equilibrium model that computes insurance premiums based on flood risk and then operationalizes these insurance premiums in a behavior module which simulates insurance uptake and adaptation effort. In this way, the effects of (increasing) flood risk and insurance system design on insurance uptake and adaptation efforts can be assessed. The insurance premiums are calculated on a NUTS3-scale (corresponding to the Dutch COROP regions). Therefore, insurance uptake (the percentage of companies that purchase an insurance policy) and adaptation effort (the percentage of companies that apply building-level flood adaptation measures) are also aggregated on this scale.

The baseline adaptation effort, and percentage of businesses purchasing an insurance policy are calibrated on survey data from the Limburg floods in 2021. Implementation costs of building-level dry-proofing and wet-proofing measures are taken from Aerts (2018) and Kreibich et al. (2015) and adapted to businesses, taking building size into account. By using an incentive system in which policyholders get an insurance premium discount equal to the EAD reduction when they implement company-level adaptation measures, the increase in adaptation effort compared to the baseline can be quantified. Consequently, the decrease in flood risk resulting from this increase in adaptation effort can be quantified in monetary terms. This exercise can be carried out for the baseline risk and the future risk.

The partial equilibrium model applies a subjective expected utility framework to simulate whether businesses are willing to apply adaptation measures under diverse types of insurance systems. In this framework, businesses compare expected utility with and without investing in adaptation efforts. In a risk-based insurance system, businesses receive an additional financial incentive to invest in adaptation through a premium discount.

More details of the methodology are available in Annex C – CS5.2.

4.2 Results

The left side of Figure 5.2.1 shows the percentage of companies that have an insurance policy in combination with adaptation measures for different insurance market forms; the right side of Figure 5.2.1 shows how this percentage changed after the insurance incentive is applied. The insurance incentive is a discount offered to current policyholders, lowering their annual premium when they invest in measures to reduce flood risk. The figure shows that the insurance incentive is most effective in areas where there is already a lot of adaptation, these areas also happen to have the highest EAD per company. Furthermore, the increase in adaptation effort is highest for the Extended Coverage scenario, followed by the Extended Coverage & Public Reinsurance scenario. This means that applying the insurance incentive is most effective in the Extended Coverage scenario, for which the EAD (both direct and business interruption) per company is generally higher.

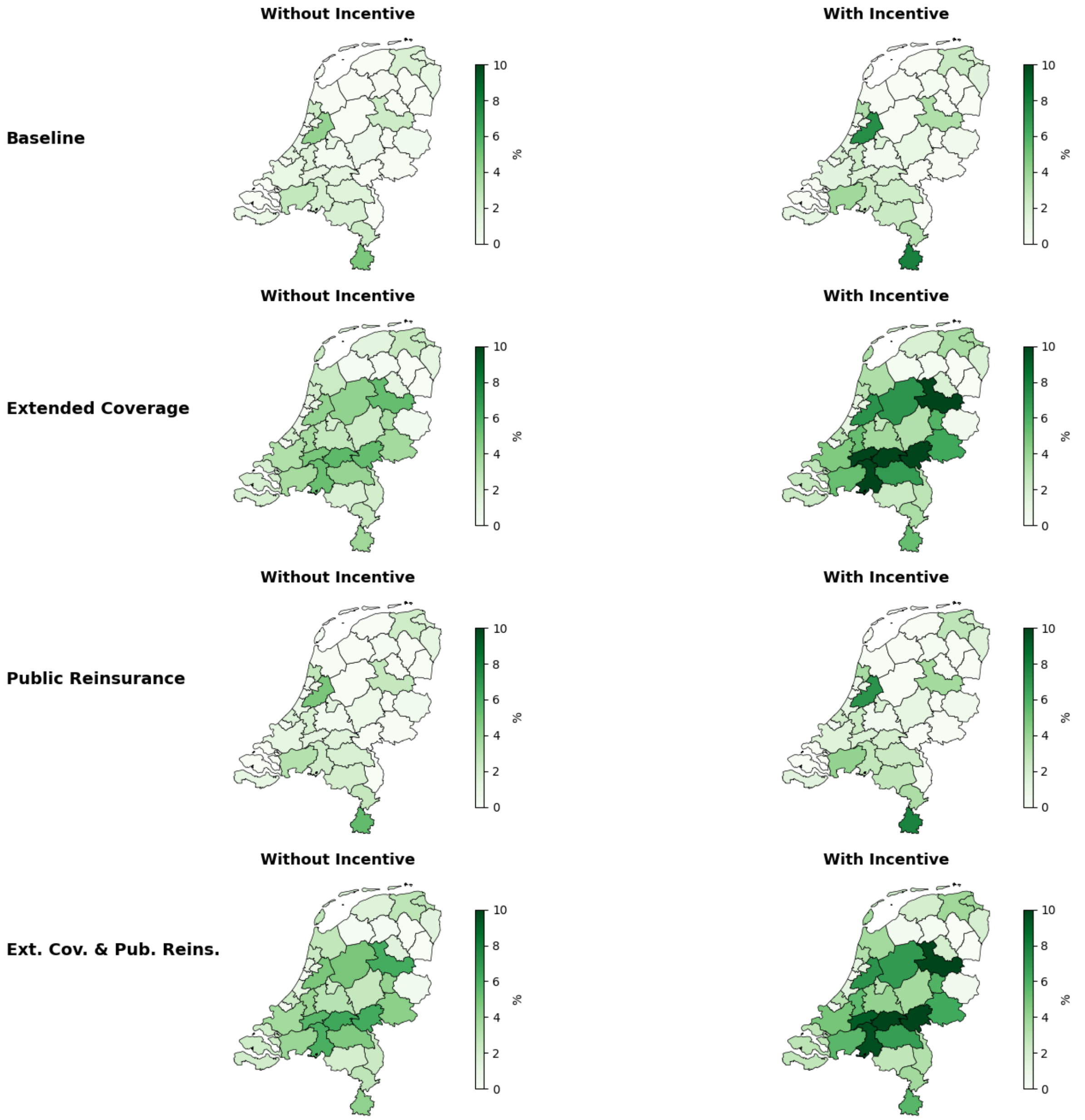


Figure 5.2.1: Percentage of companies insured and invested in adaptation with and without incentive

Table 5.2.1 shows the insurance uptake and adaptation effort for the four different insurance market scenarios considered. The table shows that extending the coverage results in similar uptake percentages (even though the number of exposed companies is greater in the extended coverage scenario). Moving from a private reinsurance system to a public reinsurance system where the government covers the largest risks leads to a reduced insurance premium. This reduced insurance premium results in higher uptake percentages for both the Baseline scenario and the Extended Coverage scenario. Moreover, Table 5.2.1 shows the average percentages of businesses are insured and have invested in floodproofing measures, before and after the insurance incentive is applied. It can be seen that the average percentages increase but that the effect is greatest under the two Extended Coverage scenarios. Furthermore, the average percentage of businesses that have invested in adaptation is remarkably higher for the extended coverage scenario. This can be explained by the higher EAD in this scenario, which makes the investment in floodproofing measures more profitable.

Table 5.2.1: Average insurance uptake and adaptation effort at NUTS3 level

	Baseline	Extended Coverage	Public Reinsurance	Extended Coverage & Public Reinsurance
% insured direct EAD	38.75	38.70	41.34	41.28
% insured business interruption EAD	36.07	35.63	38.83	38.40
% of businesses invested in adaptation	4.39	10.76	4.39	10.76
% of businesses insured and adapted	0.97	2.39	1.13	2.74
% of businesses insured and adapted after incentive	1.44	3.95	1.54	4.01

Table 5.2.2 shows the average percentages across NUTS3 regions of businesses for which the insurance premium or the adaptation investment is not affordable. Note that these numbers are based on the current assets of the companies and can therefore be viewed as upper bound values. The table shows that the insurance premium is only unaffordable for a small number of businesses, even if the insurance coverage is extended to also include Type A and Type B floods the percentage remains low. The adaptation investment cost is unaffordable for a larger number of businesses but stays under 8%. For the extended coverage scenario, the percentage of businesses for which the adaptation investment is unaffordable is even a bit lower.

Table 5.2.2: Average percentage across NUTS3 regions of businesses for which the insurance premium or adaptation investment is unaffordable

	Baseline	Extended Coverage	Public Reinsurance	Extended Coverage & Public Reinsurance
% premium direct EAD unaffordable	0.28	0.60	0.33	0.52
% premium business interruption EAD unaffordable	0.45	0.69	0.38	0.59
% adaptation investment unaffordable	7.41	7.31	7.41	7.31

Table 5.2.3 shows the average insurance uptake and adaptation effort at NUTS3 level for two future EAD levels, EAD at 2050 and EAD at 2080, based on SSP2/RCP4.5 GLOFRIS runs. Table 5.2.3 shows that, compared with Table 5.2.1, the insurance uptake percentages remain relatively stable over time but do drop slightly. Scenarios incorporating public reinsurance consistently exhibit the highest uptake rates. It is important to keep in mind that even though the percentage insurance uptake decreases slightly, this leads to a substantially higher absolute amount of damage as the EAD doubles in 2050 and more than triples in 2080. On the other hand, the Table also shows that while the intention to insure diminishes, the intention to invest in adaptation measures increases sharply. This can be explained by the fact that the higher EAD levels also increase the potential profitability of the investment in adaptation measures. Whereas the insurance premium reflects the rising EAD, the adaptation investment cost remains flat. This same effect can be seen when looking at the insurance incentive in 2050 and 2080. Since adaptation becomes more attractive in general due to the increase in EAD in combination with a flat investment cost, the insurance incentive also becomes more effective in future periods.

Table 5.2.3: Average future insurance uptake and adaptation effort at NUTS3 level

	Baseline	**Extended Coverage**	**Public Reinsurance**	**Extended Coverage & Public Reinsurance**
% insured direct EAD 2050	37.22	36.26	39.89	38.95
% insured business interruption EAD 2050	35.32	35.57	37.97	38.26
% insured direct EAD 2080	35.54	33.93	38.31	36.73
% insured business interruption EAD 2080	33.39	33.14	36.13	35.96
% of businesses invested in adaptation 2050	15.00	25.12	23.68	25.12
% of businesses invested in adaptation 2080	23.68	35.45	23.68	35.45
% of businesses insured and adapted 2050	3.25	5.57	3.76	6.36
% of businesses insured and adapted 2080	5.13	7.80	5.93	8.95
% of businesses insured and adapted after incentive 2050	6.65	12.86	6.43	12.22
% of businesses insured and adapted after incentive 2080	12.90	21.17	12.48	20.86

Table 5.2.4 shows the estimated total direct EAD and business interruption EAD for both the Baseline Scenario (flood Type C and flood type D) and the Extended Coverage scenario (flood types A, B, C, D). By comparing the increase of companies that are both insured and adapted after the incentive is applied, it becomes possible to estimate the yearly damage reduction. The damage reduction is calculated by taking into account the deductible of 15% for insurance policies (hence a 85% damage reduction) and the 35% damage reduction for adaptation. Combining adaptation and insurance then leads to an assumed damage reduction of 90.25% (adaptation reduces the damages by 35%, after which 15% remains as the deductible).

Table 5.2.4: Direct EAD and business interruption EAD

	Baseline	**Extended Coverage**
Direct EAD	€29,644,896	€125,844,571
Business interruption EAD	€39,118,158	€141,210,528
Direct EAD 2050	€59,586,240.96	€252,947,587.71
Business interruption EAD 2050	€78,627,497.58	€432,905,324.24
Direct EAD 2080	€101,978,442.24	€283,833,161.28
Business interruption EAD 2080	€134,566,463.52	€485,764,216.32

Table 5.2.5 shows the estimated EAD reduction for businesses that is achieved due to the insurance based incentive for adaptation investment. The table shows that in the current situation (Baseline) the EAD reduction due to the incentive amounts to about €300,000. This EAD reduction increases sharply in the future due to the increase in adaptation effectiveness. In 2080, the EAD reduction due to the insurance incentive in the baseline amounts to over 16.5 million euros. The effect of the incentive becomes even more noticeable when the insurance system is expanded to also cover Type A and Type B floods. Under the extended coverage scenario, the total EAD savings due to the incentive amount to over 90 million euros in 2080. When considering the public reinsurance scenarios, the EAD savings are lower than under the corresponding private reinsurance scenarios. This is because, in the public reinsurance case, there is already a larger initial group of companies that both hold insurance policies and have invested in adaptation measures. As a result, the incentive has less room to drive additional companies to adopt both insurance and adaptation, leading to a smaller overall increase and thus lower EAD savings.

Table 5.2.5: EAD reduction due to insurance incentive

	Baseline	**Extended Coverage**	**Public Reinsurance**	**Extended Coverage & Public Reinsurance**
EAD reduction due to incentive	€291,675.68	€3,759,868.74	€254,440.49	€3,060,918.78
EAD reduction due to incentive 2050	€2,595,525.17	€45,123,806.25	€2,038,250.65	€36,272,360.03
EAD reduction due to incentive 2080	€16,587,534.11	€92,862,890.37	€13,983,056.42	€82,722,290.52

5. Barriers and conditions for implementation

The main barriers that affect the effectiveness of insurance-based incentives concern the costs and coverage of insurance. Although expensive premiums in high-risk areas may be considered an appropriate incentive for businesses to reduce risk in some way, the high premium may discourage insurance uptake, which is undesirable from a societal perspective. Moreover, without insurance coverage, businesses will not be exposed to potential adaptation incentives generated by premium discounts. It is, therefore, important that a balance is struck between emitting a risk-signal and maintaining affordability. This can be achieved by enforcing a degree of cross-subsidization between low- and high-risk policyholders. A limited degree of such cross-subsidization of risk may ensure that incentives for risk-reduction are given, while issues concerning the affordability of insurance are minimized. A potential barrier concerning the feasibility of granting insurance premium discounts for adaptation effort includes uncertainty about the effectiveness of adaptation measures at reducing flood risk. Such uncertainty may complicate the estimation of such premium discounts for insurers.

There are also barriers concerning the investment in wet-proofing and dry-proofing measures. When a company has insufficient capital available to invest in an adaptation measure, this might be a barrier. Moreover, companies with larger premises will have larger adaptation investment costs which can also limit the willingness to invest in adaptation measures.

Furthermore, practice shows that it is difficult to change political support concerning public risk management strategies. The Netherlands recently rejected a proposal to change the current voluntary flood insurance system to a public-private partnership, where the government co-funds flood coverage. Germany has, several times, rejected plans to introduce flood insurance uptake requirements based on the idea that this infringes consumer freedom. Political ideals concerning disaster compensation systems are difficult to change, which is a barrier that needs to be considered when reading our case study report.

6 Transport and supply chains

Case study 6.1 – Adaptation to minimize the risk of disruptions of trade corridors (Austria)
Partner: Deltares/UniGraz
Spatial scale: National scale, in Austria
Stakeholder: Federal Ministry for Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management (BMLUK)

1. Decision context

Case 6.1 focuses on the potential risks of flooding impacts on transport infrastructure, specifically rail and major roadway corridors. In contrast to other case studies in ACCREU, this work takes a broader spatial view and assesses current and future flood risk at the national scale for Austria. As a relatively small country with a mix of heavily mountainous, Alpine regions transitioning into lowlands in the east, Austria has a large amount of experience with flood hazard in a number of contexts due to the range of geography. This variation presents unique challenges for different regions.

The deep engagement stakeholder is the Federal Ministry for Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management (BMLUK), as well as a contact at the Ministry of Innovation, Mobility and Infrastructure (BMIMI) (responsible for transport policy). The BMLUK has a range of responsibilities e.g. policy development and implementation across domains. Our interest lies in the Ministry's development of adaptation strategy and coordination across policy domains, chiefly via its drafting and revision of the National Adaptation Strategy. The Ministry focuses such planning at a national level, focuses on highlighting good adaptation practice, avoiding maladaptation, cross-sectoral measures and emphasizing spillover effects, with emphasis on coordination between different ministries and governance levels (national, federal state, municipal).

Given the BMLUK's broad mandate in this aspect as an advisory/strategy-defining ministry, the aim of the case is to provide a framework for discussing adaptation strategy between infrastructure builders and operators, other Ministries and relevant governance bodies and provide an indication of the possible costs of current and future flooding impacts on the transport sector, as well as start to discuss the possible benefits of adaptation. The goal of the case is to focus on potential worst-case scenarios and understand from the perspective of the BMLUK the hierarchy of what infrastructure is most vulnerable and determine likely impacts of corridor disruption. We can then contrast various futures with higher or lower costs and determine if some tipping points exist, where current Business-as-usual (BAU) approaches to adaptation would be untenable, and shift to transformative adaptation would become more attractive (economically, politically, socially).

2. Current and future risk

Flood risk, specifically exposure in terms of flooding extent and depth, is well-depicted for current risk in Austria, with detailed spatial mapping of exposed areas (BML 2024). In terms of risk to road and rail infrastructure, the Austrian Program on Critical Infrastructure Protection (APCIP) emphasizes protection against natural hazards such as flood, and major transportation routes have been the focus of technical measures to increase resilience to current risks. In the recent past, targets have been set to protect significant transport routes against flood events of up to 100-year return periods (Nachtnebel and Faber 2009). Current risk is also addressed by the Austrian disaster relief fund, sourced from income and corporate tax revenues, which funds both preventative DRM as well as recovery costs (but it should be noted that the fund covers a wide range of DRM and recovery costs beyond infrastructure). While operational for current risk levels, research has asserted that it will likely be inadequate to address future risks (Reiter et al. 2022).

Given the uncertainty surrounding future flood hazard in the Alpine region (see Blöschl et al. 2017), there is the potential for some river basins (e.g. Innviertel and Mühlviertel) to see an increase in the frequency of a 100 year event by 10%, while others (Traun, Enns, Erlauf and Traisen) could see a reduced occurrence (-4%). Other works project more extreme changes, with future recurrence of the currently 100 year event flood changing to up to a 10–20 year event for small tributaries of the Danube, and more major tributaries seeing a 100 year event occurring between 20–60 years (Hattermann et al. 2018).

Risk reduction measures relating to transport could be the responsibility of a number of agencies and firms e.g. spatial planning regulations are typically established at Federal state level, and responsibility for implementing technical measures is taken by either the highway management authority ASFINAG or the rail operator ÖBB, while other measures may originate from the Ministry of Land or Interior (the latter is responsible for disaster management).

3. Identifying adaptation options

In our initial discussions with the BMLUK, we focused on the different considerations at play in developing a national adaptation strategy and the possibility and criteria for pursing more transformative adaptation e.g. network- and system-level versus the current approach focused on incremental, hazard- and adaptation- level. As discussed in Section 5 on barriers to implementation, stakeholder workshops identified clear preference for incremental approaches, given perceived political, institutional and financial barriers relating to broader transformative strategies.

As such, we focus our analysis in the case on the current and future impacts of flooding, in order to identify if climate change impacts might make transformative strategies more attractive in a future with steeply rising damages. To do so, we undertake a hazard analysis for road and rail infrastructure across Austria, estimating current and future damages for key return periods and assuming a variety of possible climate impacts. To focus more concretely on the near term and strategies relevant to the stakeholder, we then assess the potential costs of more incremental strategies (in this case, asset-level improvements such as raising road or rail corridors in exposed areas) and assess different possible approaches to spending a limited adaptation budget in the near future based on different approaches to climate justice.

4. Assessment of adaptation options

4.1 Methodology

4.1.1 Risk modelling

Climate change increases the speed and intensity of the hydrological cycles, creating more changes in flooding due to extreme precipitation (Eingrüber & Korres, 2022). Thus, understanding the impact of flooding (fluvial in this study), under changing climate on infrastructure systems becomes crucial. Such an understanding can be gained by performing impact assessment analyses under the current climate, and future climate change scenarios.

In order to estimate the economic impacts of fluvial flooding events, the physical damage caused by flooding on the current Austrian rail and road networks are assessed. The physical damage costs are limited to the costs of repairing the standard cross-section rail and road segments. In the presented analysis, we will specifically assess the present road and rail network and not the future network developments.

The methodology for estimating flood-induced damage costs on road and rail infrastructure includes three main steps (Figure 6.1.1): graph creation, exposure analysis, and damage estimation. The RA2CE open source tool (Deltares, 2025) was used to create detailed rail and road network graphs by extracting data from OpenStreetMap, focusing on motorways, trunks, primary, and secondary roads. Exposure analysis involved overlaying flood maps on these networks to estimate hazard severity (water depth and velocity) at each segment. Damage estimation utilized Kellermann et al. (2015) curves for rail networks, which predict damage based on inundation depth. For roads, OSdamage curves by van Ginkel et al. (2021) were adapted to account for high-resolution flood maps, offering infrastructure-specific vulnerability estimates based on European repair cost data or the potential future damages arising from climate change, possible shifts in the return periods (likelihood) of the input flood maps (under the current climate) are considered. The damages for flooding events with return periods exceeding 300 years (the highest return period available to this study) are extrapolated (loglinearly).

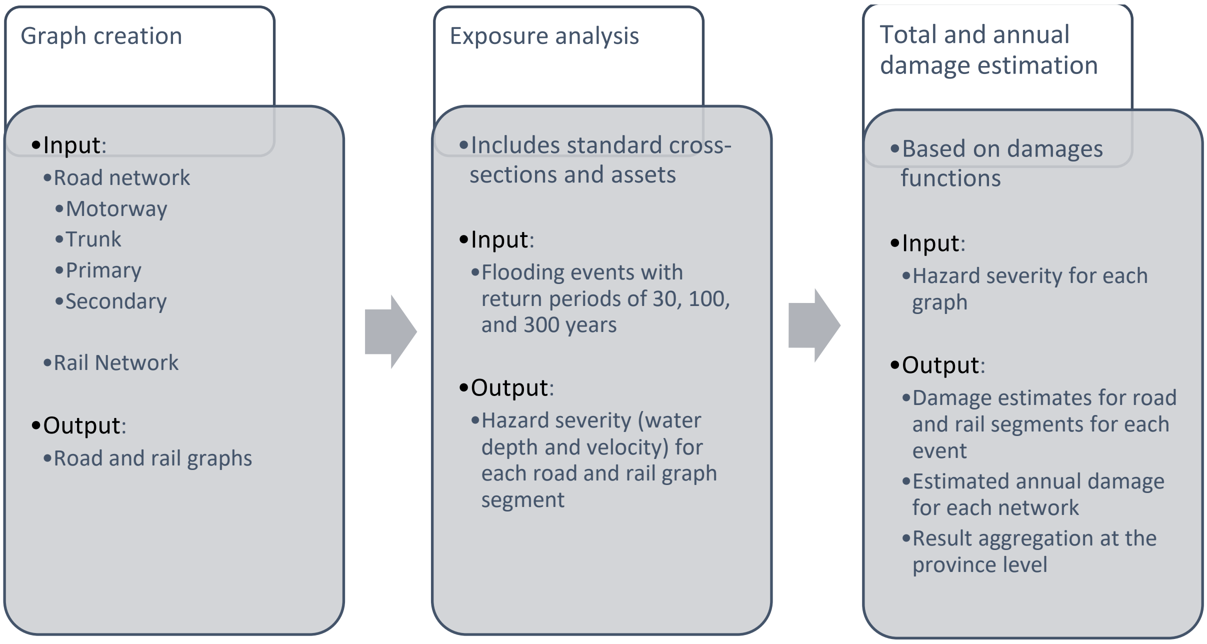


Figure 6.1.1: Damage estimation main steps

The flood maps were obtained from the Water Information System Austria (WISA). The maps illustrate the spatial extent of flooding based on various flood scenarios derived from simulations of different flood discharge values and characteristics (BML, 2024). Next to a baseline scenario (return periods of 30, 100, and 300 years), representing the current climate, the expected shifts in the return periods of the baseline scenarios due to climate change until 2100 are considered. In this approach, the flood severity (the flooding extent, water depths, and flow velocity) is assumed to stay the same, while the return period (or likelihood) is changing. These return period shifts are based on a literature review of the studies relevant to the context of Austria and benchmarking the most robust and widely accepted one.

The National Flood Risk Management Plan (BML, 2021) cites the Blöschl studies (2010, 2017) as the primary reference for understanding the hydrological impacts of climate change in Austria, a perspective supported by national flood risk experts. Blöschl et al. (2017) project locally varying changes in RP100 discharge between -5% and +10% by 2050. While more recent studies suggest significantly larger changes, these are based on coarser hydrological models and lack the credibility of Blöschl's work. Given the complexities of assessing hydrological impacts and the uncertainty in recent competing studies, the approach taken is to anchor projections in Blöschl et al. (2017), using its findings to estimate an uncertainty range.

The return period shifts resulting from the discharge changes estimated by the Blöschl et al. (2017) study are minor; therefore, no return period shift is considered due to future climate change. On the other hand, the study conducted by Hatermann et al. (2018) is used to demonstrate the implications of more severe flooding return period shifts on the damages to road and rail networks. This study reports larger changes, including those affecting the Upper Danube catchment, which spans a significant portion of Austria.

Assessing these different scenarios can allow for identifying potential tipping points or thresholds at which shifts towards transformative adaptation in future national adaptation strategies may be warranted, insights which could directly support the stakeholder’s strategic planning role, potentially informing future National Adaptation Strategy updates and discussions on when and why a shift from incremental to transformative adaptation may be warranted.

4.1.2 Assessing adaptation strategies

To evaluate the potential benefits and cost-effectiveness of incremental adaptation measures (e.g. hazard- and asset-level interventions), we develop a cost-benefit analysis framework at the sub-regional (NUTS-3 scale) for Austria, based on the results of Section 4.1.1. We focus on identifying how targeted adaptation can reduce expected annual damages (EAD) to road and rail infrastructure under current and future flood hazard conditions.

Our methodology consists of the following steps. We first conduct a static cost-benefit assessment for each region to estimate (i) adaptation costs, based on representative measures (and estimated costs) for asset protection taken from literature and (ii) avoided damages, based on the difference in expected annual damages before and after adaptation. Using the current flood hazard scenarios from Section 4.1.1. allows us to estimate cost-benefit ratios at the regional level, for a range of potential adaptation costs and impacts given different assumptions.

Cost-benefit analysis (CBA) is a well-established approach in economics, in this case, allowing us to measure the potential impact of disaster risk reduction policies at a sectoral scale, and provides an avenue towards ranking or prioritizing projects in different locations (Shreve and Kelman, 2014). Based on the return period-specific losses for exposed assets, we define two different adaptation scenarios at the regional level and assess the costs thereof, indicating respectively a more conservative and ambitious approach to adaptation. For each case, we calculate the change in expected annual damages using the results of Section 4.1.1. for 30, 100, and 300 year return periods, assuming they change as described below.

In our conservative case, we estimate the costs to protect assets at risk to high-frequency, lower impact events (30 year return period events). For rail, this is 0.67% of all Austrian railways (77 km), for road, 0.89% or 428 km. These assets exposed to 30 year events are made more resilient via asset-level adaptation, in this case, raising the level of the road or railway (as suggested in the EU TEN-T adaptation report) until they are protected against up to a 100 year event.

In our model, we assume that all damages for a 100 year event or lower are mitigated for all protected assets (all road and rail exposed to 30 year events), but for a 101 year event or higher, damages are identical to the original estimates calculated in section 4.1.1. For those assets which are not vulnerable to a 30 year event, but are to a 100 year event, no adaptation is undertaken.

In our ambitious scenario, we assume that the same measures are applied, but in this case protection is applied to all assets vulnerable to 100 year event flooding. Beyond this level, impacts are as in the case of no adaptation measures. In this case, up to 1.85% of all rail assets in Austria would be adapted (213 km) and 1.89% of roads (907 km).

Calculating the average annual losses (AAL) expected after adaptation is straightforward in the ambitious case; for the return periods below 100 years, we assume no losses, and from 101 years onward, impacts are as in the baseline with no adaptation. For the conservative case, we are unable to recalculate the effect of increasing resilience for assets exposed to 30 year events. These assets would then be resilience to a 100 year event, and thus would lower the 100 year event losses, but not entirely, as typically more assets would be exposed to this larger flood event. An approximation of the degree to which damages for a 100 year event are reduced is required.

We conservatively assume that for a 100 year event, damages are calculated as follows:

$$RP_{100}^{30-year\ event\ adaptation} = RP_{100}^{baseline} * 1 - \left(\frac{30\ year\ RP\ exposed\ asset\ total\ length}{100\ year\ RP\ exposed\ asset\ total\ length}\right)$$

As an example, for a region such as Mittelburgenland where the total road assets damaged by a 30 year RP event are 75% of the length of assets damaged by a 100 year RP event, the baseline (without adaptation) 100 year event expected loss is multiplied by 25%, since assets exposed to a 30 year event most likely will be exposed to a 100 year event as well. This is a simplification, as hazard modelling damage functions are more sophisticated and may assign only partial damage to an asset for a 30 year event and higher damages at more extreme impacts, but without more extensive modelling, we feel our assumption is conservative and indicates a lower-range for benefits. In reality, benefits of adaptation may likely be higher.

Given the assumptions above leading to new estimates of 30, 100, and 300 year event damages, average annual damages (AAD) can be calculated using the Simpson rule. Given two return periods and expected losses we can estimate the probabilistic range between the two periods and multiply this by the average loss within this range, as follows:

$$AAD_{p1-p2} = (p_2 - p_1) * \left(\frac{\left(\frac{L_1}{L_2}\right)}{2}\right)$$

The total AAD is simply the summation of the AADs from each range (0–30, 30–100, 100–300).

The adaptation measures we apply in our two scenarios have cost ranges between 90–560 thousand EUR per kilometer of asset retrofitted (Schade et al., 2024). For our central case – and for comparability to other analyses – we use an estimated cost of 400 thousand EUR consistent with recent literature undertaking similar assessments. Typically, CBA produces two values of interest; cost-benefit ratios (benefits divided by costs) and net present value of a project or measure. In this case, the costs of adaptation are lump-sum up-front costs, while benefits accrue over time in the form of reduced average annual losses. This renders the cost-benefit ratio less informative, and instead we assess the net-present value of our conservative and ambitious scenarios at the regional level, assuming a "payback time" in which we aggregate the costs and benefits of 25 years. This represents a median range of expected lifetime for asphalt road assets in the EU, although the expected lifetimes of rail assets are typically longer, e.g. 30–50 years, although this depends heavily on types of track and other assumptions.

In short, to prioritize the limited available funding on adaptation for transport infrastructure, we calculate the net present value (NPV) of our conservative and ambitious adaptation measures for road and rail assets separately, using the same assumptions, e.g. a 3% discount rate consistent with other literature. We sum the discounted costs and yearly benefits of these measures at the regional (NUTS3) level. The table below indicates our main assumptions and sensitivity analyses presented in the Results section.

Table 6.1.1: Overview of scenario assumptions

Variable	Main scenario	Sensitivity analysis
Discount rate	3%	1–5%
Payback time	25 years	20–30 years
Adaptation cost	400,000 EUR	200,000–560,000 EUR
Road damages	Low damage function	High damage function
Adaptation measures	Adapt all assets exposed to 30 year events	Adapt all assets exposed to 100 year events

Beyond identifying the direct costs and benefits of adapting all vulnerable assets, we are interested in the potential distribution of adaptation given budget or other implementation constraints. Fully funding all potential projects where benefits outweigh costs is higher than typical budgets for such in Austria (see Results), and as such we assess various regional distributions of a pre-emptive adaptation approach based on the operationalization of different fairness principles.

To demonstrate the impact of different principles and their implementation, we assume that only one third of all exposed assets can be improved, which would correspond to a total cost for both road and rail of about 70 million EUR (10.29 million for rail, 57.1 million for road), roughly in line with future indicative funding levels for adaptation found in other assessments, such as TEN-T adaptation costing study claiming pledged 50 million EUR until 2030 for Austria).

Based on van Marle et al. (2023), we investigate the implications of different fairness principles in allocating an adaptation budget for our case, leading to different hypothetical operationalizations and adaptation effort by region – but it should be noted these principles do not necessarily reflect e.g. legal requirements or limitations:

a. **Utilitarian – maximizing utility or benefits**: here we allocate the available adaptation funding to regions in two ways, reflecting two possible interpretations of a utilitarian principle. In the first approach, we allocate the funding for adaptation, corresponding to kilometers of road/rail adapted, in order to maximize total NPV of the net benefits of adaptation across Austria. In the second approach, we allocate the funding for adaptation among regions based on regional GDP, reflecting a focus on prioritizing economically productive areas.
b. **Egalitarian** – **equal benefits across spatial groups**: this approach aims at minimizing the sum of squared deviations in NPV per capita from the average value for all regions using a non-linear solver to identify an optimal allocation of funding across regions.
c. **Prioritarian – prioritizes more socially-vulnerable areas:** in this case we allocate adaptation funds based on regional GDP per capita, with poorer regions receiving a larger share of funding, relative to average GDP / capita.

The results of these different allocation mechanisms can allow stakeholders to reflect on issues of climate justice in adaptation and assess the different potential implications of near-term incremental adaptation, beyond the further-term decision processes comparing incremental versus transformative adaptation. Our stakeholder workshops have illustrated that such decisions are mainly limited by political considerations. Developing and updating the National Adaptation Strategy could be informed by the results of these different potential approaches to constrained budgets, in terms of a better understanding of where impacts are likely to be felt in the future, and how changing priorities e.g. from egalitarian to prioritarian, may change the way in which effort (and spending) on adaptation is distributed.

4.2 Results

4.2.1 Current risk

Given current hazard estimates, segments of road and rail infrastructure potentially inundated by various events (30, 100, or 300 year) are identified (see Figure 6.1.2). For rail, the majority of identified segments at risk are to the west in Tirol, the south and south-east in Kärnten and Steiermark, and to the north in Oberösterreich; road inundation follows a similar pattern with added incidence of inundation in the south, as well as more frequent incidence in areas around the capital (Vienna). Combined, expected damages due to floods are likely to be most costly for Tirol and the southern provinces of Kärnten and Steiermark, with some additional hotspots in Oberösterreich, with potential estimates of annual damages per municipality reaching up to almost 3 million EUR.

While the Tiroler Unterland is calculated as having extremely high yearly expected losses, the majority of provinces can expect average annual damages of less than 1 million EUR, with increased levels in the southern portions of the country and northern Oberösterreich. Altogether, the methodology applied here suggests a country-wide expected annual damage for both rail and road combined of between 16.6 to 18.9 million EUR. While slightly lower than previous estimates, such as Bachner (2017) which estimates yearly losses to roads (39 million) and rail (18 million EUR), these figures include other hazards outside of riverine flooding and include damages to tunnels and other infrastructure not modelled here. Thus, estimates for current risk levels can be seen as being in line with previous estimates, and possibly conservative and not overestimating expected annual damages.

4.2.2 Additional risk due to climate change

Estimating the change in average annual loss climate-change-induced flood risk increases is complicated by a lack of data on future flood extent and uncertainty surrounding return period shifts across Austria. Given the studies available (see Sections 2 and 4.1) and assuming an extrapolation of damage curves beyond 300 year events, we can derived a future storyline for stakeholders that presents a plausible account of increasing damages, in order to identify the existence of adaptation tipping points. Similar to Figure 6.1.2, expected annual damages are calculated for municipalities, and aggregated to the national level for the years 2050 and 2100 for RCPs 4.5 and 8.5, with results found in Table 6.1.2. As shown, total expected annual damages could double to almost triple in size by 2050, with even larger increases by end-of-century.

Table 6.1.2: Expected annual damages (EAD) for road and rail line infrastructure for both current risk and projected future changing flood risk for indicated time periods and climate scenarios.

EAD	Current	RCP4.5 2050	RCP8.5 2050	RCP4.5 2100	RCP8.5 2100
Road (min)	3.96	6.60	8.91	10.29	16.39
Road (max)	6.21	10.75	14.63	15.96	26.43
Rail	12.64	22.45	30.89	32.16	54.73
Sum (min)	**16.60**	**29.05**	**39.81**	**42.45**	**71.13**
Sum (max)	**18.85**	**33.20**	**45.52**	**48.13**	**81.16**

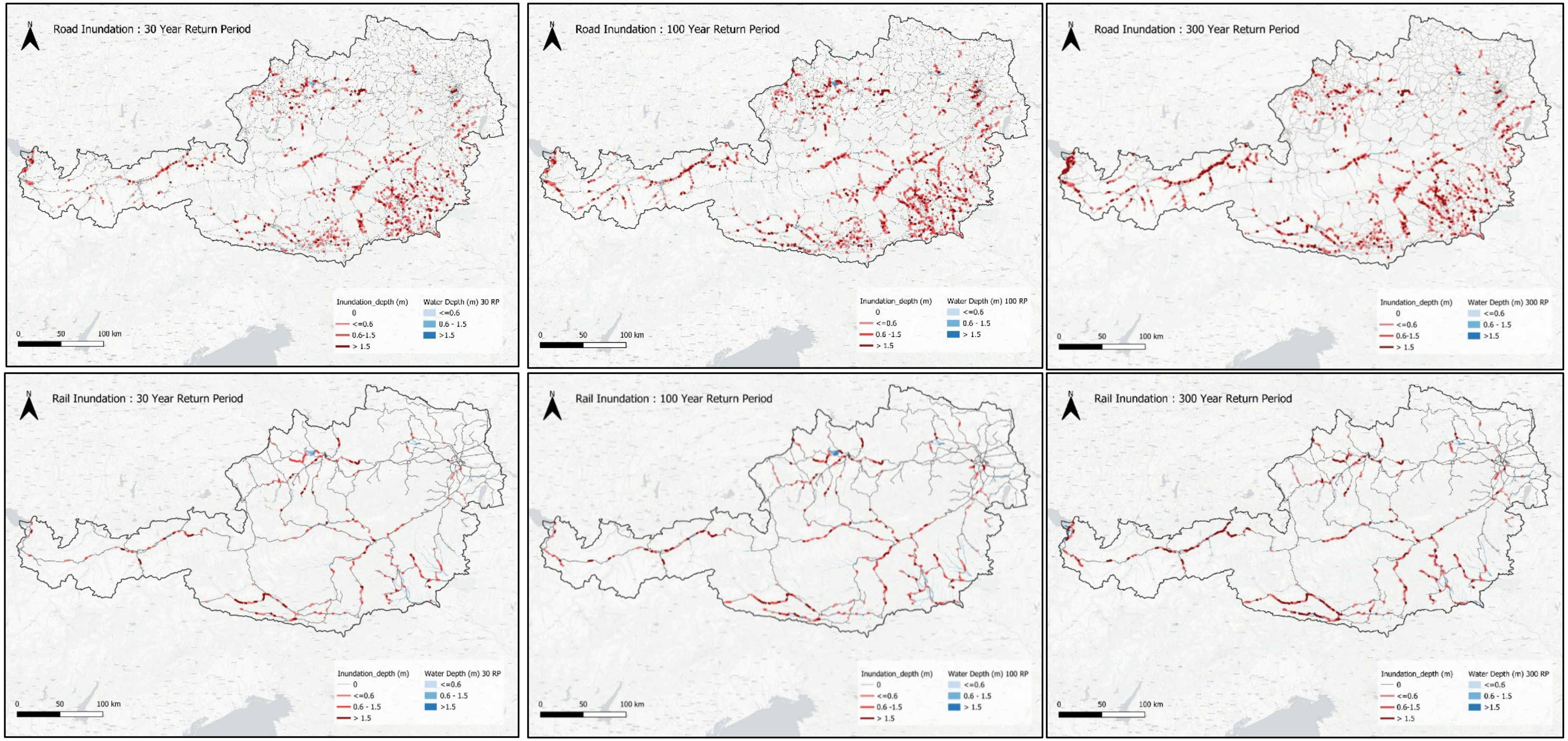


Figure 6.1.2: Road (top row) and rail (bottom row) assets inundated by 30-, 100- and 300-year flood events (left, middle and right columns respectively) for current levels of exposure - results of modeling as described in section 4.1.

4.2.3 Adaptation cost scenarios

The results from Section 4.2.1 above provide a cost basis for assessing adaptation option effectiveness and potential benefits. Tables 6.1.3 and 6.1.4 report results for rail and road infrastructure under our reference scenario: a conservative approach to adaptation, low roadway damage estimates, a 3% discount rate and a 25-year time horizon. As shown , there are stark differences between road and rail.

For roadways, a full adaptation of all exposed roads features a benefit/cost ratios (BC ratios) lower than one, in most regions. This indicates that this type of adaptation action would not be worth pursuing. Those regions with ratios above 1 (Sankt Pölten, Wiener Umland Nord, Wien) typically exhibit benefits higher than 0.3 million EUR per km, as compared to other regions.

Conversely, adapting rail infrastructure shows a BC ratios above 1 in the majority of regions. This result is robust to a number of factors, clearly adaptation costs are key parameter to consider (see below).

<u>Road results</u>

The total cost of increasing the resilience of the estimated 420 kilometers of road assets, which are exposed during a 30-year event, to withstand 100 year events is 171 million EUR for all regions. Although being just 0.04% of Austria's GDP in 2024, it is over four times larger than estimates of Austria's planned budget for transport infrastructure adaptation until 2030.

Table 6.1.3: Results of regional cost benefit analysis of conservative adaptation scenario for road assets (improving all assets exposed to a 30 year event and making them resilient to a 100 year event). Benefits are conveyed as the change in average annual damages from the no-adaptation baseline, costs are in the estimated kilometers of asset to be treated multiplied by the per km adaptation cost. BC ratio are benefits / costs, and NPV is the sum of discounted costs and benefits over a 25 year time horizon. Bolded regions indicate areas where NPV is positive, greyed out regions negative.

Region	**Benefits - reduction in AAD (thousand EUR)**	**Costs (thousand EUR)**	**BC ratio**	**NPV (25 year lifetime, thousand EUR)**
Mittelburgenland	3.4	383.7	0.2	-323.10
Nordburgenland	62.8	5 678.9	0.2	-4556.53
Südburgenland	24.5	2 539.3	0.2	-2100.68
Mostviertel-Eisenwurzen	14.0	1 014.6	0.2	-764.35
Niederösterreich-Süd	30.6	4 197.6	0.1	-3649.71
Sankt Pölten	0.2	2.2	1.5	1.14
Waldviertel	44.0	1 389.4	0.6	-603.51
Weinviertel	0.0	0.3	0.1	-0.29
Wiener Umland/Nordteil	13.2	151.9	1.6	83.70
Wiener Umland/Südteil	46.1	2 094.3	0.4	-1270.76
Wien	100.4	502.1	3.6	1292.45
Klagenfurt-Villach	77.9	7 639.7	0.2	-6247.39
Oberkärnten	111.1	7 137.8	0.3	-5151.02
Unterkärnten	194.9	11 767.7	0.3	-8283.00
Graz	149.7	13 275.8	0.2	-10600.34
Liezen	80.7	7 172.9	0.2	-5729.57
Östliche Obersteiermark	188.6	9 735.7	0.3	-6364.71
Oststeiermark	204.9	18 419.7	0.2	-14755.99
West- und Südsteiermark	136.9	17 022.2	0.1	-14575.22
Westliche Obersteiermark	231.0	15 035.6	0.3	-10906.31
Innviertel	45.1	5 425.2	0.1	-4618.34
Linz-Wels	73.5	6 718.5	0.2	-5405.04
Mühlviertel	321.1	10 236.3	0.6	-4495.23
Steyr-Kirchdorf	11.3	697.5	0.3	-495.41
Traunviertel	41.7	3 784.7	0.2	-3038.41
Lungau	-	-	0.0	0.00
Pinzgau-Pongau	0.0	1.6	0.4	-0.94
Salzburg und Umgebung	-	-	0.0	0.00
Außerfern	0.4	25.5	0.3	-18.38
Innsbruck	22.5	1 586.1	0.3	-1183.79
Osttirol	1.6	226.5	0.1	-197.26
Tiroler Oberland	22.3	1 559.0	0.3	-1160.62
Tiroler Unterland	171.8	7 805.4	0.4	-4733.86
Bludenz-Bregenzer Wald	17.8	1 422.8	0.2	-1105.13
Rheintal-Bodenseegebiet	122.7	6 615.3	0.3	-4421.45

We investigated different approaches to distributing a scarce budget (for 1/3 of exposed roadways) based on an ethical framing focused on utilitarian, egalitarian and prioritarian framings as described in the Methods section, with the results found in Figure 6.1.3.

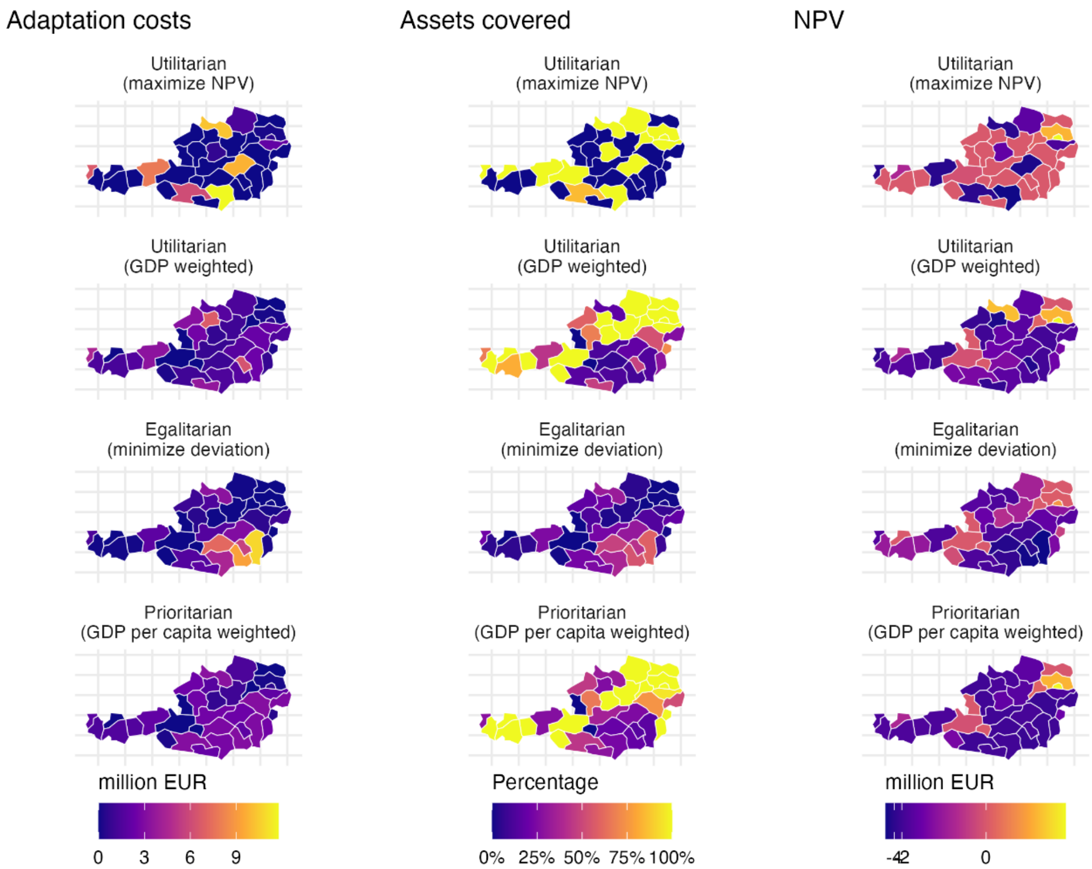


Figure 6.1.3: Adaptation costs, percentage of assets covered, and NPV under different allocation scenarios of a scarce budget for adaptation for road assets. The right column shows adaptation costs, middle column share of assets affected, and right column the estimated NPV of adaptation by 2050. Each row contains a different allocation strategy, with top corresponding to a utilitarian approach of maximizing total NPV or distributing based on regional GDP, middle representing an egalitarian effort to minimize the deviation in per-capita NPV across regions, and bottom a prioritarian approach of weighting adaptation funding based on regional GDP per capita.

The figure illustrates the vast difference in potential allocation of the budget given different ethical approaches. The utilitarian approach shown in the top row would concentrate adaptation in the regions with the highest NPV of net benefits. In this scenario, all exposed assets in 13 regions scattered throughout the country would be fully adapted, with one region, Oberkärnten with the lowest BC ratio of the selected regions, improving 85% of exposed assets. This would result in an NPV of net benefits of adaptation of -33 million EUR, significantly less negative than the other approaches, and would lower nationwide AAD by over 1.3 million EUR.

The second utilitarian interpretation, allocating adaptation funding weighted by regional GDP to prioritize economically-productive regions, would lead to a concentration of improved assets mainly in the north and west of Austria, while the south and east would see significantly less investment. The total NPV of net benefits of this approach is estimated to be -40 million EUR, lowering AAD by 0.9 million EUR.

An egalitarian approach aimed at providing as close to equal-per-capita NPV across regions would conversely lead to a more even distribution, of assets protected, with a higher level of adaptation in the south. However, no region will upgrade the resilience of all the assets currently exposed to events with a 30-year return period. The resulting national effects would be similar to the GDP-weighted allocation above, reducing AAD by 0.8 million EUR at an NPV of -43 million EUR. The egalitarian method, which used a non-linear approach to minimize differences in NPV per capita, did not work well. Significant variation between regions remained in the 'optimal' solution, indicating that other allocation methods may be needed.

The prioritarian approach focusing on an inverse-per-capita-GDP distribution would also result in a very similar allocation of effort as the utilitarian GDP approach. Although adaptation spending is allocated differently, many regions would initially receive a higher allocation than needed, with a second round of allocation redistributing funds to regions with less need from a prioritarian standpoint, resulting in some similarities between the two approaches.

Rail results

The total cost to increase the resilience of 77 kilometers of Austrian rail assets exposed to 30-year return-period events to withstand 100-year return-period events is estimated to be 30.9 million EUR. In contrast to the road results, under our baseline assumptions almost all regions show a BC ratio larger than 1. In 15 out of 35 regions , the amount of rail exposed to flooding for 30-year return-period events is less than 1 km, leading to extremely low adaptation costs compared to the benefits derived (as seen in Table 6.1.4).

Table 6.1.4: Results of regional cost benefit analysis of conservative adaptation scenario for rail (improving all assets exposed to a 30-year return-period event and making them resilient to a 100-year return-period event). Benefits are conveyed as the change in average annual damages from the no-adaptation baseline, costs are in the estimated kilometers of asset to be treated multiplied by the per km adaptation cost. BC ratio are benefits / costs, and NPV is the sum of discounted costs and benefits over a 25 year time horizon. Bolded regions indicate areas where NPV is positive, greyed out regions negative.

Region	**Benefits - reduction in AAD (thousand EUR)**	**Costs (thousand EUR)**	**BC ratio**	**NPV (25 year lifetime, thousand EUR)**
Mittelburgenland	-	-	0	0.00
Nordburgenland	**6.4**	**88.2**	**1.3**	**26.2**
Südburgenland	-	-	0	0.00
Mostviertel-Eisenwurzen	**0.2**	**1.7**	**2.2**	**2.1**
Niederösterreich-Süd	**0.0**	**0.2**	**1.3**	**0.05**
Sankt Pölten	**4.5**	**62.2**	**1.3**	**18.5**
Waldviertel	**40.1**	**474.3**	**1.5**	**242.3**
Weinviertel	**0.0**	**0.4**	**1.3**	**0.1**
Wiener Umland/Nordteil	**0.2**	**2.8**	**1.3**	**0.8**
Wiener Umland/Südteil	**57.3**	**718.7**	**1.4**	**305.6**
Wien	**1.3**	**3.5**	**6.4**	**19.2**
Klagenfurt-Villach	**185.3**	**2 439.7**	**1.4**	**873.1**
Oberkärnten	**413.3**	**2 736.9**	**2.7**	**4,651.9**
Unterkärnten	**259.8**	**3 252.8**	**1.4**	**1,391.3**
Graz	**55.5**	**729.6**	**1.4**	**262.2**
Liezen	**44.8**	**554.2**	**1.4**	**246.6**
Östliche Obersteiermark	**382.4**	**2 728.3**	**2.5**	**4,107**
Oststeiermark	**286.2**	**3 484.1**	**1.5**	**1,632**
West- und Südsteiermark	**21.6**	**196.8**	**2.0**	**189.6**
Westliche Obersteiermark	**373.1**	**5 119.9**	**1.3**	**1,550**
Innviertel	**42.7**	**451.4**	**1.7**	**312.7**
Linz-Wels	**129.9**	**1 385.0**	**1.7**	**936**
Mühlviertel	**502.3**	**1 616.0**	**5.6**	**7,363**
Steyr-Kirchdorf	**3.3**	**33.7**	**1.7**	**25**
Traunviertel	**64.6**	**703.3**	**1.6**	**451.6**
Lungau	-	-	0.0	0.00
Pinzgau-Pongau	-	-	0	0.00
Salzburg und Umgebung	-	-	0.0	0.00
Außerfern	-	-	0	0.00
Innsbruck	**8.5**	**66.2**	**2.3**	**85**
Osttirol	**11.8**	**135.3**	**1.6**	**75**
Tiroler Oberland	**1.6**	**9.0**	**3.2**	**19**
Tiroler Unterland	**493.2**	**3 639.5**	**2.4**	**5,177**

Bludenz-Bregenzer Wald	**0.1**	**1.9**	**1.3**	**0.6**
Rheintal-Bodenseegebiet	**19.8**	**231.6**	**1.5**	**122**

Similar to road assets, we assess the potential distributional consequences of various allocation mechanisms based on utilitarian, egalitarian and prioritarian criteria (see Figure 6.1.4).

The stark differences in the distribution of rail and road assets is immediately visible. While allocations based on external factors (e.g. regional GDP or inverse GDP per capita) are similar between the two sectors, a utilitarian approach aimed at maximizing NPV would focus adaptation on a small set of regions, notably Vienna, Östliche Obersteiermark, Mühlviertl, and three regions in Tirol and Kärnten, resulting in an NPV of 20 million EUR over 25 years. An egalitarian approach aimed at close to equal per capita NPV across regions would lower total NPV to 8.8 million EUR, with adaptation focused mainly in the south and west. The GDP-weighted utilitarian approach and prioritarian allocation are similar in adaptation cost and asset coverage distribution, with some small differences e.g. in southern Steiermark and Burgenland due to difference in prevalence of exposed road and rail assets.

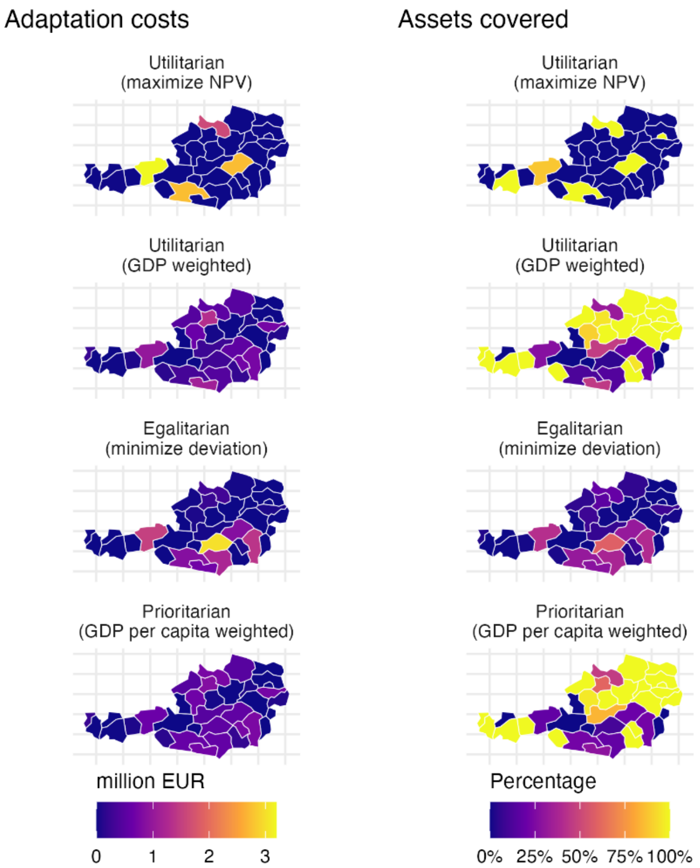


Figure 6.1.4: Rail Adaptation costs, percentage of assets covered, and NPV under different allocation scenarios of a scarce budget for adaptation. The right column shows adaptation costs, middle column share of assets affected, and right column the estimated NPV of adaptation by 2050. Each row contains a different allocation strategy, with top corresponding to a utilitarian approach of maximizing total NPV or distributing based on regional GDP, middle representing an egalitarian effort to minimize the deviation in per-capita NPV across regions, and bottom a prioritarian approach of weighting adaptation funding based on regional GDP per capita.

4.2.4 Sensitivity analysis

Our analysis relies on a number of assumptions. Here we investigate the robustness of our findings to such assumptions, summarized in Figure 6.1.5. Changing in discount rates, costs, and accounting time periods has minor impacts on the resulting benefit-cost ratio and NPV. As expected, lower costs lead to slightly higher BC ratios and NPV, and conversely high discount rates depress NPV, but results remain mostly the same for both road and rail.

This said, due to our conservative assessment of the regional costs and benefits of adaptation we consider our results a lower bound in terms for the net present value of adaptation, especially when taking into account indirect effects are not modelled here.

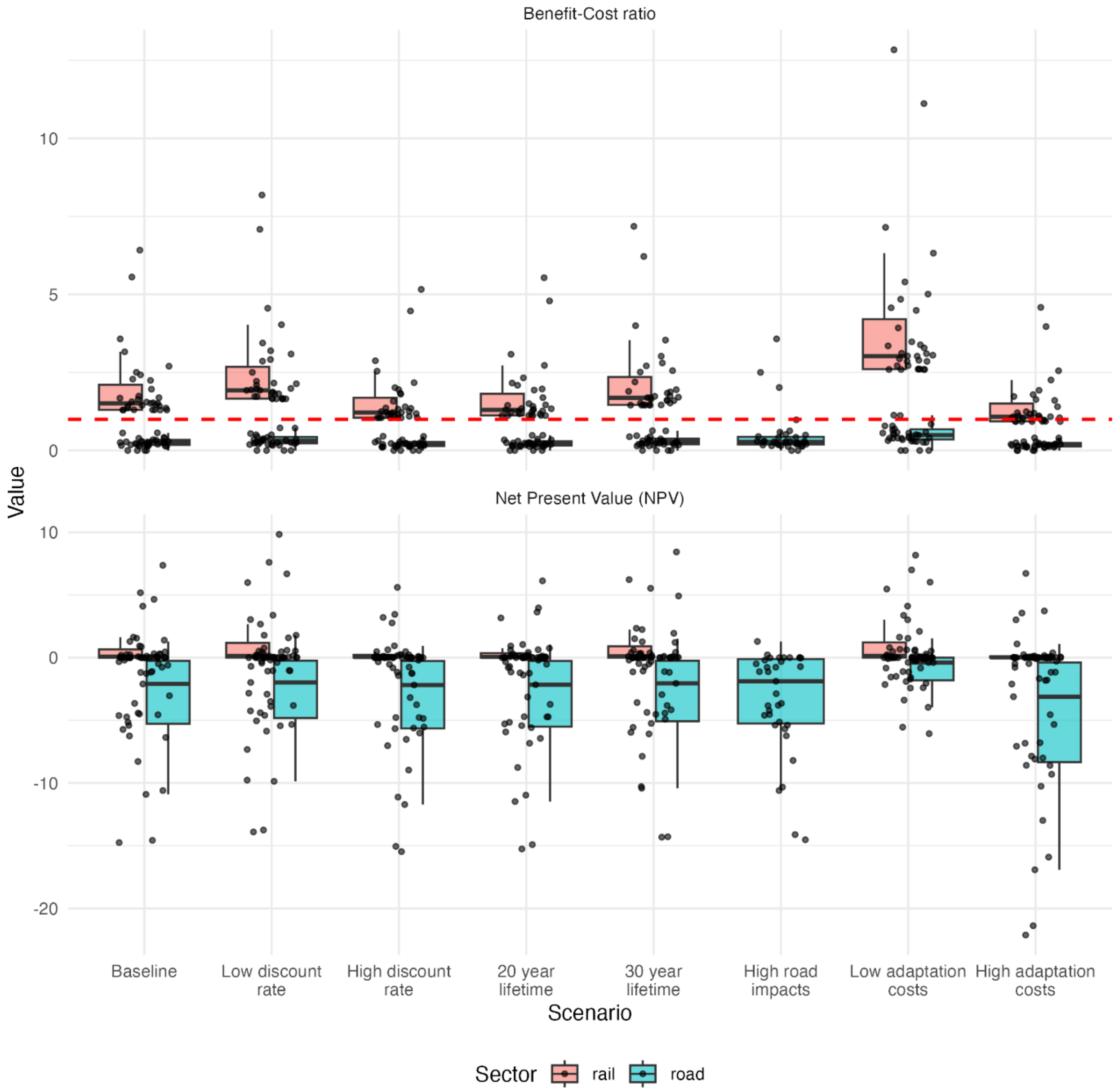


Figure 6.1.5: Sensitivity of results to scenario assumptions for rail (red boxes) and road (blue) assets. The top box plot panel illustrates changes in benefit-cost ratios and the bottom panel changes in NPV. The blue boxes indicate scenario results using a low (0.01) and high (0.05) discount rate; green boxes either a 20-year or 30-year accounting period for benefits, the red box shows the result of using the higher expected damages for roads from the hazard calculations, and the orange boxes the impact of assuming either low (200) or high (560 thousand EUR) adaptation costs per km of road or rail. In the upper panel, the dashed red line indicates a BC ratio of 1, or where a project would be seen as worth undertaking.

The sensitivity analysis conducted at the regional level (Figure 6.1.6) shows higher variation especially across regions and for rail. Regardless, there are few regions which find themselves straddling the BC ratio breakeven point (e.g. Waldviertel and Sankt Pölten, and to a lesser extent Wiener Umland, for road assets).

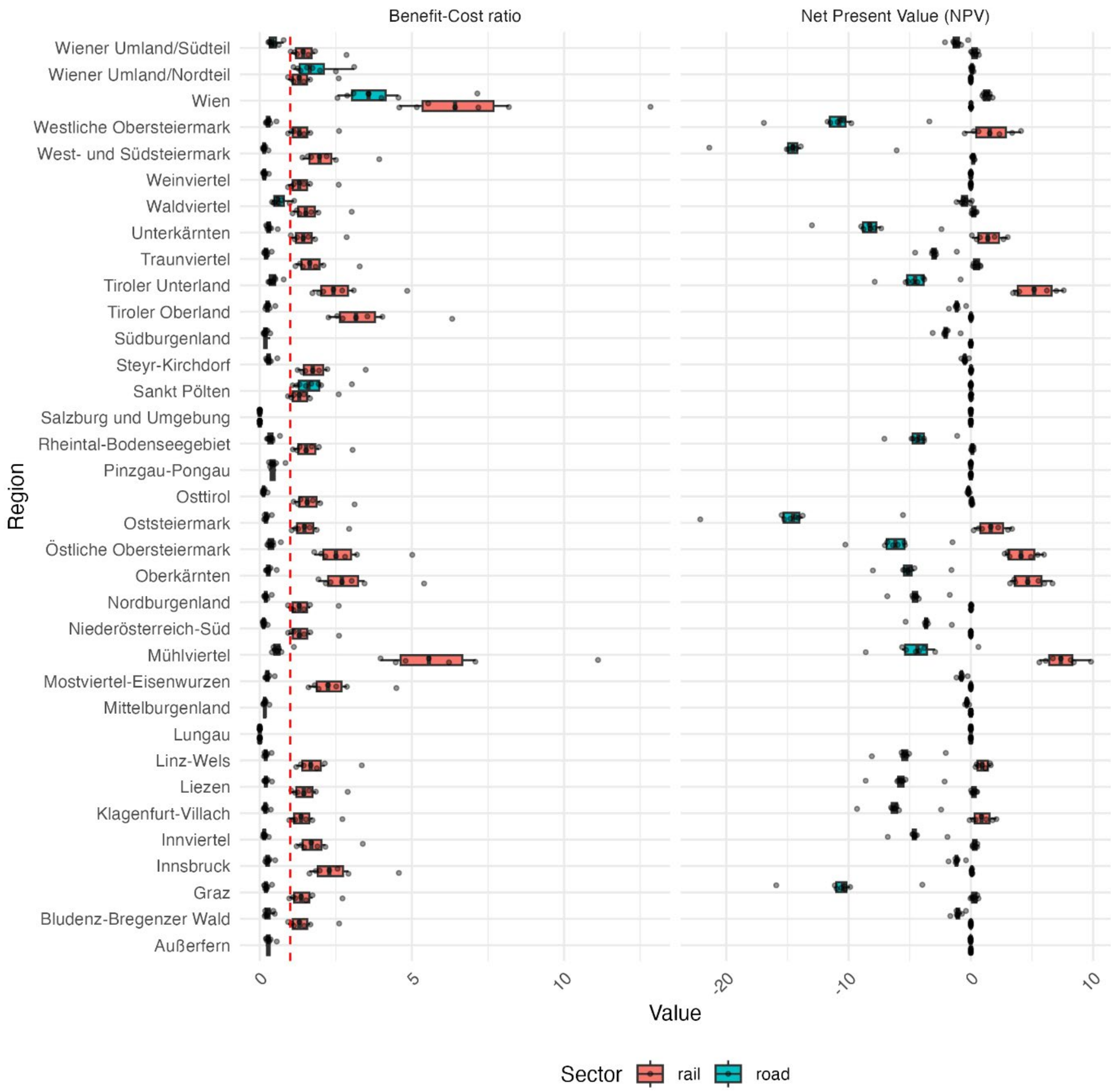


Figure 6.1.6: Sensitivity of results by region for rail (red boxes) and road (blue) assets. The left box plot panel illustrates changes in benefit-cost ratios and the right panel changes in NPV, in each region for all scenarios described in Table 6.1.1. In the left panel, the dashed red line indicates a BC ratio of 1, or where a project would be seen as worth undertaking.

5. Barriers and conditions for implementation

In discussion with stakeholders, a clear preference for more incremental adaptation options emerged as the current status quo. Transformative adaptation approaches such as network and system change are perceived as too difficult, mainly due to political pressures also motivated by costs (Table 6.1.2). Given the method by which risk mitigation or adaptation options are financed, it is generally much easier to fund incremental adaptation. Financing for adaptation is limited to only what is specified in yearly budgets; special funding beyond typical yearly expenditures would have to be approved by Parliament, which was seen by stakeholders as severely limiting the possibility of transformational adaptation strategies. There are additional difficulties mainly revolving around jurisdiction – the example of spatial planning was raised, as it is generally the purview of state or local levels, rather than via national policymaking. Any attempts to make spatial planning decisions at higher levels is met with discussions of rights (e.g. local right to determine plans) and shuts down discussion.

Beyond the above, jurisdictional issues are also perceived as a barrier to adaptation implementation in terms of multiple Ministries potentially being responsible for a given aspect of flood risk and adaptation. The Ministry of Agriculture, Forestry, Climate and Environmental Protection, Regions and Water Management (BMLUK) may have purview over spatial planning issues, the Ministry of Innovation, Mobility and Infrastructure (BMIMI) is responsible for transport policy, while the Ministry of the Interior addresses disaster response and planning. In addition, attempting transformative strategies such as network- or system-level adaptation would likely be complicated by EU-level governance, which was noted by stakeholders as making relocation of rail and road lines difficult.

1. Discussion

As the scope of the case is nation-wide and covers a range of different geographies and potential options, the different types of adaptation applicable to transport infrastructure are correspondingly broad. In our initial stakeholder consultations, we aimed to focus on similarly broad adaptation options and strategies. As a starting point, we suggested a typology of options developed in part by the EU Project MIRACA (Gonzalez et al., 2024) and found below, which represent potential approaches to adaptation options for road and rail that range from more incremental in approach to sharply transformative adaptation strategies:

- Hazard-level adaptation: measures that focus on hazard mitigation; for flood hazard, examples would be installing dikes or other means of protecting exposed assets to flood. The option is not specifically performed on infrastructure or for such infrastructure alone, but benefits from hazard mitigation in the area.
- Asset-level adaptation: Contrasting the above, such adaptation options alter the infrastructure asset potentially exposed to flooding, e.g., raising roads or rail lines to be out of risk of floodwater.
- Network-level adaptation: it identifies where redundancies or alternative transport pathways in the network would be available to re-route flows in case of disruption due to flood, and/or creating new pathways to do so.
- System-level adaptation: it changes the aims of the system, e.g. limits to adaptation of the transportation sector, so in the future businesses would be required or encouraged to keep larger stockpiles of materials, have multiple suppliers or transport options etc.

Our goal was to assess differences in more incremental adaptation versus transformative, and to identify potential adaptation tipping points, whereby transformational adaptation may become more desirable to stakeholders. However, as we held further stakeholder consultations, a clear preference for more incremental approaches emerged, as discussed in section 5 above, which was also emphasized in an ADT6 stakeholder workshop held in July 2025, in that there is still too much uncertainty surrounding transformative adaptation measures such as network or system-level adaptation.

Given these barriers, we focused more on asset-level adaptation (although hazard-level adaptation would follow a similar approach and likely similar results), to illustrate different potential approaches to distributing scarce adaptation resources, here based on various fairness criteria. This supports ADT6 in assessing the causes behind a relative lack of pre-emptive adaptation in transport and supply chains, here focusing on assessing direct costs and benefits of adaptation.

It has to be noted that in our analysis we do not account for indirect costs and co-benefits. In the case of transport and supply chains, such co-benefits (for example, reduction in delay in delivery time for goods or increased travel time for workers or leisure travel) could be substantial. However, estimates as to the size of such effects are contextual in nature (e.g. a study from the USA indicates that the total indirect impacts from flooding could well beyond 100 times larger than the direct damage to transit infrastructure (JEC, 2024).

Inclusion of such estimates requires more elaborate modelling frameworks not available for this case study. Additionally, of interest would be to compare pre-emptive adaptation with reactive approaches which emerged from workshops as standard in the sectors, e.g. comparing the benefits of reactive 'building back better' with proactive adaptation. For the case study, a final meeting with our deep engagement stakeholders will be held to present our results and inform our future work on identifying possible adaptation tipping points, where impact estimates in the future become so high that policymakers may view transformative adaptation as worthwhile.

Case study 6.2 – Supply chain resilience analysis for individual businesses (Austria)
Partner: UniGraz
Spatial scale: firm-level (headquarters in Austria)
Stakeholders: two internationally operating companies

1. Decision context

Businesses across the globe are increasingly facing disruptions driven by extreme weather events (World Economic Forum 2024). As climate change progresses and global temperatures continue to rise, more frequent and severe climatic extremes are expected (IPCC 2023), increasing the exposure of businesses to climate-related risks. The deep integration of global markets and supply chains has created complex interdependencies, making supply chain disruptions a key channel through which climate risks affect businesses operations (Pankratz and Schiller 2024, Marbler 2025). Even companies with limited direct exposure to climate risks can suffer significant consequences due to disruptions in their supplier networks (Carvalho et al. 2021).

Considering these challenges, a central question emerges: how will businesses respond to the growing risk posed by climate change, both directly and through extended supply chains? Proactive integration of climate risk management into strategic decision-making is essential for safeguarding future operations and maintaining competitive advantage.

To explore how businesses are responding to these risks, we conduct a case study focusing on two Austrian companies operating in industries closely tied to renewable energy and electronics. These companies serve as the deep engagement stakeholders in our case study. By analyzing their climate risk management practices, particularly within the context of supply chain management, we assess the adaptive measures they have already implemented and those they plan to adopt in order to strengthen their resilience to climate-related risks. The overarching policy questions of the stakeholders guiding this study revolve around how to adapt to physical climate risks transmitted through supply chains and how to embed climate risk considerations into broader decision-making processes.

2. Current and future risk

The two stakeholder companies operate at different stages of the value chain, offering a comprehensive view of supply chain management and exposure to climate-related risks. One company is positioned at the downstream end, specializing in photovoltaic technologies. All its production facilities and direct business partners are based in Europe; however, many of its European suppliers are sourcing inputs from Asia. In contrast, the other company operates at the upstream end of the value chain, specializing in printed circuit boards (PCBs) technologies. This company has production facilities in both Europe and Asia, with 90% of its input sourced exclusively from Asia, making its supply chain heavily dependent on Asian suppliers.

The primary production sites and first- and second-tier sourcing locations for both stakeholder companies are largely concentrated in Western and Central Europe, as well as East and Southeast Asia. According to the stakeholders, the companies face direct or indirect risk from multiple climate hazards, including extreme heat, drought, and flooding.

Extreme heat can pose a dual threat to operations. First, exposure to heat reduces labor productivity (Somanathan et al. 2021), potentially affecting stakeholder company-owned facilities and supplier operations. According to the stakeholders this, however, is only a threat in non-air-conditioned environments. Second, surges in cooling demand during heatwaves can strain power grids, increasing the risk of power outages and government-imposed electricity rationing, especially in Asia, as reported by the stakeholders. This could disrupt critical production processes along the supply chain, as has happened, for example, during the heatwave in Sichuan, China, in 2022 (Yao et al. 2022).

Drought conditions compound these risks by constraining water availability for industrial use and reducing hydropower output, which can drive up electricity prices according to the stakeholders. In severe cases, water scarcity may force government-imposed cuts in water supply for industrial production, as was the case during the 2021 Taiwan drought (Barbiroglio 2021). Additionally, declining water levels in key inland waterways increase transport times and logistic costs, disrupting the flow of goods along shipping corridors (Meuchelböck 2025).

Flooding exhibits a direct threat to physical infrastructure, with potential damage to production facilities, warehouses, and logistic networks across both own operations and suppliers' sites. According to the stakeholders, the risk from flooding events stems from extended downtime, inventory loss, and delays throughout the supply chain.

These risks can be expected to increase with climate change both at the stakeholder companies' production sites and sourcing locations. According to the regional fact sheets from Working Group I of the IPCC's latest assessment report (IPCC 2021), temperatures in all European regions are rising faster than the global average. The frequency and intensity of heat extremes have increased over recent decades and are projected to rise further under all emission scenarios, while cold extremes are expected to decline. Additionally, extreme precipitation and pluvial flooding are anticipated to increase at global warming levels above 1.5°C. In Western and Central Europe, river flooding has shown an increasing trend, with projections indicating a significant worsening at global warming levels above 2°C. This is also expected for hydrological, agricultural and ecological droughts.

According to Working Group I of the IPCC's latest assessment report (IPCC 2021), in East Asia, daily precipitation extremes have already increased and are projected to become more frequent and intense. Droughts have become more common in most parts of continental East Asia, although they are less frequent in arid regions of Eastern Central Asia. Tropical cyclones have become more frequent and intense in East Asia, with cyclone tracks shifting poleward. In Southeast Asia, future warming is expected to be slightly lower than the global average, with rainfall projected to increase in northern areas and decrease in southern regions. The combined effects of changing climate, land use, and human activity are expected to increase flood risk and inundation in the Mekong Delta. In terms of tropical cyclones, Southeast Asia has experienced fewer but more intense storms in recent years. Heat extremes have increased across both East and Southeast Asia, while cold extremes have decreased, a trend expected to continue in the coming decades.

The reliance on Asian production sites and suppliers thus exposes both stakeholder companies to climate risks originating in Asia, in addition to those in Europe. Although both companies are based in Austria and operate within the renewable energy and electronics sectors, their supply chain structures and risk profiles differ significantly. One company's supply chain is largely centered in Europe, offering some insulation from global supply chain shocks. Its reliance on second-tier Asian suppliers, however, still necessitates careful consideration of potential vulnerabilities to climate-related disruptions in Asia, especially as future climate risks intensify. The other company, by contrast, is more deeply integrated in the global supply chain, with a greater dependence on production facilities and suppliers in Asia, particularly in China. This exposes it to higher risk of supply chain bottlenecks and climate-related disruptions in the region.

3. Identifying adaptation options

Although proactive adaptation to climate change risks is not yet a central objective of the two stakeholder companies' supply chain management practices, these practices can still play a significant role in building resilience against climate-related risks. By analyzing prevailing supply chain management practices, this case study explores the potential (co-)benefits, (co-)costs, barriers, and path-dependencies that may arise when companies implement adaptation measures to enhance the climate resilience of their supply chains.

Diversification, recognized as a key supply chain management practice that supports climate change adaptation, was a central topic in discussions with the stakeholders. Other adaptation options explored include increasing inventory levels, enhancing operational flexibility, localizing supply chains, and implementing climate risk assessment and monitoring systems.

These adaptation options are primarily incremental and soft in nature, meaning they can be implemented with minimal disruption to existing operations. By identifying the benefits, trade-offs, and challenges associated with adaptation options, this case study aims to support the deep engagement stakeholders, as well as other relevant actors, in evaluating and implementing a tailored adaptation strategy that addresses the evolving climate-related supply chain risks.

4. Assessment of adaptation options

4.1 Methodology

This case study employs semi-structured and unstructured expert interviews to gain insights from the deep engagement stakeholders. Interviews were conducted with representatives from various departments within the two companies, including those responsible for supply chain risk management, covering the monitoring and mitigation of supply chain-related disruptions, and sustainability reporting, including compliance with the Corporate Sustainability Reporting Directive (CSRD). All interviews were conducted with representatives from the risk management department or the sustainability reporting team. In total, we conducted 12 interviews (nine with one company and three with the other) with representatives of the two stakeholder companies.

The primary objective of these interviews was to first identify how the companies currently manage physical climate risks along their supply chains and how they plan to address such risks in the future. A central question explored is whether businesses are proactively implementing adaptation options or merely are responding to climate risk in a short-term, reactive manner. Additionally, interviewees were asked to simulate a scenario in which a critical supplier is disrupted by an extreme event. This exercise aims to uncover how individual businesses respond to climate-related supply chain shocks and which coping mechanisms they have in place to minimize the resulting damage.

Whenever possible, stakeholders were encouraged to quantify the costs associated with adaptation options, such as transitioning from single- to multi-sourcing. Qualitative information on co-benefits and co-costs were also collected wherever possible and barriers to adaptation as well as path-dependencies that may influence decision-making were discussed with the stakeholders.

4.2 Results

Currently, the stakeholder companies primarily rely on ex-post measures to address climate-related supply chain disruptions. These measures typically involve monitoring potential risks and then making reactive adjustments to operations. Proactive measures specifically designed to mitigate climate-related risks within supply chains are not yet in place. However, some level of climate risk reduction occurs as a co-benefit of broader risk management practices in supply chain operations, such as multi-sourcing or maintaining safety stocks.

With the evolving reporting requirements of the European Union, particularly through the Corporate Sustainability Reporting Directive (CSRD) and the Corporate Sustainability Due Diligence Directive (CSDDD), large European companies are in the process of establishing frameworks for reporting physical climate risks, including those affecting their supply chains. The next mandated step in this process involves identifying climate change adaptation investment needs. As a result, it can be anticipated that large businesses across the EU will soon begin to consider proactive, ex-ante adaptation measures to mitigate physical climate risks and assess the financial resources required to implement such measures, not only within their own operations but also across their supply chains.

Since supply chain risk management practices aimed at addressing physical climate risks do not significantly differ from broader supply chain management practices used to mitigate other types of risks, such as trade restrictions, pandemics, or geopolitical instability, it is possible to identify climate change adaptation options, along with their associated costs, benefits, barriers, and path-dependencies. These adaptation options can then be integrated into a comprehensive adaptation strategy that align with the broader goal of supply chain resilience.

4.2.1 Adaptation Options and Associated Costs

The stakeholders identified several adaptation options to enhance supply chain resilience against climate-related risks. These include localization, which involves sourcing from European suppliers or Europe-based distributors that produce in Asia, thereby reducing the direct sourcing risks; increased inventory levels, such as maintaining a safety stock to buffer against short-term supply shortages; improved operational flexibility, which entails adjusting production plans and resource allocation to minimize the impact of production shortfalls; and supplier diversification, involving multi-sourcing to reduce switching times between suppliers.

In terms of ex-post responses to climate-related supply chain disruptions, such as flooding at sourcing sites, both stakeholder companies rely on near real-time monitoring systems. These systems are based on a third-party, AI-supported platform that uses web scraping to process global media coverage relevant to their business partners. The annual subscription cost for this platform is approximately €40,000, which varies depending on the selected service package. In practice, when an alert about a potential disruption is received, the risk management team consults with the purchasing team to assess whether the highlighted risk is materializing, its potential consequences, and available alternative sourcing options.

For example, during the 2024 flooding events in Europe, one company's risk management team received alerts for both their own and their suppliers' production sites. In this case, the risk did not materialize, and production remained unaffected. This company employs approximately 7,000 people and currently dedicates 2.5 full-time positions to managing supply chain risks, including reactive, ex-post responses to physical climate risks. The total annual cost of this company's supply chain risk management, including personnel, software and audit expenses, amounts to around €400,000. However, for a more comprehensive climate risk assessment and proactive adaptation planning, the stakeholder estimates that doubling its risk management staff would be necessary, adding approximately an additional €250,000 in annual costs at current wages levels.

Monetized cost estimates were generally limited for most adaptation options, except for supplier diversification, where the stakeholders conducted a scenario analysis. One company's stakeholders simulated a disruption involving a printed circuit board (PCB) supplier, which provides around 10 different PCBs to the stakeholders' company. In the disruption scenario, flooding rendered the supplier unable to deliver, affecting the stakeholders' company downstream production of welding machines. To simplify the complexity of the scenario, the stakeholder focused on one of these PCBs used in ten of its final products.

The financial impact was calculated based on revenue at risk. As of Fall 2024, the short-term impact amounted to approx. €300,000 in lost revenue due to an inability to fulfil orders. Without mitigation measures, the annual revenue loss could reach up to approx. €1.5 million. While reputational damage, reduced machinery utilization, and the long-term revenue losses were acknowledged, these were not quantified. The process of qualifying a new PCB supplier takes about two years, with internal personnel costs estimated at approximately €15,000 in additional costs. However, this figure does not include potential price increases from new suppliers that happen during market shortages. For instance, during the COVID-19 pandemic, the company experienced huge price spikes for electrical components and semiconductors. These would substantially increase the estimated costs.

For other components than PCBs, such as aluminium die-cast parts or custom-designed chips, where additional investments in tools or software are required, the costs for establishing a second qualified and production-ready source can exceed one million. Thus, the cost of switching from single- to multi-sourcing varies significantly depending on the component under consideration, making it impossible to derive a single general cost estimate. The bandwidth ranges from €16,000 to one million or more.

Even when a second source is already qualified, switching suppliers is not instantaneous, typically requiring 2–4 months. To bridge this gap, companies must develop an integrated adaptation strategy centred on diversification and complement it with other adaptation options, such as maintaining adequate safety stock inventories and enhancing operational flexibility. In the best-case scenario, sufficient inventory can cover the shortage. However, when inventories are insufficient, stakeholders emphasize that adjusting production plans and prioritizing customer orders of unaffected components, along with flexible resource allocation, especially regarding personnel, is essential to minimize losses during transition periods.

As noted earlier, climate risk assessment is another adaptation option employed by the stakeholder companies. However, the two companies employ different approaches to establish their climate risk assessment. One stakeholder company's sustainability department developed an Excel-based tool that uses open-source climate-risk and vulnerability indicators. In contrast the other stakeholder company, which employs approximately twice as many people as the other company, collaborated with an external consultancy that draws climate-risk data from a third-party platform operated by Jupiter Intelligence.

4.2.2 (Co-) Benefits

Many of the adaptation options designed to address supply chain disruptions offer broader operational and strategic benefits beyond climate risk mitigation. These include the reduction of exposure to geopolitical instability, market fluctuations, and regulatory changes. According to stakeholders, supply chain diversification and localization generate substantial co-benefits.

For the stakeholders' company, spreading suppliers across different geographic regions or diversifying suppliers within a region has reduced exposure to risks concentrated in a single location or supplier, whether those risks stem from climate-related events, political instability, or other unexpected shocks. This brings enhanced flexibility, enabling more effective management of disruptions.

Supplier diversification has also fostered competition among suppliers, resulting in benefits in the form of cost savings. Sourcing from multiple suppliers enhanced the stakeholders' company's bargaining power, allowing them to negotiate more favorable pricing terms. In sectors such as electronics, where price volatility is common, this flexibility is especially advantageous. Another key benefit of having access to a broader supplier base is exposure to a wider range of technological innovations, which in turn has driven internal innovation and improved the overall business competitiveness of the stakeholders' company.

Localization within Europe has also brought additional benefits, particularly in strengthening customer relationships. One stakeholder company, for instance, uses its ability to trace components back to European suppliers as a competitive advantage. In an era where customers increasingly demand supply chain transparency, this localization allows the stakeholder company to assure its clients that its products meet local regulatory and sustainability standards. By prioritizing European suppliers, the stakeholder company not only meets customer demands but also enhances supply chain resilience by reducing reliance on global shipping routes, which are more vulnerable to climate and geopolitical disruptions.

5. Barriers and conditions for implementation

Despite these (co-)benefits, the stakeholders identified several barriers to implementing the adaptation options discussed. A key challenge is the additional financial, technical, and organizational effort required. For instance, transitioning from single-sourcing to multi-sourcing involves significant costs related to supplier qualification and component testing. Furthermore, many products must comply with a wide range of technical standards and national regulations across different countries. Thus, before a product can be introduced into a market, it must undergo a series of certifications. As a result, introducing alternative components often requires reinitiating the certification processes, making diversification both costly and time-consuming. This creates a major barrier to diversification, as it involves not only additional financial costs but also increased personnel efforts in supplier qualification, product reconfiguration, and certification preparation.

Another major barrier to supply chain diversification and localization stems from the market structure of certain products. In some cases, products are sourced from a highly concentrated market, such as semiconductor components, or a geographically highly concentrated industry, such as photovoltaic components. The lack of viable alternatives outside a specific region or concentrated market limits the ability to diversify supply chains effectively.

In addition to these structural challenges, there are specific barriers related to climate change adaptation. One key issue is the knowledge gap. Often organizations lack the internal expertise required to process and analyze climate data, making it difficult to conduct reasonable climate risk assessments without external support. However, as stakeholders emphasized, building in-house capabilities is often preferred over relying on external consultancy services.

Finally, there are also organizational barriers. Often it remains unclear which department within a company is responsible for climate change adaptation and resilience building. Is it the purchasing, sustainability, or risk management department? Currently, these responsibilities are often not clearly defined, and this lack of clarity can complicate the development and implementation of integrated adaptation strategies.

To overcome these challenges and to enable the implementation of effective adaptation strategies, organizations must establish clear responsibilities and accountability for climate adaptation planning and implementation. This prevents fragmented decision-making and enables the formation of more integrated adaptation decisions. In the context of supply chain management, supplier selection should follow a structured onboarding process that incorporates both current and future climate risks at suppliers' production sites. Especially, for business-critical components, multiple suppliers should be identified and qualified. This can help to avoid situations where past sourcing decisions create lock-in effects with high-risk suppliers, making it difficult to transition towards a more resilient supplier in the future.

6. Conclusion and reflection on adaptation strategies focused on diversification

While supplier diversification is an important step toward increasing the climate-resilience of supply chains, it is not always sufficient on its own. Our case study shows that even when a second qualified supplier is already in place, switching suppliers almost never occurs instantaneously and typically takes between two to four months. Therefore, supply chain diversification must be complemented by additional adaptation options to effectively manage disruptions.

First, maintaining adequate safety stock of critical components can help bridge shortfalls during transition periods. Second, increasing operational flexibility allows for adjustments to production schedules, prioritizing unaffected customer orders, and the flexible reallocation of personnel. Finally, real-time monitoring of climate risks across the supply chain is essential for timely and informed response planning.

Combining supply chain diversification with inventory management, increased operational flexibility, and real-time monitoring into a comprehensive adaptation strategy can be key to minimizing losses during climate-related supply chain disruptions. This integrated approach not only enhances resilience but also supports more proactive and adaptive decision-making in the face of evolving climate risks.

7 Cross-cutting decisions

Case study 7.1/7.2 – Costs and benefits of national adaptation programmes/Implications of adaptation for the Government public finances (United Kingdom)

Partner: PWA, Uni Graz
Spatial scale: National Scale, England/UK
Stakeholders: His Majesty's Treasury (HMT), Department for Environment, Food and Rural Affairs (Defra), Office for Budget Responsibility (OBR)

1. Decision context

This case study focuses on the use of economics in national adaptation plans and programmes, working with English government (UK) stakeholders.

In the UK, there is a statutory requirement—as set out in the Climate Change Act 2008 (UK Government, 2008)—for Government to undertake an assessment of the risks to the UK of the current and predicted impact of climate change. This assessment is repeated every five years. The UK has now completed three rounds of this policy cycle, with the 3rd Climate Change Risk Assessment (CCRA3) technical assessment published in 2021 (CCC, 2021) and Government report in 2022 (HMG, 2022).

There is also a statutory requirement to publish a national adaptation programme following each CCRA, setting out how the Government will address the risks identified. In the UK, adaptation is devolved, and so the countries of England, Scotland, Wales and Northern Ireland prepare their own adaptation programmes. In England, the 3rd National Adaptation Programme (NAP3) was published in 2023 (Defra, 2023). NAP3 set out the English Government's proposed programme of adaptation actions over the next 5 years (2023–2028). A long list of specific actions was published (collated under five thematic areas). However, there was no analysis of costs or benefits of these adaptation actions.

The ACCREU UK stakeholders were consulted on the possible areas of interest for the UK case study. These stakeholders include His Majesty's Treasury (HMT), who are the Ministry of Finance in the UK, the Department for Environment, Food and Rural Affairs (Defra), who have the lead responsibility for domestic adaptation (and the NAP), and the Office for Budget Responsibility (OBR), which has a scrutiny role providing advice to Government on fiscal forecasts and risks.

The overarching policy questions determined by the stakeholders were:

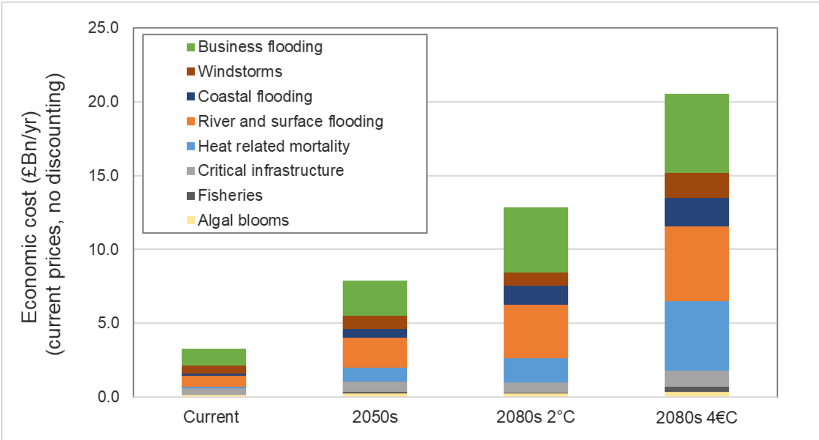
- What are the costs of the 3rd National Adaptation Programme and what are the potential economic benefits it might deliver?
- What are the macroeconomic and fiscal costs and benefits of adaptation and what are the net implications for the public finances?

The first case study (7.1) developed a costing of NAP3, and extended this to also look at the potential economic benefits of adaptation, working with individual actions. This provides important information on the likely costs and benefits of adaptation for Government. This cost information is relevant for the UK's 3-year medium term expenditure framework (MTEF) and the multi-year spending review, which sets out the public spending across Government departments for the next three years (from 2025), and in turn the annual budget. It also helps build the evidence base on the economic benefits of adaptation.

The analysis has also been extended to a second case study (7.2), looking in more detail at key national adaptation options in NAP3 and estimating the costs and economic benefits of this adaptation for different climate scenarios, and then feeding this information into a Computable General Equilibrium (CGE) Model to look at the effects on GDP and on the public finances. This has focused on the potential costs and benefits of flood protection (for coastal, river and surface water floods. The analysis is linked with activities in WP4, and the collaboration with the University of Graz to run their CGE model (COIN) (Bachner et al., 2019). This provides information on the economic and fiscal costs and benefits of adaptation.

2. Current and future risk

The current and future risks for England are set out in the CCRA3, and the monetary value of these were assessed in the CCRA3 monetisation report (Watkiss et al., 2021). This includes 61 risks and opportunities. An analysis of the most important risks identifies these have annual economic costs of several £billion/year today, rising in future periods, see Figure 7.1.1. The previous project COACCH results were also included in the Government CCRA3 report (HMG, 2022) and assessed the potential macro-economic impacts of climate change.

A)


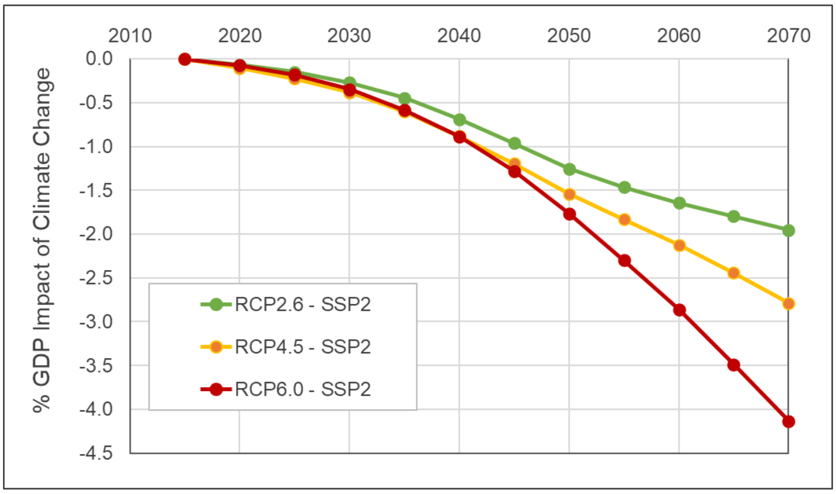
B)


Figure 7.1.1: A) Estimated annual costs of climate change in the UK for a selection of risks. Source Watkiss et al., 2021. B) Net aggregate economic costs of climate change for warming scenarios (RCP2.6, 4.5 and 6.0) for England. Source COACCH project (Bosello et al., 2020).

3. Identifying adaptation options

The 3rd National Adaptation Programme set out the English Government's proposed action over the next five years (2023–2028) to address the 61 risks and opportunities identified in the CCRA3. This includes 389 individual actions. These include a wide range of structural and non-structural options, grouped into five thematic areas (infrastructure, natural environment, health and well-being, business, and international). However, the NAP3 did not provide an overall estimate of the costs to deliver this plan. This was identified as a key gap in the development and implementation of adaptation, including its integration into public spending budgets. There was also no assessment of the economic benefits of this adaptation.

One of the largest economic costs of climate change for the UK is flooding (see figure above), from the combination of sea-level rise (coastal flooding in the figure) and from river and surface water flooding. A deep dive was therefore undertaken on this hazard in the second case study, developing more detailed analysis of the costs of these adaptation actions, as well as the benefits, and using this information as an input into a CGE analysis (linked to WP4).

4. Assessment of adaptation options

4.1 Methodology

The initial analysis reviews the 389 unique actions in NAP3. This found the majority are evidence and research (87 actions) and process options (153), with 70 direct investments or actions, and a further 79 that are mixed, in that they may lead to subsequent investment or action. This highlights the focus on evidence and process within national adaptation planning, in line with adaptive management approaches

For those options that involved more direct investments, the analysis then moved to cost assessment. To do this a typology was developed for assessing the potential incremental costs of adaptation for different types of investments. This work drew on the Joint methodology for tracking climate change adaptation finance of the Multi-Lateral Development Banks (EIB, 2022). This identifies three types of adaptation actions:

- Building climate resilience into programmes and investments (climate proofing, Type 1). In this case adaptation is a secondary objective. For example, the costs of addressing climate risks in the design and building of new road investments or new national rail projects. In this case only the additional (incremental) adaptation costs of making the investment climate resilient are counted and costed as adaptation (not the costs of the underlying road or rail investment).
- Investments where adaptation is one of a number of objectives (mixed adaptation, Type 2). For example, investing in peatland restoration delivers multiple benefits, including improved ecosystem services, water regulation, carbon sequestration, but also enhanced climate resilience (on-site and off-site). A proportion of these investments can therefore be counted as adaptation, but a judgement has to be made of the proportion of adaptation compared to other objectives (attribution). This is more difficult and often involves more subjective assessment.
- Targeted adaptation programmes and investments (pure adaptation, Type 3), where the primary objective is to reduce vulnerability to climate change. For example, investing in coastal flood protection to address sea-level rise. In this case the total investment is counted as adaptation.

The analysis then looked at the major options in NAP3 and assigned these the categories above, then costed these based on existing government expenditure data or estimates based on the literature (e.g., the typical % uplift for climate proofing road investments). A review of government documents (including regulatory impact assessments) and the wider literature was then undertaken to assess the potential economic benefits of each of these adaptation categories.

For the second part of the study, the costs and benefits of sector level adaptation were taken. This analysis focused on floods and drew on the national assessment of flood costs and benefits modelled in the CCRA3 (Sayers et al., 2020: Watkiss et al., 2021) and a detailed analysis of recent expenditure (Defra, 2023b) and potential future costs of flood investments (EA, 2019). The analysis of the economic impacts of flooding included the impacts of current climate variability and future climate change, and the expected annual damage to residential and non-residential properties, as well as to infrastructure (public and private). It also included the indirect impacts to the economy, from cascading impacts on transport, business disruption, as well as the impacts of floods on health, including reductions in productivity and additional treatment costs. The benefits of adaptation from the reduction in these impacts was also assessed, based on the sources above (Sayers et al., 2020: Watkiss et al., 2021). The information on costs and benefits for different climate scenarios were then fed into the CGE COIN model of University of Graz to look at the macroeconomic effects and the implications for the public finances. This uses the same method as previous applications to Austria (Bachner et al., 2019) and focuses on 2030 and 2050.

4.2 Results

The results indicate the total adaptation costs for the full delivery of NAP3 would amount to approximately £9 billion per year in the period 2025–2028 for England. This is approximately 1% of current Government spending or around 0.4% of GDP (HMT, 2024). This is a significant increase over the estimated adaptation costs in the pre-NAP3 period (estimated at approximately £3 billion/year).

The breakdown of annual adaptation costs is shown in Figure 7.1.2, where the size of the bubble represents the annual value. The values are split top to bottom into each of the three types of adaptation (climate proofing, mixed objectives and pure adaptation), and between the left and right as being borne either by the public finances, or by households through utility charges or other pass through costs. It is stressed that a large proportion of these costs are already existing spending rather than proposed costs.

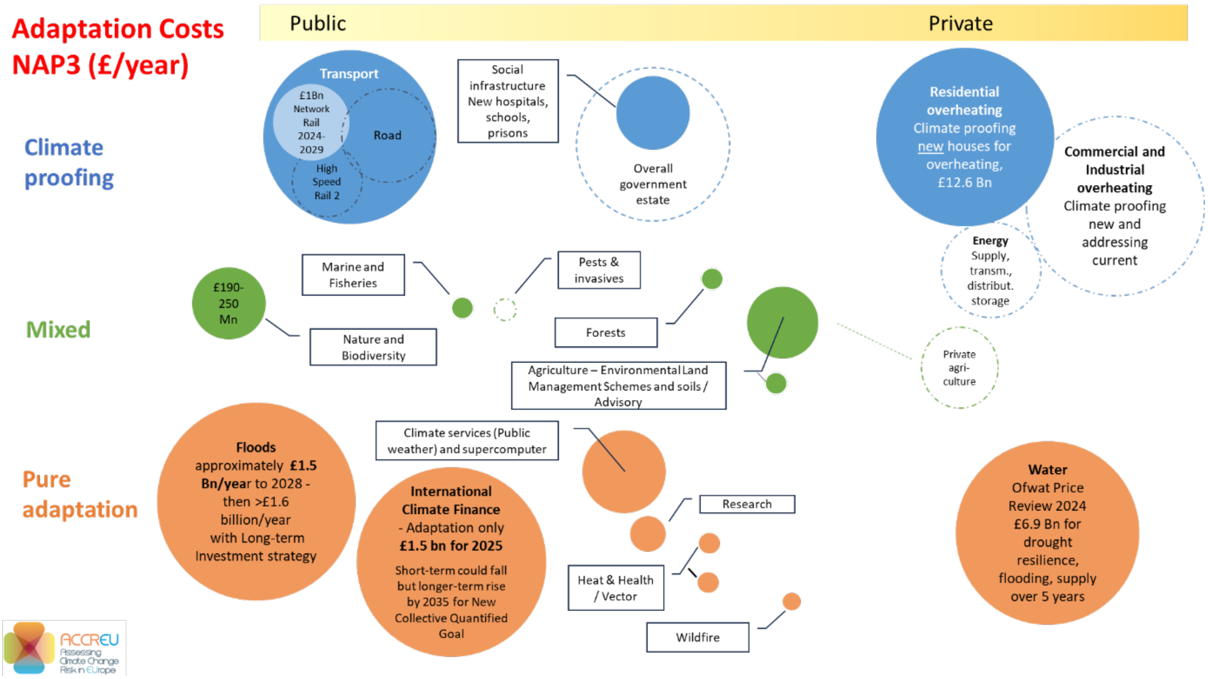


Figure 7.1.2: Estimated annual costs of adaptation for NAP3. Note that the size of the bubbles reflect annual adaptation spending (£billion/year) for announced multi-year commitment.

The results show that majority of these costs (approximately 55%) fall to the public budget. The remaining costs fall to the private sector through privatised utilities for water and electricity sectors, and which will then be passed on to regulated industries and households, e.g. through water and energy bills, as well as costs for new buildings, which will be passed through in higher costs to house prices.

The results also show that while the highest costs are associated with pure adaptation (Type 3) at the bottom of the figure, from flood protection, international climate finance and water, there are high costs associated with climate proofing new infrastructure including both public and private infrastructure. This includes the existing climate resilience in design announced in NAP3 and in place in the road and rail sector, in public buildings such as hospitals and prisons, and through to private residential property through building codes.

A key insight of this analysis is that NAP3 primarily focused on climate proofing new public and private infrastructure, but it does not tackle the larger impact of addressing growing climate impacts (e.g. overheating) to the current stock of critical and public infrastructure. This is a much bigger issue and is likely to mean much higher costs in future NAPs. For example, while there is a cost in NAP3 for climate proofing new hospitals, the current government programme is only building and refurbishing 10–20 hospitals, but there are approximately 1100 hospitals in the UK (NHS, 2024). Retrofitting climate adaptation in this stocks (and the same for prisons, schools, public buildings) would have very large potential cost implications for the public finances, especially as many of these have long life-times and are likely to face rising climate risks within their design lifetime.

An analysis was also made of the evidence base on the economic benefits of the adaptation action in NAP3 (Figure 7.1.3). This was based on an extensive review of government business cases and impact assessments, as well as the wider literature. The results are shown in the figure below. This found that most (but not all) adaptation actions had net economic benefits, with economic benefit-cost ratios (BCRs) >1, though it is stressed that these assessments are based on ex ante economic appraisal studies, including business cases submitted by government departments to HMT. As such, they will include positive BCRs because this is generally a pre-requisite to get approval.

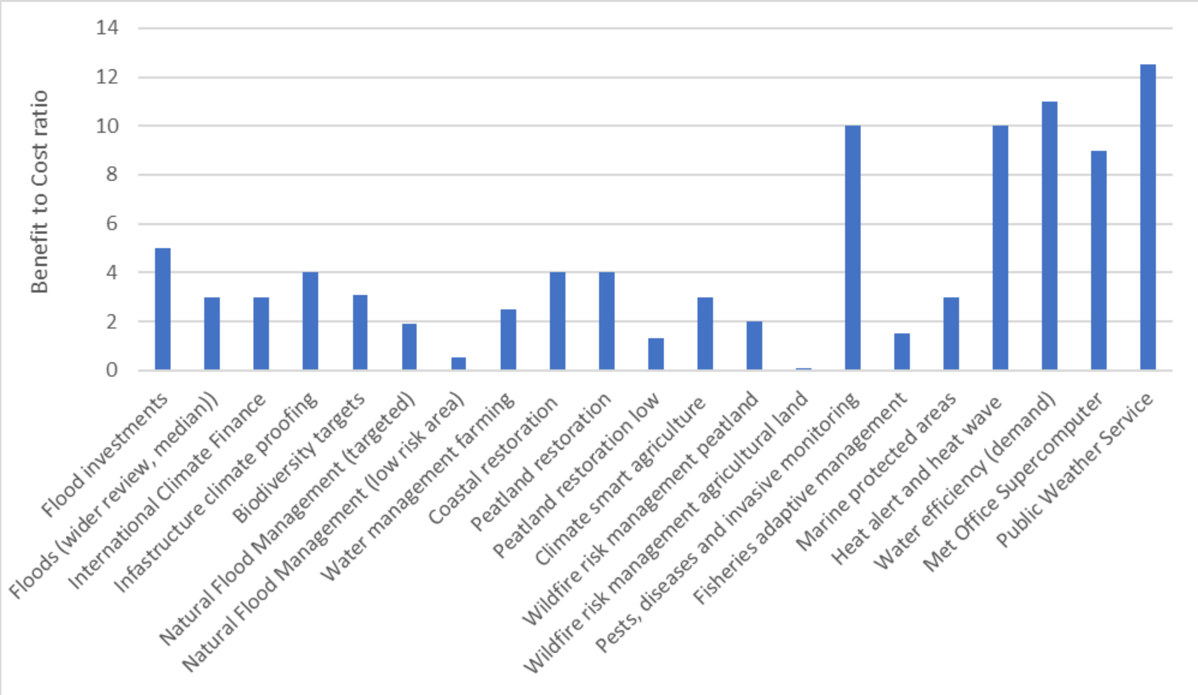


Figure 7.1.3: Estimated economic benefit to cost ratio for a selection of adaptation actions in NAP3.

For the second case study, the analysis identified the current budget for flood protection in England, which is based on the £5.2 billion flood and coastal defences protection capital funding programme for 2021–2027. There has also been a detailed future capital investment programme for flood protection set out, to look at future investment needs to address rising climate change risks, published in the Long-Term Investment Scenarios (LTIS) (EA 2019) for England. This identified that the long-term optimal level of investment (depending on policy choices) could range from £1.0 billion to £1.2 billion (in 2019 prices) for England over coming decades, but that much higher investment costs would be needed in a more extreme warming scenario. The benefits of flood protection (current and future) were based on CCRA3 assessments (Watkiss et al., 2021). The analysis of future risks, adaptation costs and benefits, considers the future years 2030 and 2050, planning for two different warming scenarios as used in CCRA3, associated with 2 and 4 degrees Celsius of global average warming by the end of the century relative to pre-industrial. The results are shown below (Figure 7.2.1).

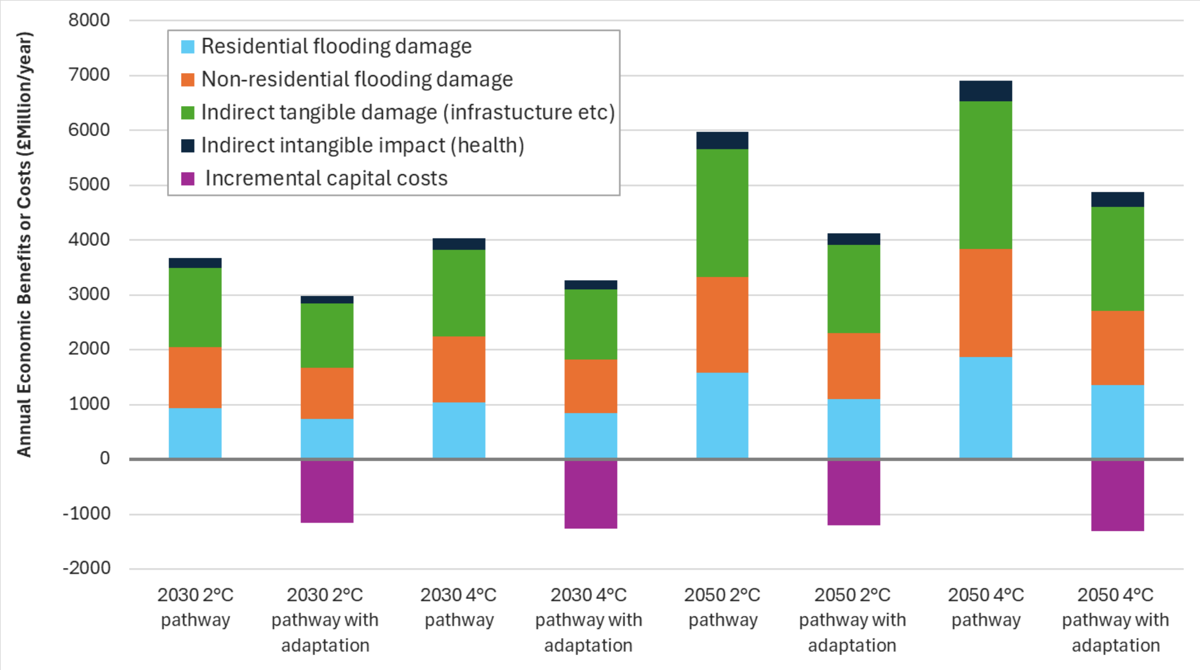


Figure 7.2.1: Estimated cost of flood expected annual damage and costs and benefits of flood adaptation in the UK for a 2 and 4 degrees pathway, with and without adaptation.

These results were then used as an input for the CGE modelling, which is reported in WP4 (Deliverable 4.3). The results indicated that adaptation (increased flood protection) reduces the future economic costs of climate change, and even though it requires increased investment from public budgets, it was still found to have positive net effects for the public finances, because it reduces other government expenditure and avoids revenue losses.

5. Barriers and conditions for implementation / reflection

The main barrier for the implementation of adaptation is financial, because ramping up adaptation would mean an increase in government spending in a time of fiscal constraint, as well as higher costs passed through to households. While the analysis above shows that adaptation has net positive economic (societal) benefits, and even net positive fiscal benefits, it involves higher spending in the short-term, and due to the current pressure on the public finances, this makes it difficult as it requires either reducing other areas of spending or increasing taxation or borrowing (these choices are investigated further in the WP4 Deliverable 4.3). The analysis also shows that there is a significant opportunity to include adaptation in new government spending infrastructure programmes with climate proofing, but that there is a larger problem with addressing the large stock of existing infrastructure, that will likely require much higher costs.

6. Conclusion

National adaptation programmes across Europe will need to scale up to meet the challenge of rising climate change. This will involve difficult choices for governments, as it requires additional spending. It is critical that governments start costing national adaptation programmes and plans, and also assess the economic and fiscal costs and benefits of adaptation. This will be important in setting out the resource needs and helping to make investment and prioritisation choices.

Case study 7.3 – Cross-sectoral economic analysis for adaptation (Cyprus)
Partner: CyI
Spatial scale: National (Republic of Cyprus)
Stakeholder: Ministry of Agriculture, Rural Development and Environment of Cyprus; Ministry of Finance of Cyprus

1. Decision context

After conducting a climate change vulnerability and risk assessment in 2016, the government of Cyprus adopted a national strategy for climate adaptation and a relevant Action Plan in 2017. This strategy was considered to be relatively weak in its implementation; according to a relevant European Council Recommendation of 2024, this was partly due to the lack of the proper institutional setting that would make implementation binding for public authorities.

During 2024–2025, the Republic of Cyprus revised its 'National Strategy on Adaptation to Climate Change'. The national Ministry of Agriculture, Rural Development and Environment was leading the study that led to the revised Strategy, with the aid of external consultants. This revision was scheduled to be submitted to the Cabinet (Council of Ministers) during summer 2025, with capacity-building and dissemination actions pending for autumn 2025. The Strategy's findings constituted a valuable starting point for this Case Study as it was possible to use some of its information and combine it with further data from our analyses and from the broader available literature.

As the revised adaptation strategy was the outcome of several discussions with national stakeholders, it was clear from the Strategy report which were the open questions; they had to do with actual financing needs – for which no concrete figures were included in the Strategy – and barriers to implementation. After consultation with the Ministry of Finance, it became evident that the most crucial questions related to the planned and the necessary funds to implement the Strategy in the prospect of deteriorating climate change. Following these consultations, we attempted to address in our Case Study the following questions:

i. What are the current adaptation investment needs up to 2030/2050?
ii. Which of these investments are ongoing or planned with a specific budget and time plan?
iii. Which part of these investments must be covered by public or private funds?
iv. What are the damages from unmitigated climate change expected for 2050/2100?

2. Current and future risk

As outlined in national and other policy reports (see e.g. Republic of Cyprus, 2023, and IMF, 2024), Cyprus experiences a pronounced semi-arid Mediterranean climate characterized by distinct seasonal patterns in temperature, rainfall, and overall weather. Being located in the Eastern Mediterranean and Middle East (EMME) region, Cyprus is in a significant climate change hotspot as the region has experienced faster warming than the global average, leading to noticeable changes in the hydrological cycle, including more severe and prolonged heatwaves, droughts, dust storms, and flash floods. The average yearly temperature in both urban and rural areas is on the rise. The country has experienced a noticeable surge in hot days. With temperatures steadily rising, summers have become increasingly intense, characterized by prolonged periods of extreme heat and more frequent heatwaves. Recent scientific evidence has reinforced these findings and has given rise to more detailed assessments of the economy-wide costs of climate change in the short, medium and long term (see Zachariadis et al., 2025).

3. Identifying adaptation options

The consultation of the Ministry of Agriculture, Rural Development and Environment with all relevant public authorities in the frame of the revised National Adaptation Strategy (NAS) led to the identification of an extensive list of adaptation policies and measures across the Cypriot economy. The final NAS report came up with 119 policies and measures in total. The policy areas and the number of measures proposed per area are shown below.

Policy areas – NAS 2025 (no. of measures per policy area in brackets)
Agriculture (9)
Biodiversity and Ecosystems (10)
Cultural Heritage (8)
Disaster Risk Management, Civil Protection and Critical Infrastructure (8)
Economy, Industry and Finance (5)
Energy (5)
Fisheries and Aquaculture (5)
Forestry (10)
Health (6)
Hydrological Regime and Water Management (13)
Sea and Coastal Areas (3)
Soil (7)
Spatial Planning (5)
Tourism (3)
Infrastructure, Transport and Buildings (10)
Cross-sectoral governance measures (7)
Cross-sectoral educational measures (5)
Total: 119

4. Assessment of adaptation options

4.1 Methodology

The following steps were followed:

1. Out of the list of 119 adaptation measures described above, we attempted to assign costs to each one of these measures. The NAS document provides a one-page fact sheet for each measure and a rough indication of its cost ('low-medium-high'), but this cost assessment had to be cross-checked and become more concrete.
2. We considered that, in principle, the full list of measures expresses the adaptation investment needs up to 2030. In some cases, we expanded the needs with own information; for example, the NAS does not include in its measures the installation of new mobile water desalination units, which was announced in December 2024 to address exacerbating water scarcity, so we included it in the investment needs. In other cases, we omitted some measures because it was clear from their description that they are general measures addressing current challenges and are not adopted specifically for climate change adaptation (e.g. installation of technologies to detect leakages in water distribution networks).
3. By checking the fact sheet of each measure, we obtained additional information about whether that measure (a) is ongoing, (b) has been partly or fully included in the plans and budgets of public authorities, or (c) there is no provision yet. In this way it is possible to determine those investment needs per policy area that are ongoing or already planned.
4. Comparing the entire set of measures and the resulting total investment needs (from step 3 above) with those already planned (step 4) leads to an assessment of the adaptation gap and the adaptation funding gap.
5. To assess the investment and maintenance costs of each adaptation measure, we consulted additional policy documents of the Republic of Cyprus that the draft NAS is citing, such as:
    a. The National Investment Plan of Water Works of September 2024.

b. The Strategic Document for measures related to the implementation of the Common Agricultural Policy in Cyprus in 2023–2027, which includes several investments and grant schemes addressing climate adaptation in agriculture, forestry, and biodiversity.
c. The National Energy and Climate Plan and the National Building Renovation Strategy that were submitted to the European Commission in December 2024.
d. The Ten-Year Plan for the Development of the Electricity Transmission System.
e. The October 2023 report about the preparation of flood risk maps in the frame of the revised Flood Risk Management Plan.

6. To assess the costs of unmitigated climate change impacts, so as to compare them with the investment needs mentioned above, we used findings from recently completed work that was conducted for the Cypriot Ministry of Finance, on the costs of climate change impacts per economic sector (Zachariadis et al., 2025). It was possible to assess economic impacts of climate change in 2050 (and sometimes in 2100) for the areas of energy demand, electricity grid resilience, heat-related mortality, water resources, agriculture, tourism, coastal infrastructure, forestry, and labour productivity.

4.2. Results

Out of the questions we listed above, first we address (i) and (ii), with Table 7.3.1 presenting the results of our assessment and Annex C CS7.3 including the full list of adaptation measures and their estimated budget. As also illustrated in Figure 7.3.1, across all policy areas there is a significant gap between the investments *planned* for climate change adaptation (orange bars) and those having been identified as *necessary* (blue bars). *The need for additional investment up to 2050 is estimated at 4.1 billion Euros at today's prices, or 0.5% of national GDP of the entire period.* However, less than 30% of this is currently planned, i.e. projects worth about 1.2 billion Euros; this implies *an adaptation funding gap of 2.9 billion Euros'2023.*

Our assessment shows that *the level of required additional investments is not prohibitive for the Cypriot economy* since both the public and the private sector have already implemented several measures to adapt to the existing climate conditions in Cyprus. For example, current expenditures to address water scarcity, to increase protection from forest fires and floods, to ensure availability of air-conditioned spaces in residences, offices, hospitals etc., are not recorded here because they are taking place anyhow irrespective of the extent and severity of climate change in the future. Hence the estimates of Figure 7.3.1 refer to *additional* investments aiming specifically to address future climate conditions in the country.

A significant part of the necessary investments (70% according to Figure 7.3.2) is related to energy efficiency related renovations of buildings, which contribute to both adaptation and mitigation of climate change. There are already legislative obligations through at least two recently revised EU Directives in this field – the Energy Efficiency Directive (EU) 2023/1791 and the Energy Performance of Buildings Directive (EU) 2024/1275.

Table 7.3.1: Assessment of required and planned climate change adaptation investments.

Investments up to 2050 (million Euros'2023)			
	Investment needs		
Policy area	Total	From public (national + EU) funds	**Investments budgeted and/or planned**
Coastal protection	31	31	0
Electricity grids	100	100	0
Energy-efficient buildings	2,713	1,628	968
Forest fires	26	26	1
Water resources	200	71	66
Public health	94	94	0
Agriculture	169	169	15
Mitigation of urban heat stress	500	400	100
Tourism	0	0	0
Biodiversity	20	20	10
Cultural Heritage	14	14	1
Disaster Risk Management	7	7	2
Economy, Industry and Finance	1	1	1
Education	150	150	41
Fisheries	4	4	1
Governance	1	1	0
Infrastructure	19	19	5
Soil protection	21	21	0
Spatial planning	6	6	1
TOTAL	**4,075**	**2,760**	**1,212**

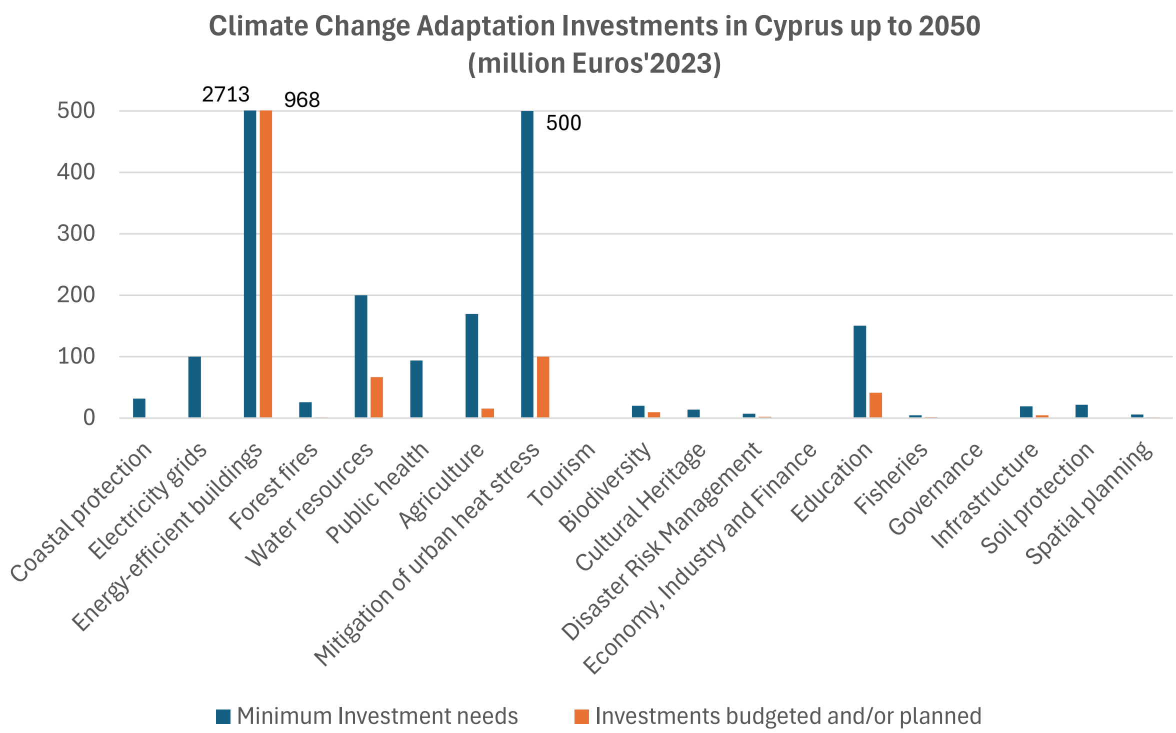


Figure 7.3.1: Assessment of required and planned climate change adaptation investments.

To implement these obligations, a substantial number of energy renovation projects in residential and non-residential buildings are underway, accounting for 83% of the planned adaptation investments (as shown in Figure 7.3.3). The buildings sector is an illustrative case where a climate change mitigation project contributes to adaptation and vice versa, while at the same time it has multiple additional benefits because it can also help reduce energy poverty and lower the country's dependence on fuel imports.

At the same time, however, attention should also be paid to investments that have not been considered urgent for Cyprus until now. As Figure 7.3.3 illustrates, projects such as *protecting coastal infrastructure* from sea level rise, enhancing the *resilience of the electricity grid* to heat waves, and mechanisms to *monitor public health* problems due to heat waves and communicable diseases, although identified in the National Adaptation Strategy, have not yet started to be adequately implemented.

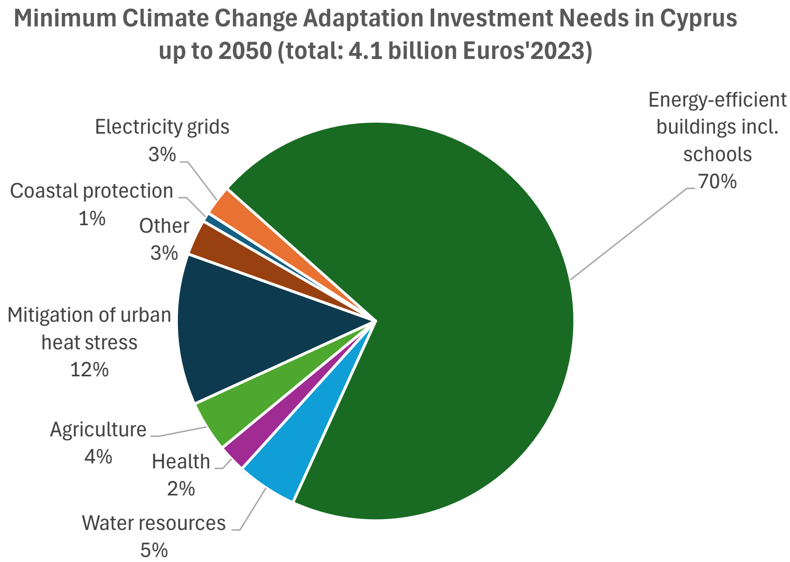


Figure 7.3.2: Estimated allocation of the required climate change adaptation investments.

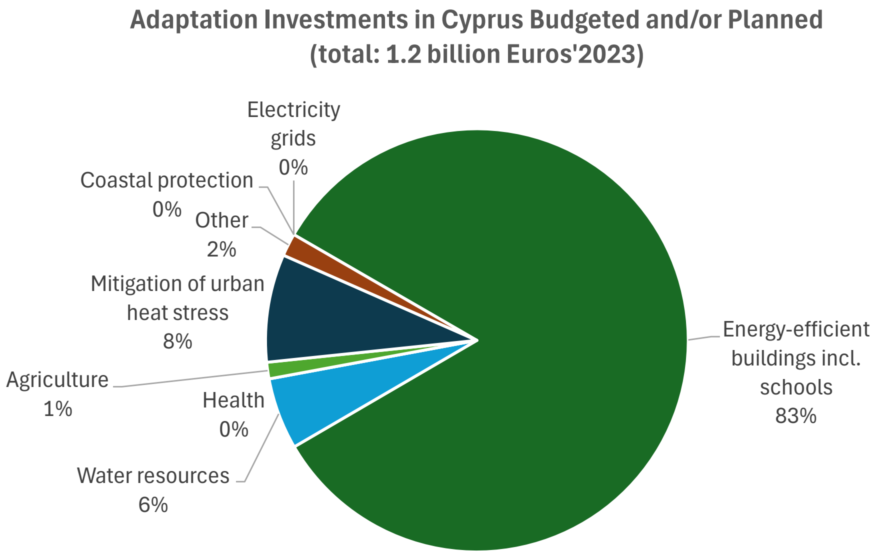


Figure 7.3.3: Estimated allocation of the planned climate change adaptation investments.

We now turn to question (iii) mentioned in Section 1, i.e. the amount of the identified investment that must come from public resources. As shown in the third column of Table 7.3.1, we estimate that out of the 4.1 billion Euros of necessary investment, *almost 70% (or 2.8 billion) should be provided by public funds* for the protection and upgrading of various infrastructures, as well as for grants to individuals and enterprises to take the necessary adaptation measures.

To address question (iv), Table 7.3.2 and Figure 7.3.4 show the expected economic impacts of unmitigated climate change up to 2050, bringing together the most recent findings from analyses carried out either for Cyprus or from estimates for other Mediterranean countries and adapted to Cypriot conditions – see Zachariadis et al. (2025).

At today's prices, the present value of these losses is estimated at 18.2 billion Euros. The costs that dominate are those of heat-related mortality, loss of labour productivity and foregone tourist revenues; their common feature is that – under unabated climate change and in the absence of adaptation measures – they occur every year and gradually increase. Other impacts related to infrastructure damages (in the electricity grid and in coastal assets affected by sea level rise) are important as point estimates but appear to be lower in cumulative terms because the infrastructure damage is considered to be gradual and is not expected to be destroyed several times in the period up to 2050. It also has to be underlined that these are the expected *additional* impacts due to climate change; hence, in some sectors the cost seems to be modest because it involves impacts which already occur because of the usual semi-arid climate of Cyprus (e.g. regarding water scarcity and forest fires).

In any case, the costs of unmitigated climate change demonstrate clearly that the necessary adaptation investments (estimated at 4.1 billion Euros by 2050 as already mentioned) will help avoid a very substantial part of the 18.2 billion Euro losses. Therefore, as many international studies have shown, *adaptation to the climate crisis brings multiple benefits which far outweigh costs and hence should be a priority in economic policy.*

The benefit of adaptation investments is significantly higher if the potential impacts up to 2100 are considered. It is clear from the scientific literature that the most severe climate change impacts are expected after 2050 and could multiply the damage costs if the adaptation measures included in the National Adaptation Strategy discussed above are not adopted on time. Keeping in mind the uncertainty about developments post-2050, we estimate the present value of the cumulative costs of the period 2051–2100 (additional to those up to 2050) at 72 billion Euros'2023.

Note that the above estimates – especially those up to 2050 – should be regarded as conservative because they do not include:

- Impacts that may evolve in a non-linear way because some tipping points in ecosystems may have been passed.
- Severe weather events (prolonged heat waves, flash floods, severe water scarcity) which are considered to be rare but which, due to climate change, are becoming more frequent.
- Chain effects of an event (e.g. overheating of electrical cables, in addition to direct damage, leads to power cuts and possibly forest fires; and vice versa, a forest fire may destroy parts of the electricity grid).
- Impacts that are still very difficult to quantify (e.g. loss of biodiversity or damage to cultural heritage sites).

Table 7.3.2: Assessment of unmitigated climate change impacts by sector.

Unabated climate change impacts (million Euros'2023)		
Sector	**Cost up to 2050**	**Cost up to 2100**
Coastal floods	348	5,000
Energy infrastructure	500	1,000
Energy demand	2,659	8,409
Forest fires	44	202
Water resources	341	1,358
Public Health	3,750	26,620
Agriculture	1,687	3,000
Tourism	5,186	27,598
Labour productivity	3,753	17,136
TOTAL	**18,270**	**90,324**

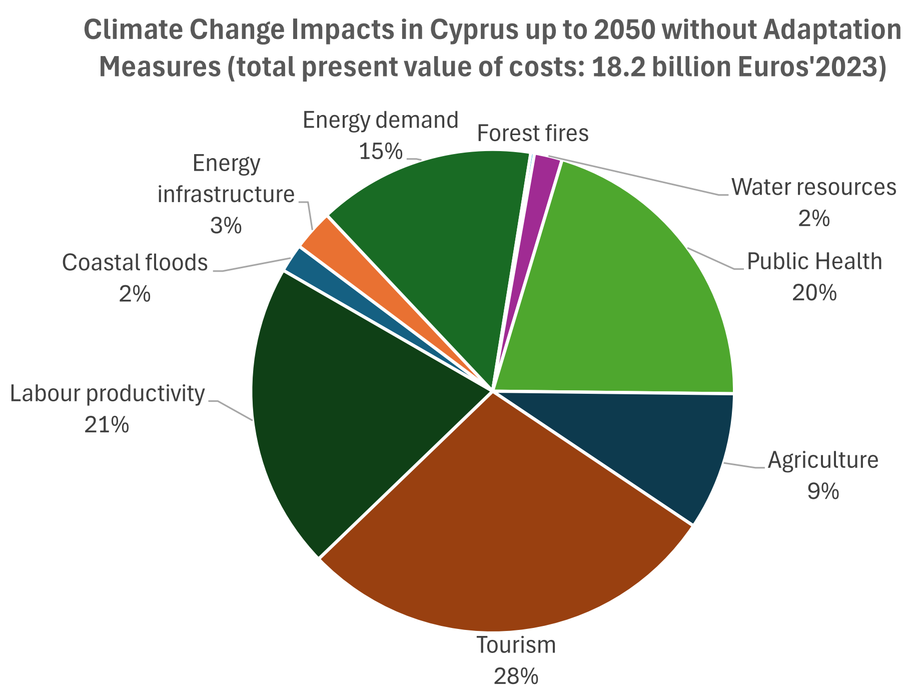


Figure 7.3.4: Allocation of unmitigated climate change costs by sector.

5. Barriers and conditions for implementation

As our analysis is wide-ranging and encompasses actions across the economy of Cyprus, there are different barriers to implementation of the measures that have been identified as necessary but have not been included in state budgets yet. Even for measures that have already been planned full implementation should not be taken for granted. For example:

- An important aspect are financial barriers – the financing gap that has been identified above, based on Figure 7.3.1, shows that less than a third of the necessary investments has been planned. It is hoped that the comparison – presented here for the first time – between the costs of adaptation and the several times higher costs of uncontrolled climate change can convince policymakers about the need for full implementation of the National Adaptation Strategy.

- Governance/institutional barriers are also important since several adaptation measures require a coordinated action of several public authorities.
- Human capital related barriers are also significant. Construction works for the refurbishment of residential buildings are very desirable and aligned with both climate change mitigation and adaptation objectives, but construction companies favour the construction of new buildings, which is more profitable to them than the renovation of existing buildings. Therefore, the limited labour available in the construction sector is not sufficient to implement all works that are necessary to fulfil the national building renovation priorities. To partly overcome this barrier, targeted tax or other incentives are necessary for building contractors so that they have an economic motivation to invest in building renovations.

6. Reflections on climate adaptation policies

In addition to the provisions for natural disaster compensation, which are already considered in national budgets, the aforementioned necessary public investments to adapt to the climate crisis should be taken into account in the government's medium-term fiscal planning. These measures should not be seen as a cost, but as an investment to ensure national security and social well-being, which is expected to deteriorate severely without adaptation measures. Decisions taken must be assessed with reference not to the current situation, which is unsustainable, but to the new normal, characterised by the risks of climate change in the years immediately ahead.

Evidently, since the country's climate will change anyhow, both the choice of adaptation measures and their financing will have to be monitored both by the Environment Ministry and the Ministry of Finance and may need to be adjusted whenever necessary.

For the next 10–20 years, impacts are expected to be influenced both by the natural variability of the current climate and by climate change of a relatively small magnitude, hence the uncertainty about the necessary measures is not great. The investments to be made with a relatively short lifetime, e.g. up to 20 years, are roughly known (e.g. new desalination plants, new fire prevention tools, early warning systems for health issues) and should proceed according to the recommendations of the revised National Adaptation Strategy.

When authorities have to decide about investments with a long lifetime extending to the end of the 21st century, e.g. strengthening coastal infrastructure or the electricity grid and planning interventions to alleviate the urban heat island effect, uncertainty increases because climate change by 2100 depends on the evolution and interaction of various natural phenomena and the extent of emission reductions achieved by humanity. In such cases, planning should take into account the possibilities of different climate scenarios and include continuous monitoring systems so that infrastructure can be strengthened if the effects of the climate crisis become worse.

As far as public finances are concerned, barring any major negative surprises regarding the impacts of the climate crisis by 2050, public financing of adaptation measures is probably within the capabilities of the Cypriot economy, provided that public spending is redirected towards the required adaptation projects. However, it should be borne in mind that for the period beyond 2050, when the worst impacts of the climate crisis are expected, the sustainability of public finances and public debt may be at serious risk. *Unless serious adaptation measures are taken now – at least those foreseen in the National Adaptation Strategy –*

public expenditures for infrastructure reinforcement and rehabilitation and for natural disaster compensations could derail public spending.

The available scientific literature suggests that spending on early climate adaptation can have a positive macroeconomic impact and maintain fiscal balance (Bachner et al., 2019). However, this requires timely action and appropriate reallocation of public spending. More generally, addressing the impact of the climate crisis leaves no room for complacency in public finances: as shown by a recent study on the public debt of many countries, *environmental sustainability is a prerequisite for long-term fiscal sustainability*. (Calcaterra et al., 2025)

Apart from the fiscal and wider economic consequences that are expected if no adaptation measures are taken, unmitigated climate change also undermines social justice. Globally, scientific studies have shown that *climate change exacerbates economic inequality* within a country, especially in the hottest regions of the world such as that of the Eastern Mediterranean (Gilli et al., 2024). Another recent pan-European study carried out for the European Economic and Social Committee highlights that *Cyprus is expected to be one of the countries with the strongest negative impacts on vulnerable households due to climate change* (Campagnolo et al., 2023). Household expenditure on food, electricity and health services are projected to increase, and these expenditure categories are regressive, i.e. poorer households spend a larger share of their income on them. Negative effects on labour productivity and possibly a gradual loss in the value of household property can also be expected.

7. Conclusion

Because estimates of the costs of adapting to climate change are inherently uncertain, it may be useful to enrich them with results from additional studies that we may not have considered or from newer analyses that will be published in the near future. In any case, it is clear that both pillars of climate policy (*mitigation* of climate change by reducing emissions and *adaptation* to the climate change already taking place) are simultaneously necessary for economic prosperity, social cohesion and fiscal stability in Cyprus. *Economic policy cannot afford to ignore the climate crisis.*

Annex to case study: Detailed List of Adaptation Measures Identified in the Revised National Adaptation Strategy of Cyprus and Assessment of Each Measure's Cost Performed in this ACCREU Case Study (see Annex C – 7.3)

4. ACCREU support and policy impact

A key objective of ACCREU is to ensure that research directly supports stakeholder decision-making and informs adaptation policy and practice. The policy-first approach and deep stakeholder engagement throughout the case study process resulted in several direct applications to adaptation planning and decision-making by government and institutional stakeholders. Table 5 documents specific examples of how case study findings have been used by stakeholders in policy development, strategic planning and resource allocation decisions. Further, Table 5 also highlights the connections to other ACCREU tasks.

Table 5: ACCREU support to stakeholders: documented policy uptake and impact by case study, and link to other ACCREU deliverables and modelling.

1.1	<u>Policy support:</u> Discussions with deep engagement stakeholders on the results of the superdike case study provided them with insights on the ways broader welfare perspectives and lock-in can be analysed for adaptation and housing policies.
1.2	<u>Policy support:</u> Within the ACCREU project, the case study on the German Baltic Sea coast has supported stakeholders in understanding the economic and ecological trade-offs of different coastal adaptation strategies. The discussions and modelling exercises provided valuable insights into where managed realignment and wetland restoration could be economically justified under future sea-level rise scenarios. This evidence base is helping regional stakeholders and planning bodies consider nature-based and hybrid solutions as viable components of long-term coastal protection strategies. <u>Link to ACCREU Model(s), Task and/or Deliverable:</u> DIVA model (GCF), ACCREU Task 2.1: “Impacts on infrastructure and built environment”, and Task 2.4 “Impacts on Ecosystems & Biodiversity”
2.1	<u>Policy support:</u> Our results support the implementation of drone-based surveillance systems as the most suitable strategy for the Campania region. This strategy demonstrated cost-effectiveness across all future climate scenarios by enabling early detection of fire outbreaks and rapid response efforts, thus limiting forest and infrastructure damage. The costs of the drone-based surveillance system were found justified given the benefits achieved. <u>Link to ACCREU Model(s), Task and/or Deliverable:</u> ForeFire-Climate model (DTU), ACCREU Task 2.4 “Impacts on Ecosystems & Biodiversity”, and Task 2.5 “Extremes, catastrophic events & supply chains”
2.2	<u>Policy support:</u> Our results indicate that the stakeholder “Miljö och Skog i Leksand AB” could benefit economically from implementing the strategies of planting more fire-resistant trees and constructing firebreaks, as these strategies provide the highest economic return on investments among the adaptation strategies assessed. Planting more fire-resistant trees, such as deciduous trees and birch trees, involves relatively low adaptation costs while generating substantial benefits by reducing wildfire damage and maintaining timber value. Additionally, this strategy offers positive spillover effects on the overall forest community by also protecting nearby forests from wildfire damage. Constructing firebreaks can greatly reduce the likelihood of wildfire spreading across the stakeholder property, whether they are being established diagonally across the area or completely surrounding it. Furthermore, these options were also the most effective in reducing carbon emissions. <u>Link to ACCREU Model(s), Task and/or Deliverable:</u> ForeFire-Climate model (DTU), ACCREU Task 2.4 “Impacts on Ecosystems & Biodiversity”
3.1	<u>Policy support:</u> The modelling work and discussions conduct regarding the Ebro basin, validated the current planning to restrict irrigation water withdrawal to maximize the benefits of all water using sectors. <u>Link to ACCREU Model(s), Task and/or Deliverable:</u> CWatM & GLOBIOM models (IIASA), ACCREU Task 2.2: “Impacts on food, energy, and water”
3.2	<u>Policy support:</u> The research on the protected area Oasis Alberoni in Venice consisting of intense discussions between representatives of the area manager (WWF) and researchers and the modelling of future climate impacts on the distribution of species in the area has improved the understanding of zones of the protected area that will be particularly affected by climate change impacts in the future, and will support the design of their management strategy. <u>Link to ACCREU Model(s), Task and/or Deliverable:</u> IBIS model (IIASA), DIVA model (GCF), ACCREU Task 2.4: “Impacts on Ecosystems & Biodiversity”, and Task 2.1: “Impacts on infrastructure and built environment”

4.1	Link to ACCREU Model(s), Task and/or Deliverable: ACCREU Task 2.3: “Impacts on Health and Wellbeing”
4.2	Policy support: The findings in Bremen drew attention to ways in which adaptation action on heat and health may overlook the social justice dimensions of adaptation. The analysis demonstrated that support for marginalised and vulnerable groups concentrated on emergency responses to heatwaves, rather than medium to longer-term adapting urban planning. The case study also developed a set of indicators for monitoring the social justice dimensions of heat and health adaptation policies. Link to ACCREU Model(s), Task and/or Deliverable: ACCREU Task 2.3: “Impacts on Health and Wellbeing”
5.1	Policy support: Within the context of the ACCREU project, ongoing research and discussions among DNB, academic, and policy experts are supporting a better understanding of how climate-related physical risks, such as flooding, may affect financial stability. These interactions have helped to clarify where knowledge gaps remain and which aspects, such as macro-financial linkages, forward-looking sea level rise effects, and market sentiment, are most relevant for future adaptation of financial risk assessments. The work contributes to a learning process and provides a basis for developing further scenarios and exploring how analytical insights can inform adaptation strategies from a financial perspective. Link to ACCREU Model(s), Task and/or Deliverable: ACCREU Task 2.5: “Extremes, catastrophic events & supply chains”
5.2	Policy support: For Dutch insurers, ACCREU provides better insight into climate risks. The project connects us with examples from abroad, from which we can learn. Through research, knowledge questions relevant to the insurance sector are answered. The workshops with stakeholders link this knowledge to practice, ensuring that the insights gained take root in practice. Link to ACCREU Model(s), Task and/or Deliverable: GLOFRIS & DIFI models (VU), ACCREU Task 2.1: “Impacts on infrastructure and built environment”, and Task 4.3 “Financial & fiscal impacts analysis”
6.1	Link to ACCREU Model(s), Task and/or Deliverable: RA2CE model (Deltares)
7.1/7.2	Policy support: The information on the costs of adaptation in the UK were shared extensively (through meetings and data provision) with the UK Treasury (the Ministry of Finance) and fed into some of their discussions with line ministries as part of the Spending Review (the three year medium term expenditure review). The data was also shared with the UK Office of Budget Responsibility and provided inputs to their fiscal risk and sustainability report and the chapter on climate change. Finally the data was discussed and provided to the UK Climate Change Committee as an input to the UK Climate Change Risk Assessment 4 and to their forthcoming well-adapted report. The CCC also have used this cost data (on adaptation costs per household) for public surveys on the costs of adaptation and it will be presented at a citizen forum in October 2025. These various activities are informing national level adaptation, including budget allocations and policy advice. Finally, the data and analysis has been provided to Defra (Ministry of Environment) for their use in the National Adaptation Programme 4, which will be developed over the next 2 years. Link to ACCREU Model(s), Task and/or Deliverable: COIN CGE model (UniGraz), ACCREU Task 4.3: “Financial & fiscal impacts analysis”
7.3	Policy support: Work conducted in this case study of ACCREU has provided an assessment of the costs of adaptation for the first time in Cyprus. As it has coincided with the preparation and adoption of the revised National Adaptation Strategy of the country, the ACCREU work has been considered by the Ministry of Environment as valuable and was therefore provided as complementary information to the government's Cabinet. This has reinforced the adoption of the revised Strategy by the Cabinet in autumn 2025.

5. Conclusion

This deliverable reports on the final implementation of the ACCREU framework across 15 case studies spanning seven adaptation decision types. All case studies successfully applied the framework developed in D3.1, demonstrating its flexibility across diverse contexts, from local biodiversity conservation to national adaptation planning, and its value for comprehensive economic appraisal that extends beyond traditional cost-benefit analysis.

Key findings: a critical analysis of adaptation barriers

The systematic analysis across case studies reveals a striking pattern in adaptation barriers that challenges common assumptions about what prevents climate adaptation implementation. Perhaps most surprisingly, technological constraints are not the primary barriers to adaptation. While technical and physical challenges were identified in approximately half the cases (47%, 7/15), they rank only fifth among barrier types. This finding contradicts the often-held perception that adaptation is primarily limited by technological readiness or physical constraints. Instead, **institutional and governance barriers** emerge as the dominant constraint, present in all 15 case studies (100%). These include fragmented responsibilities, weak inter-agency coordination, lack of political support, restrictive regulatory frameworks, competing policy objectives, short planning horizons, lack of stakeholder support and resistance to transformative planning. Financial barriers follow closely as the second-ranking constraint at 93% (14/15 cases), encompassing high upfront costs of adaptation measures, limited capital availability, lack of long-term funding mechanisms, and financing structures that favour incremental over transformative approaches.

This dominance of institutional and financial barriers is followed by social and cultural challenges (73%, 11/15), knowledge and information gaps (47%, 7/15), technical and physical limitations (47%, 7/15), human capital constraints (40%, 6/15) and economic barriers such as market dynamics and resource competition (40%, 6/15).

The adaptation paradox: positive economics versus implementation reality

A critical paradox emerges from the findings: most economic analyses demonstrate that the benefits of adaptation substantially outweigh the costs, yet implementation remains constrained primarily by financial and institutional barriers. This highlights the essential relationship between robust economic appraisal and effective governance. This is particularly critical for transformative, green and soft adaptation measures, or the measures that are not the ‘status quo’ and that require a more systemic change.

The ACCREU framework's focus on comprehensive economic appraisal, broadly developed to include not only traditional cost-benefit analysis but also co-benefits, co-costs, distributional impacts, and path-dependencies, is fundamentally connected to overcoming institutional barriers. This connection is especially pronounced for adaptation approaches that diverge from conventional grey infrastructure solutions. The institutional barriers identified, such as fragmented responsibilities, lack of political support, weak coordination, are often based on or exacerbated by inadequate economic evidence to support decision-making, particularly when measures involve nature-based solutions, behavioural change, or systemic transformation. This connection is evident in several ways:

1. **Fragmented governance requires integrated appraisal**: When responsibilities are dispersed across agencies, comprehensive economic appraisal that captures cross-sectoral benefits and costs provides a common analytical foundation for coordination and joint decision-making. This is especially important for green and soft adaptation measures whose benefits often comprise multiple sectors (e.g., ecosystem services, health co-benefits, social equity).
2. **Political support depends on credible evidence:** a lack of political support is often connected to uncertainty about outcomes. A thorough economic appraisal, particularly when it quantifies co-benefits and addresses distributional concerns, provides the evidence base that builds political confidence and legitimacy for adaptation action. Grey infrastructure measures with established track records may face

lower evidence thresholds, while transformative approaches and nature-based solutions require more comprehensive benefit quantification to overcome institutional inertia and financing structures that favour incremental measures.

3. **Financial barriers are information barriers:** the difficulty in securing adaptation finance is compounded by persistent challenges in quantifying and monetizing adaptation benefits, particularly co-benefits such as ecosystem services, biodiversity gains, health improvements, and social justice outcomes. These co-benefits are central to the value proposition of green and soft adaptation but remain difficult to monetize, creating asymmetric evidence requirements where transformative and nature-based approaches must demonstrate more comprehensive benefits than conventional grey infrastructure to secure equivalent political and financial support.

While available economic analyses consistently show favourable adaptation economics, incomplete quantification of benefits, especially co-benefits, undermines political acceptability and policymaker confidence. This evidence gap disproportionately affects transformative adaptation and green/soft measures, as incremental grey infrastructure can often rely on established cost-estimation methods and familiar risk-reduction metrics. To advance adaptation beyond incremental grey infrastructure towards more transformative, integrated, and nature-based approaches, a comprehensive economic analysis is a necessity. More precise and comprehensive quantification of adaptation costs, benefits, and co-benefits strengthens the evidence base that institutional reforms require, while governance improvements enable economic evidence to be more effectively integrated into decision-making processes.

Methodological insights and key challenges

The framework used for the case studies demonstrate that comprehensive appraisal ideally requires integration of co-benefits, distributional impacts, barriers, and path-dependencies, which are often overlooked in traditional cost-benefit analysis. Case studies employed different methods including CBAs, integrated assessment models, flood and species distribution assessments, multi-criteria analysis, risk modelling and qualitative stakeholder interviews, collectively showing that comprehensive economic appraisal extends well beyond traditional CBA approaches.

However, implementation of the framework also identified some structural methodological challenges:

- **Quantification gaps:** Monetizing co-benefits (ecosystem services, biodiversity, social justice outcomes) remains difficult, limiting their influence on decision-making despite their recognized importance.
- **Strategy-level appraisal:** Most case studies focused on individual adaptation options rather than integrated strategies, reflecting the complexity of assessing option portfolios and their interactions.
- **Distributional analysis:** Only a limited number of cases assessed equity impacts across social groups, constrained by data availability and methodological limitations.

These challenges contribute directly to the adaptation paradox described above, as incomplete quantification undermines the full economic case for adaptation and thus implementation even when partial analyses are positive.

Success factors and enablers

Despite the identified barriers, most case studies also identified critical success factors. Governance and institutional enablers emerged most frequently (58% of cases), including policies supporting integrated measures, robust governance frameworks enabling collaboration, strong inter-agency cooperation, effective multi-level coordination, balanced pursuit of different policy goals, clear responsibilities and accountability structures, and mandatory distributional impact assessments.

Financing enablers appeared in 42% of cases, encompassing access to diverse funding sources, dedicated long-term funding mechanisms, and financial instruments aligned with adaptation timeframes. Other important enablers included strong stakeholder engagement processes, supportive legal frameworks, adequate knowledge and evidence availability, clear organizational responsibilities, and long-term planning horizons matching adaptation needs.

The prominence of governance and institutional enablers as success factors directly mirrors the dominance of governance and institutional barriers, reinforcing that adaptation implementation is fundamentally a governance challenge rather than a technical or knowledge gap issue.

Policy impact and demonstrated uptake

Several case studies have directly informed policy and practice, demonstrating the value of the policy-first co-creation approach. The UK case studies (CS7.1/7.2) provided adaptation cost data to HM Treasury for spending reviews, the Office of Budget Responsibility for fiscal risk assessments, and the Climate Change Committee for the Climate Change Risk Assessment. In Cyprus (CS7.3), the first comprehensive national adaptation cost assessment supported Cabinet adoption of the revised National Adaptation Strategy. In Italy (CS3.2), research on climate impacts in the Venice lagoon will support protected area management strategy development. In Germany, the Baltic Sea coast case study (1.2), is helping stakeholders consider green adaptation measures, and the Bremen case (CS4.2) helped stakeholders in identifying social justice criteria for adaptation monitoring.

Transferability and broader relevance

Beyond these direct policy impacts, the case studies provide transferable insights and methodological approaches applicable to similar contexts across Europe and beyond. The demonstrated flexibility of the ACCREU framework, successfully applied from local conservation projects to national strategies, suggests its utility for adaptation assessment across diverse decision contexts, governance levels, and sectoral applications.

Key transferable elements include:

- **Methodological approaches**: the diverse methods employed (CBA, integrated assessment models, MCA, risk modelling, social justice frameworks, stakeholder interviews) provide templates for similar analyses in other regions, with clear documentation of data requirements, analytical steps and stakeholder engagement processes
- **Analytical frameworks**: The systematic assessment of co-benefits, barriers, distributional impacts, and path-dependencies offers a comprehensive approach to adaptation appraisal that European regions can adopt and adapt to their specific contexts.
- **Stakeholder engagement practices:** The policy-first co-creation approach, stakeholder collaborations and iterative framework development demonstrate effective mechanisms to research relevance and policy uptake, applicable to adaptation planning processes across governance levels.
- **Cross-cutting lessons:** Common patterns in barriers (financial, institutional, knowledge, technical, social) and success factors (coordination, clear responsibilities, adequate financing) provide actionable insights for adaptation planners facing similar challenges across Europe.
- **Sectoral insights:** Sector-specific findings on coastal adaptation (CS1.1, CS1.2), wildfire management (CS2.1, CS2.2), financial sector resilience (CS5.1, CS5.2) and supply chains (CS6.2) offer guidance for similar sectoral adaptation decisions in different European contexts.

The diversity of case study contexts, from Mediterranean islands, Baltic coasts, Alpine regions, and Atlantic coastlines; addressing both rapid-onset (wildfires, floods) and slow-onset (sea-level rise, water scarcity) hazards; engaging stakeholders from local municipalities to national governments and private companies, enhances confidence in the generalizability of findings across European adaptation contexts.

Policy implications and recommendations

The findings point to clear priorities for advancing adaptation implementation:

1. **Address the governance gap:** Since institutional and coordination barriers dominate alongside financial constraints, adaptation policy must prioritize governance reforms, such as clarifying responsibilities, strengthening inter-agency coordination, aligning political incentives, and establishing long-term planning frameworks that transcend electoral cycles.
2. **Bridge the evidence-to-policy gap:** The adaptation paradox suggests that positive cost-benefit ratios are necessary but insufficient. Research outputs must be better tailored to decision-making processes, potentially through policy briefs, decision-support tools, and sustained engagement with budgetary authorities.
3. **Enhance benefit quantification:** Continued methodological development for valuing co-benefits and assessing distributional impacts will strengthen the economic case for adaptation and address decision-maker concerns about incomplete information.
4. **Develop adaptive financing mechanisms**: Financial barriers require innovative solutions including long-term dedicated funding streams, financing instruments aligned with adaptation timeframes, and mechanisms that support transformative rather than only incremental measures.
5. **Invest in coordination capacity:** The prominence of fragmented responsibilities as a barrier suggests that investment in coordination mechanisms, clear accountability structures, and multi-level governance frameworks yield high returns for adaptation implementation

Future directions and connection with Task 3.3 (Adaptation Decision Types)

The findings provide a foundation for Task 3.3 on Adaptation Decision Types (final deadline September 2026), which will further synthesize lessons learned across similar decision contexts and develop generalized guidance for seven adaptation decision types. The case studies highlight priority research needs: enhanced methods for valuing co-benefits and assessing equity, tools for managing deep uncertainty, approaches for evaluating transformative adaptation, and mechanisms to overcome institutional and financial barriers.

The demonstrated policy uptake validates the policy-first co-creation approach and suggests pathways for broader impact across European adaptation planning and implementation. The ACCREU framework, refined through application across 15 diverse case studies, offers a robust foundation for comprehensive economic appraisal of adaptation that can inform evidence-based decision-making at local, national, sectoral and European levels. However, realizing this potential requires explicit attention to the institutional and financial dimensions that, rather than technical or knowledge constraints, emerge as the primary determinants of adaptation implementation success.

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7. Annex

Annex A: Bilateral meetings

The ACCREU project adopts a policy-first, co-creation approach with deep engagement stakeholders. This section documents the bilateral exchanges conducted to support case study development, apply the methodology and maintain alignment with stakeholder needs and decision contexts.

1.1 Initial bilateral exchanges

In March 2024, bilateral exchanges were held with all case study owners. The objectives were to i) check progress on framework implementation; ii) provide methodological support where needed; iii) assess the unique contribution (niches) of each case study; and (iv) agree on deliverables for milestone 3.1b. Below are summaries of these exchanges.

Case study 1.1 Sub-national adaption investments for coastal and/or riverine floods
Partner: Deltares
Date: No bilateral exchange taken place, as case study is led by Deltares.
Participants: NA
Summary: NA

Case study 1.2 Large scale and long-term coastal nature-based solution policies for rural regions in Europe and the German Baltic coast
Partner: GCF
Date: March 7th, 2024
Participants: Kees van Ginkel, Anoek van Tilburg (Deltares); Sebastiano Bacca, Jonas Haas, Jochen Hinkel, Daniel Lincke (GCF)
Summary: This case study focuses on both a European level and sub-national analysis of coastal retreat. The European assessment will primarily inform Task 3.3 on the Adaptation Decision Types (ADTs). This pan-EU level assessment is complemented by an analysis of the same policy question (where to retreat) for two sub-national regions in Europe: the German Baltic Sea coast region and another yet to be chosen. For the first milestone, it was agreed that a short text would be written a short text about the decision context for the Baltic Sea coast region (Mecklenburg-Vorpommern, Schlesswig-Holstein and WWF Germany as stakeholders) and potential co-benefits and barriers of such a strategy. A first version of this text, based on the inputs of a mid-May stakeholder workshop, is reported in Section 3.2. At a later stage in the ACCREU project, the generic and specific barriers identified for the sub-national level assessment can complement the European scale analysis of potential coastal retreat locations for the decision type task.

Case study 2.1 & 2.2 Multi-sectoral adaptation to wildfire risk in a densely populated region with high natural values / Adaptation options for reduction of forest fire
Partner: DTU
Date: March 11th, 2024
Participants: Maaike van Aalst, Anoek van Tilburg (Deltares); Martin Drews, Marcella Veronesi (DTU)
Summary: Fire risk management is examined into two different contexts: the Sweden case study focuses on forest fire management by the private sector, facilitating the quantification of avoided damages. The Italian case study, on the other hand, focuses on public sector management with a greater emphasis on nature and recreation, of which the effects are harder to quantify. Both contexts already involve some level of existing forest management. During interactions the need emerged to better detail the type of management that is currently in place (the business-as-usual) and the additional options that are newly considered. Furthermore, a clear distinction between options and strategies would be beneficial. Currently, some adaptation options are in fact formulated as more general strategies. For the options, more context-specific details are needed, such as the size or interval of prescribed burning. The level of detail will also depend on the available data for economic appraisal. If direct costs and benefits can be quantified at the

strategy level, this is acceptable, and further detail might not be necessary. However, it might be easier to provide this level of detail at the very specific options level.

The case studies can also offer insights into the barriers and limits to adaptation, as previously raised by stakeholders for CS2.2. While not required, stakeholders' input on ranking these barriers and limits could be valuable. Path-dependencies and lock-ins can be relevant to the case studies as well, particularly in the context of land use changes (2.1). Strategic directions for the case studies can be formulated focusing on hazard, exposure, vulnerability, and adaptive capacity. Additionally, a Dynamic Adaptive Policy Pathways (DAPP) visualization may be developed for case study 2.1. Close collaboration with the IIASA team working with the Global Biosphere Management Model (GLOBIOM) is integral to the case study work.

Case study 3.1 Integrated adaptation decisions in managing the water-food nexus in Europe, Spain and Czech Thaya river catchment
Partner: IIASA
Date: March 11th, 2024
Participants: Maaike van Aalst, Anoek van Tilburg (Deltares); Juliana Arbelaez-Gaviria, Dor Fridman, Amanda Palazzo
Summary: In this case study, two separate analyses are conducted: one focusing on the Thaya River basin (Czech Republic) and the other on the Ebro River basin (Spain). Both case studies address water allocation issues, its various competing uses, and the sustainable management of water resources. The adaptation strategies for both cases are quite similar, revolving around two main strategic paths: 1) water supply management, encompassing aspects such as irrigation, reservoir management, and international coordination; and 2) water demand management, which involves potential shifts in diets, import patterns and crop selection).

To enrich the analysis (specifically block O in the PowerPoint framework), it is advisable to include more context-specific details that clarify the practical implications of these strategies on the ground. This can be achieved by delineating specific options. Although quantifying costs and benefits might be challenging for certain options or strategies due to the optimization-based model, efforts should be made to include such quantifications wherever feasible in the final deliverable.

The Thaya case study will likely explore transformative adaptation options and/or strategies. It is important to note that what may be considered transformative in one region might not necessarily be transformative in another context. We discussed that it is not necessary for each case study to cover both transformative and incremental strategies. Neither case study considers distributional effects. For milestone 3.1, both case studies were expected to update the PowerPoint framework, incorporating information in part 1 based on the provided feedback, and include relevant information applicable to each case study in part two.

Case study 3.2 Integrated species distribution model for estimating potential economic impacts of conservation and impact mitigation preservations.
Partner: CMCC
Date: March 6th, 2024
Participants: Maaike van Aalst, Anoek van Tilburg (Deltares); Margaretha Breil (CMCC)
Summary: This case study focuses on a small part of the Venice lagoon. The main concern of the stakeholder is conserving biodiversity through nature-based solutions. The main pressures on biodiversity are sea-level rise and human activities. The primary benefits of adaptation measures are improvements in biodiversity, which can be quantified but not easily monetized. To facilitate quantification, one of the identified action points is to establish contact with IIASA to develop a suitable model.

Another action point identified was to compile a list of potential options and strategies for consideration, and to indicate whether they are more incremental or transformative. Such a list or table could also provide estimates of the approximate costs associated with these actions under low and extreme sea-level rise. Additionally, the case study analysis could include some information on barriers to adaptation, in particular spatial barriers; as well as insights into potential lock-in effects and path-dependencies of alternative developments, such as dikes and real estate projects.

Case study 4.1 & 4.2 Adaptation policy assessment, focus on health and distributional aspects / Qualitative assessment of social justice dimensions of climate policy
Partner: BC3/Ecologic
Date: March 13th, 2024
Participants: Maaike van Aalst, Anoek van Tilburg (Deltares); Elisa Sainz de Murieta (BC3); Benedict Bueb, Katriona McGlade, Jenny Tröltzsch (Ecologic)
Summary: Case study 4.1 (Basque country) and 4.2 (Bremen) focus on the Adaptation Decision Type Health & Social Justice. The extent to which these two elements are intertwined or distinct will be explored soon. The PowerPoint framework will be separately completed for the two regions in the next iteration. The options considered are highly detailed, and it might be challenging to classify them strictly as either incremental or transformative. However, for the strategies, such classification could be feasible, and it could even be extended to include categories such as incremental, transformative, and transformational.

Regarding the Bremen case study: To determine the appropriate level of detail for the options, it is advisable to refer to the policy question(s) and determine which options are being evaluated in the appraisal (i.e., in this case assess the social justice outcomes). For future iterations of the framework, it would be ideal to provide more detail on how vulnerable groups are defined or classified in the case studies. Additionally, the barriers to adaptation could be reframed as necessary enabling conditions for the implementation of the strategies for the case studies if that aligns better with the context. One suggestion is to classify the different options into overarching strategies (e.g., cooling, awareness, training), and possibly link them to hazard reduction, vulnerability reduction, exposure reduction, and increasing adaptive capacity if this helps to contextualize the strategies.

Case study 5.1 Adaptation options for enhancing financial stability
Partner: Deltares
Date: NA
Participants: NA
Summary: NA

Case study 5.2 Stimulation of private sector adaptation through insurance arrangements
Partner: VU
Date: March 13th, 2024
Participants: Kees van Ginkel, Anoek van Tilburg (Deltares); Jan Brusselaers, Michiel Ingels (VU)
Summary: This case study examines how flood insurance can drive adaptation in the commercial sector. Investigations are ongoing whether different insurance market forms are favored by different sectors or company sizes. Employing the Dynamic Integrated Flood and Insurance (DIFI) model, this study focuses on assessing the protection gap, and the uptake and affordability of insurance, and the extent (%) to which damages are covered. Additionally, it considers adaptation decisions made at the household or organization level as endogenous variables. For this case study, the DIFI model will be expanded with insurance policies for the commercial sector and the inclusion of adaptation decisions at the company level. While exploring disaster risk reduction through government-implemented adaptation measures is also a consideration, this will be achieved by introducing variance in the scenarios run in the model.

For the updated PowerPoint framework iteration, the options and strategies will be refined to be more specific to flood insurance for the commercial sector. The policy question block will provide a more detailed description of business-as-usual adaptation, particularly in relation to insurance and the commercial sector, including wetproofing and dry proofing measures. Qualitatively reporting on the different barriers to the implementation of insurance will provide valuable insights of this case study. It is unlikely that this case study will cover time- and path-dependencies.

Case study 6.1 Adaptation to minimize the risk of disruptions of transport networks
Partner: Deltares, UniGraz
Date: May 27th, 2024
Participants: Kees van Ginkel (Deltares); Birgit Bednar-Friedl, Keith Williges, Nina Knittel (UniGraz)
Summary: This case study focuses on Austria's primary road and rail network. The aim is to assist the Federal Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) in prioritizing adaptation measures and formulating comprehensive adaptation strategies based on prioritization criteria. In this adaptation process, the BMK ministry has a coordinating role, primarily involved in drafting and formulating a national adaptation strategy rather than directly managing infrastructure operations. Their main policy question is: how can we mainstream adaptation activities in all transport planning processes, while considering future risks?

The case study work is carried out in two steps. Initially, a quantitative climate risk assessment will be conducted for Austria's road and rail network. Subsequently, the results of this assessment are discussed with the stakeholder, fostering dialogue on potential adaptation measures. This discussion will be structured using a specialized infrastructure adaptation framework developed within the Horizon-Europe project MIRACA (https://miraca-project.eu). The framework delineates adaptation measures at four levels: 1) hazard-level adaptation, 2) asset-level adaptation, 3) network-level adaptation, 4) system-level adaptation.

Case study 6.2 Reduction of critical raw material supply chain risks for the photovoltaics industry
Partner: UniGraz
Date: March 14th, 2024
Participants: Kees van Ginkel, Anoek van Tilburg (Deltares); Birgit Bednar-Friedl, Alexander Marbler (UniGraz)
Summary: This case study addresses adaptation to supply chain risks, primarily focusing on soft adaptation options. Quantifying costs and benefits pose challenges for several of these options. Therefore, emphasis of the appraisal should be placed on options for which numerical data, even if approximate, can be provided. This could be based on input from stakeholders themselves.
Ideally, strategies are formulated that align closely with specific options, such as diversification of suppliers or increasing inventory buffers. Options should be delineated more explicitly, for example, by specifying an additional supplier from the United States.

At the strategy level, the case study can provide some information on the barriers to adaptation, drawing insights from stakeholder inputs to understand why certain strategies have not been implemented thus far. Additionally, the case study will address questions regarding the timing of the investments, including qualitative assessments of transfer costs. For the upcoming milestone, the PowerPoint framework will be updated to reflect these elements.

Case study 7.1 & 7.2 Cross-sectoral economic analysis for adaptation of region/community / Economic analysis for national and EU partner
Partner: PWA
Date: March 5th, 2024
Participants: Ad Jeuken, Anoek van Tilburg (Deltares); Alistair Hunt, Paul Watkiss (PWA)

Summary: CS7.1 (Defra as stakeholder): This case study remains more open-ended and is anticipated to start after June 2024. Instead of focusing solely on the Glasgow region, this case study will now expand to a national scope, with Defra as key stakeholder. This expanded case study will likely focus more on the distributional component of adaptation and include more transformative adaptation strategies.

CS7.2 (HMT as stakeholder): The initial phase of the case study is expected to finish by Spring 2024. Subsequently, the results will be integrated into the Computable General Equilibrium model by UniGraz, with outcomes expected to be shared in April, serving as input for Milestone 3.1. While this case study does not explicitly explore transformative adaptation options or barriers and limits to adaptation, it will touch upon some aspects of path-dependencies in adaptation. Furthermore, co-benefits are included in the appraisal results, with the potential to separate them from direct benefits and costs in the results. Additionally, the case study incorporates information on the distributional aspects of private and public investments for adaptation. The appraisal primarily focuses on two broad strategies: lower- and higher-ambition adaptation efforts.

1.2 Bilateral exchanges since first milestone

Following the first milestone, additional bilateral exchanges were conducted with partners who requested further support or had specific questions about framework implementation or reporting requirements.

Case study 2.1/2.2
Partner: DTU
Date: June 20th, October 8th
Participants: Maaike van Aalst, Anoek van Tilburg (Deltares); Marcella Veronesi (DTU)
Summary: During the first of these two meetings we discussed the information from the framework that could be collected during the in-person meetings with the deep engagement stakeholder that were planned shortly after. During the second meeting, we discussed the reporting format for the second milestone (this task), as well as on starting the process for task 3 in this work package.

Case study 7.3
Partner: CyI
Date: November 11th, 2024
Participants: Maaike van Aalst, Anoek van Tilburg (Deltares); Theodoros Zachariadis (CyI)
Summary: As this was the first meeting for this case study, the case study framework was explained. The plans for the case study and stakeholder engagement were discussed. We agreed that for this milestone, a brief description of the planned research for this case study would be provided.

Annex B: Methods and relevance of case studies for stakeholders

This section outlines the contribution of the ACCREU case study findings to adaptation assessment in general for each case study, discussing the methods used and relevance of the outcomes for different stakeholders.

Case study 1.1 Sub-national adaption investments for coastal and/or riverine floods

Partner: Deltares

Method: Cost-benefit analysis (CBA)

Relevance: The results of the cost-benefit analysis provide information to deep engagement stakeholders on the advantages and disadvantages of robust (long-term) versus incremental (short-term) adaptation to sea-level rise, considering various climate- and socioeconomic scenarios for both current and future generations. Additionally, this case study is relevant to other regional stakeholders who are responsible for sea-level rise adaptation, due to the intergenerational wellbeing assessment. Due to the large uncertainty in climate change projections over time, many regions face the challenge of taking incremental shorter-term adaptation measures or taking longer-term measures.

Case study 1.2 Large scale and long-term coastal nature-based solution policies for rural regions in Europe and the German Baltic coast

Partner: GCF

Methods: Cost-benefit analysis and DIVA (Dynamic Interactive Vulnerability Assessment) model

Relevance: The assessment results provide deep engagement stakeholders with insights into the cost-efficiency comparison between grey (dikes) and green (wetlands and retreat) coastal adaptation. Furthermore, this case study will offer European-level insights into the potential timing and locations where coastal retreat could be beneficial. Since many regional authorities across coastal areas in Europe are tasked with sea-level rise adaptation and struggle with selecting the most suitable adaptation strategy for the area, this information is highly relevant to many European stakeholders. Besides identifying which regions in Europe retreat may be beneficial, the regional assessment will provide relevant information to European stakeholders regarding the barriers, enabling conditions, and benefits associated with grey versus green adaptation.

Case study 2.1 Multi-sectoral adaptation to wildfire risk in a densely populated region with high natural values / 2.2 Adaptation options for reduction of forest fire

Partner: DTU

Methods: Cost-benefit analysis; Environmental Impact Assessment; ForeFire model; Interviews

Relevance: These case studies offer insights into the deep engagement stakeholders into the optimal combination of adaptation options to adapt to regional forest fire risk across sectors. This information is relevant to public, private, and public-private organizations concerned with implementing grey, green, and/or soft adaptation measures in the short and long term. As forest fire risks are increasing in Europe, many private and public stakeholders in Europe are keen on safeguarding the different functions of natural areas, including agriculture, forestry, recreation, biodiversity, and human safety. Given the case studies' multi-sectoral approach and private sector focus respectively, the results will be relevant to numerous European stakeholders involved in forest fire adaptation efforts. The case studies provide valuable insights into the costs and benefits of different adaptation options, as well as potential barriers, co-benefits, and temporal trade-offs of adaptation strategies.

Case study 3.1 Integrated adaptation decisions in managing the water-food nexus in Europe, Spain and Czech Thaya river catchment

Partner: IIASA

Method: Integrated Impact Assessment; GLOBIOM (Global Biosphere Management Model) & CWatM (Community Water Model)

Relevance: This case study offers deep engagement stakeholders with information on sustainable water management amid a changing climate. The integrated assessment of the case studies will provide insights into the optimal water allocation for drinking water, agriculture, and ecosystems for two different European regions. In addition to providing relevant information to deep engagement stakeholders regarding the optimal mix of grey, green, and soft adaptation measures for sustainable water management in the river basin, it also provides valuable insights to other regional stakeholders across Europe, who share the common goal of balancing water needs across different sectors and functions in a sustainable manner.

Case study 3.2 Integrated species distribution model for estimating potential economic impacts of conservation and impact mitigation preservations

Partner: CMCC

Method: Species modeling; multi-criteria analysis

Relevance: The outcome of the case study offers deep engagement stakeholders' valuable insight into the benefits and costs of protecting biodiversity and natural habitats from the impacts of climate change. The methodological design and results could also provide relevant insights for other European stakeholders concerned with protecting biodiversity and ecosystems against climate change impacts.

Case study 4.1 Adaptation policy assessment, focus on health and distributional aspects

Partner: BC3/Ecologic

Method: Health impact assessment; econometric models; cost-benefit analysis

Relevance: This case study provides information to the deep engagement stakeholders on the climate change risks faced by the health sector and the distribution of risk and adaptation outcomes for different social groups. The findings will inform the stakeholders to assess the optimal combination of grey, green, and soft adaptation options and understand the distributional effects of these policies. Since climate change will increase heat risks across Europe, the case study can provide relevant insights to other regional stakeholders in Europe, in particular related to mitigating the exacerbation of social injustice resulting from heat policies.

Case study 4.2 Qualitative assessment of social justice dimensions of climate policy

Partner: Ecologic/BC3

Method: Health impact assessment; econometric models; cost-benefit analysis; social justice policy assessment

Relevance: This case study informs deep engagement stakeholders about climate change risks for the health sector and the distribution of risk and adaptation outcomes among different social groups. Additionally, the case study offers insights into the social justice implications of climate adaptation policies. The results guide stakeholders in identifying the optimal and socially just combination of grey, green, and soft adaptation options to implement. With climate change expected to worsen heat risks across Europe, the case study also provides relevant insights for other regional stakeholders in Europe on mitigating social justice concerns resulting from heat policies.

Case study 5.1 Adaptation options for enhancing financial stability

Partner: Deltares

Method: Flood risk models; financial risk models

Relevance: The assessment offers deep engagement stakeholder insights into the necessity of adapting to extreme flooding. The methodological approach and research insights are relevant for other central banks in Europe seeking to assess the risks of climate change on financial stability. Additionally, it provides valuable information on potential adaptation options available to mitigate these risks to financial stability.

Case study 5.2 Stimulation of private sector adaptation through insurance arrangements
Partner: VU
Method: GLOFRIS (GLObal Flood Risk for Image Scenarios) & DIFI (Dynamic Integrated Flood and Insurance) models
Relevance: The results of the case study offer deep engagement stakeholder insights into the viability of flood insurance for mitigating business-level flood risks for commercial sector. This information holds relevance for advising insurance companies on the suitability and optimal design of insurance policies to stimulate business-level adaptation. As many European regions and countries have to deal with flood risk, this information is valuable to other European insurance providers, countries and businesses. It enables them to assess whether implementing private sector flood insurance would be a beneficial climate adaptation measure within their local context.

Case study 6.1 Adaptation to minimize the risk of disruptions of transport networks
Partner: Deltares, UniGraz
Method: Flood risk model; climate risk assessment
Relevance: The results of the assessment provide information to the (national level) deep engagement stakeholder on the optimal adaptation options and strategies to protect rail networks from flooding. This information can inform deep engagement stakeholder on the design of climate adaptation policies for the Austrian transport sector. As rail is gaining importance as a transport mode due to the climate mitigation challenges, identifying the risks and potential climate adaptation options for rail networks is highly relevant to national stakeholders across Europe that seek to avoid transport disruptions and enhance sustainable transportation networks.

Case study 6.2 Reduction of critical raw material supply chain risks for the photovoltaics industry
Partner: UniGraz
Method: Climate risk assessment; interviews
Relevance: The results of the assessment provide information to deep engagement stakeholders on the risks to their supply chains and the optimal adaptation options and strategies to apply to minimize these risks. As photovoltaics play a large role in the energy transition, identifying risks and potential adaptation strategies to deal with these risks is relevant information for other private companies to gain insights in ways to minimize these risks. Since this case study assesses adaptation options for a small and large private company, the results can provide relevant insights to other private companies with various sizes. Moreover, the insights from this case study can provide relevant information for public sector stakeholders interested in protecting critical infrastructure across Europe.

Case study 7.1/7.2 Economic analysis for national partner
Partner: PWA, UniGraz
Method: Literature review; stakeholder models; cost-benefit analysis; macroeconomic modelling
Relevance: The assessment results provide deep engagement stakeholders with detailed information regarding national adaptation costs and effective adaptation measures that could be implemented. This information offers valuable insights regarding the necessary adaptation budgets for stakeholders and macroeconomic implications of these investments. Moreover, the results of the case study provide relevant information to other national public authorities seeking to understand the required adaptation budget and potential adaptation strategies.

Case study 7.3 Cross-sectoral economic analysis
Partner: CyI
Method: literature review; cost-benefit analysis
Relevance: The assessment results provide deep engagement stakeholders with detailed information regarding climate adaptation costs and required national budgets for climate adaptation. This information is also of relevance to other national authorities that seek to understand the required adaptation budget.

Annex C: Appendices to case study results

CS1.2 – Large scale and long-term coastal nature-based solution policies for rural regions in Europe and the German Baltic coast

This study uses the new DIVACoast library and the model development carried out in Deliverables 2.1 and 2.4 (Haas et al., 2025; Palazzo et al., 2025) of the ACCREU project.

We construct a global coastal wetland-floodplain database that includes spatial information on mangroves, salt marshes and tidal flats, overlaid with socio-economic attributes as detailed in ACCREU D2.4 (Palazzo et al., 2025). Building on the approach by Vafeidis et al. (2008), this database has been updated using higher-resolution spatial datasets and a more refined method for delineating coastal floodplains, based on ACCREU D2.1 (Haas et al., 2025). Floodplains are defined as low-lying land connected to the ocean and situated below the local 1-in-100-year extreme sea level (ESL), using surge data from COAST-RP (Dullaart et al., 2022). The global dataset contains nearly 138,000 floodplain units.

Each floodplain is characterized by combining elevation data from meritDEM (Yamazaki, 2019) with population information from the Global Human Settlement Layer (Schiavina et al., 2023) to assess human exposure. The economic value of exposed assets is estimated by multiplying the affected population by national GDP per capita (Kummu et al., 2018) and scaling it using a global average produced capital to GDP ratio of 2.8, based on Hallegatte et al. (2013). This allows a consistent estimation of asset exposure across countries.

$$\text{Assets} = GDPpc \times Pop \times 2.8$$

To map wetlands to individual floodplain units in DIVA, we apply a K-nearest neighbors (KNN) algorithm using the DIVACoast library's GIS capabilities. This algorithm maps coastal wetlands remote sense data on mangroves from Bunting et al. (2022), salt marshes from Mcowen et al. (2017) and tidal flats from Murray et al. (2019) to specific coastline segments. Wetlands are assumed to lie within the tidal elevation range between mean low water (MLW) and mean high water spring (MHWS) levels.

The protective function of wetlands against ESL events is modeled by assuming a linear attenuation of extreme water level height across the wetland surface. This is calculated using a static, type-specific attenuation coefficient a_j for each wetland type j, as defined in Vafeidis et al. (2019). The total attenuation Δx for each wetland segment is computed as:

$$\Delta x = w \times a_j$$

where w is the wetland width, derived by dividing the mapped wetland area by the length of the floodplain it spans. This approach allows the flood attenuation potential of wetlands to be directly linked to their spatial extent and type within each floodplain.

The cost of building engineered flood defenses (sea-dikes) is computed using a method based on Nicholls et al. (2019) and Jonkman et al. (2013). Unit costs for sea-dikes, originally derived from Dutch construction data, are scaled to each country using country-specific cost factors (CCFs). Rural floodplains use the lower-end Dutch cost values, while urban areas apply the higher-end Dutch values, reflecting the Netherlands' advanced flood protection standards. All costs are expressed in 2011 PPP USD. The total cost of sea-dike protection includes both the initial investment (capital cost) and annual maintenance (assumed to be 1% of the total investment), using the formula:

$$\mathrm{S} = \mathrm{h} \times \mathrm{L} \times C_i \times (1 + 0.01)$$

where S is the total cost of sea-dike defence, h is the dike height, L is the length of the protected coastline and C_i is the unit cost for country i.

We model the green strategy relocation (and coastal migration) as in Lincke & Hinkel (2021) computing the cost of coastal relocation as:

$$\text{Relocation} = \text{GDP pc} \times \text{Pop} \times 3$$

The coefficient 3 used to calculate the relocation cost is originally computed in Tol (1995).

The cost of inaction or the residual damage cost is calculated using the expected annual damage calculation as in Hinkel et al. (2014).

Depth-damage functions *(v)* map the water depth by which the assets are submerged to the share of damage to the asset measured in percent. We assume a continuous logistic function with inundation height $h = x - y$ where x is the water level and y the elevation (Hinkel et al., 2014).

$$v(h) = \frac{h}{h+1}$$

This means that a 1 meter submersion of any given asset, results in 50% of damage to the asset.

The damage function d is defined as the integral from *0* to water level x of the depth-damage function multiplied by the derivative of the cumulative exposure function (hypsometric profile). This yields the damage for a water level x.

$$d(x) = \int_0^x v(x-y)e'(y)dy$$

Expected annual damages (EAD) are then the integral from x_0 to x_{max} of the product of the probability of exceeding an extreme water level x, given by the probability density function $f(x)$ (PDF) and the damage due to x as defined by the damage function d.

$$E(X,d) = \int_{x_0}^{x_{max}} d(x) \cdot f(x)dx$$

To estimate the cost of sediment nourishment, we adopt an empirical approach based on econometric regression using a comprehensive dataset of real-world case studies from the United States. The dataset comprises 1,466 nourishment projects carried out between 1926 and 2025. By analyzing this data, we derive an empirical cost function that predicts the unit cost of sediment nourishment (in US$2024 per cubic meter) based on a set of explanatory variables reflecting project characteristics, geographic location, economic conditions, and project objectives.

The regression model takes the following logarithmic form:

$$\log(C) = \beta_0 + \beta_1 \log(V) + \beta_2 \cdot \text{Lat} + \beta_3 \cdot Y + \beta_4 \cdot B + \beta_5 \log(L) + \beta_6 \log(\text{Pop}) + \beta_7 \log(W) + \beta_8 \cdot R + \beta_9 \cdot SP + \beta_{10} \cdot E + \beta_{11} \cdot N + \beta_{12} \log(\text{GDP}) + \varepsilon$$

In this model:

- **C** is the dependent variable, representing the cost of sediments in constant 2024 US dollars.
- **V** is the total volume of sediment used in the project.
- **Lat** indicates the geographic location (latitude) of the project.
- **Y** is the year the project was completed.

- **B** is a binary variable equal to 1 for sandy beaches and 0 otherwise.
- **L** is coastal length in km
- **Pop** is the total population of the state in 2020.
- **W** is the total production value of the water transport sector in each state in 2023 (in current prices).
- **R** is a dummy variable equal to 1 if the project included ecosystem restoration objectives and 0 otherwise.
- **SP** is a dummy variable equal to 1 if the project aimed at shoreline protection and 0 otherwise.
- **E** is a dummy variable equal to 1 if the project aimed at emergency nourishment and 0 otherwise
- **N** is a dummy variable equal to 1 if the project aimed at navigation and 0 otherwise
- **GDP** is the total local GDP

This model allows us to capture the relationship between nourishment costs and influencing factors, enabling a more accurate estimation of the costs of sediment nourishment adaptation strategy.

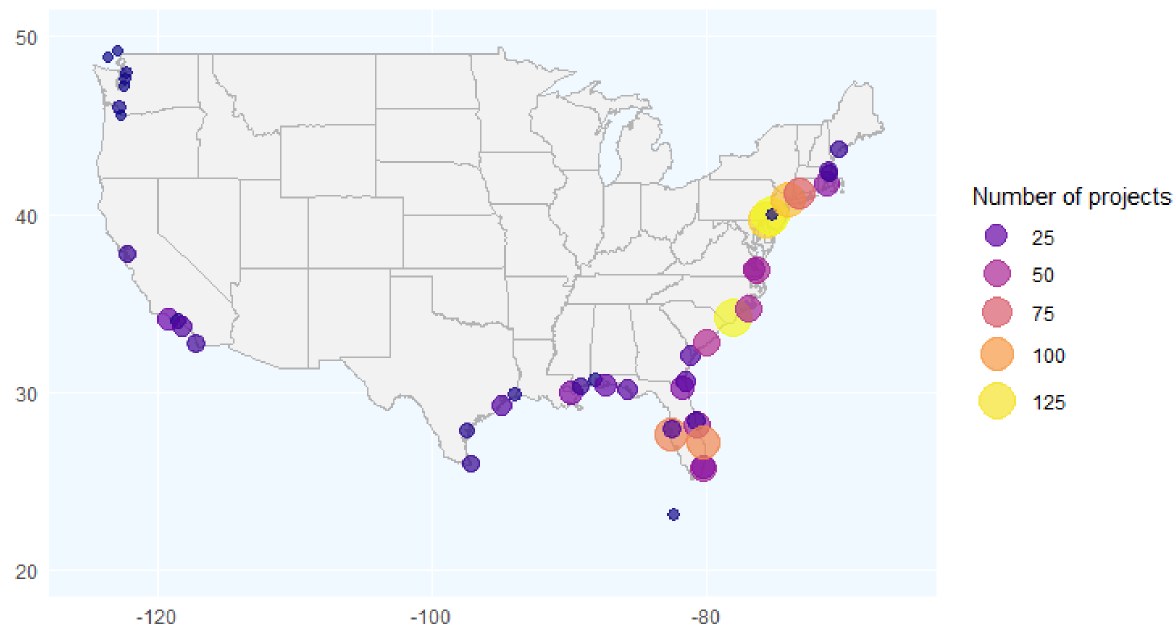

Figure C.1.2.1: Sediment nourishment projects sites in the United States from 1923 to 2024, n.obs: 1466. Source: https://coast.noaa.gov/digitalcoast/tools/beach-nourishment.html

Table C.1.2.1: Regression results using OLS with robust standard errors.

Variable	Estimate	Significance
Intercept	-7.80	***
log(V)	0.75	***
Lat	0.02	***
Y	0.01	***
B	1.03	*
log(L)	0.14	***
log(W)	-0.04	**
R	0.72	***
SP	0.20	***
E	0.25	***
N	-0.22	***
log(GDP)	0.06	*
Adjusted R-squared:	0.77	

Avoided damage

The avoided flood damage approach estimates the benefits of coastal wetlands by comparing expected flood damages under current conditions with those expected if wetlands were lost (Figure C.1.2.2 and C.1.2.3). Wetlands reduce extreme sea level (ESL) events (such as storm surges and sea level rise) by attenuating water height as it crosses the floodplain. This attenuation depends on wetland type and width, with wider wetlands offering greater protection.

By lowering the height of incoming water, wetlands shift the distribution of flood events toward lower, less damaging levels. This reduces both the frequency and severity of floods, resulting in lower expected annual damages (EAD). The avoided damage is calculated as the difference in EAD between scenarios with and without wetlands.

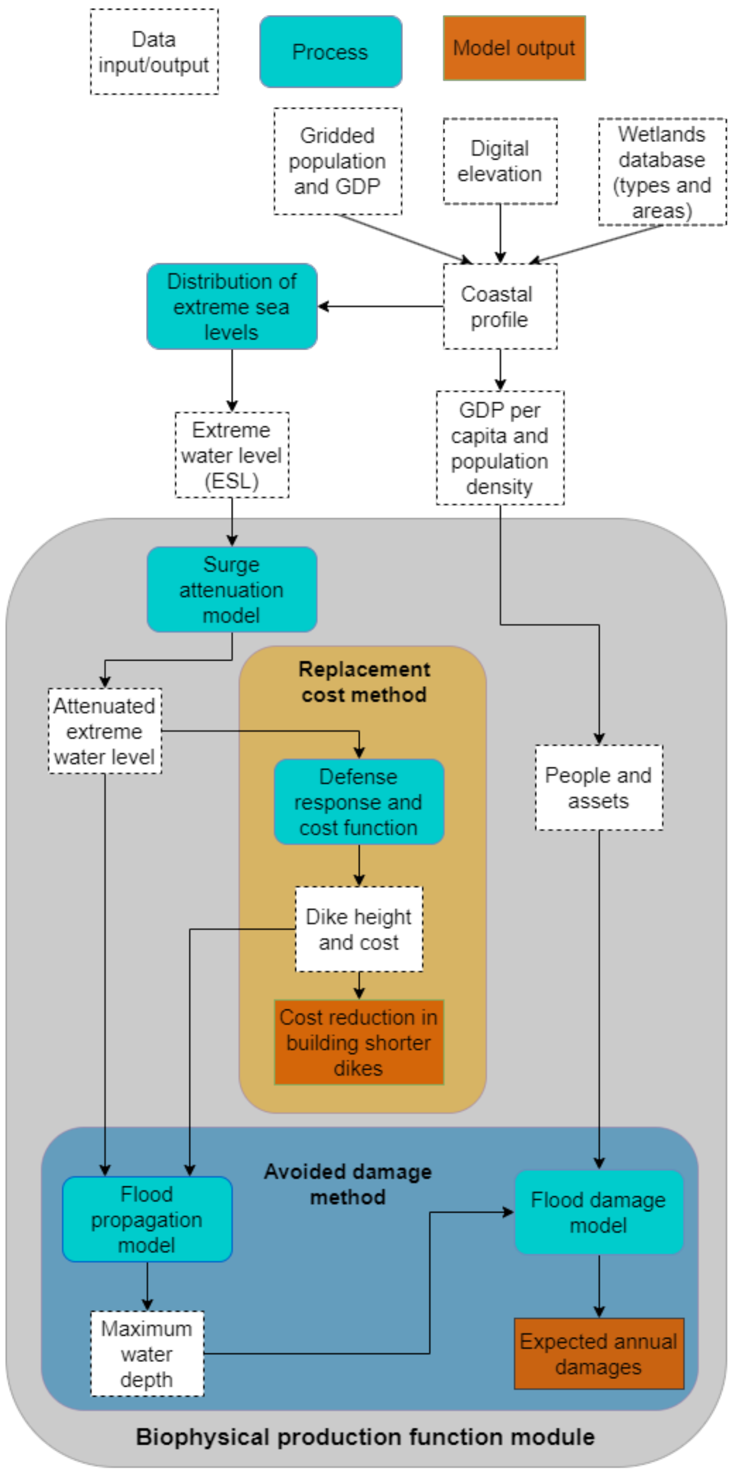

Figure C.1.2.2. Flowchart showing the processes and module interactions in DIVA modeling framework and the ecosystem services valuation modules: the biophysical production function module composed by the avoided damage and replacement cost models.

Replacement cost

The replacement cost method estimates the monetary value of coastal wetlands protection service by calculating the additional investment needed in engineered coastal defenses (Figure A2 and A3) specifically, the extra sea-dike height required to maintain the same level of flood protection in the absence of wetlands attenuation. This approach is based on the principle that wetlands naturally reduce storm surge and wave energy, thereby lowering the effective extreme sea level (ESL) that must be defended against. If this natural attenuation is lost, it must be compensated for by building higher dikes.

The key parameter in this method is the wetland attenuation height tΔx, which represents the reduction in required dike height due to the presence of wetlands. Mathematically, it is defined as the difference between the required dike height without wetlands h_{base} and with wetlands h_w:

$$\Delta x = h_{base} - h_w$$

This height difference directly translates into a cost saving, since it reflects the extent of dike construction that is avoided thanks to the protective function of wetlands. The replacement cost is then calculated as:

$$\text{Replacement cost} = \Delta x \cdot L \cdot C_i \cdot (1 + r)$$

where:

- L is the length of the dike,
- C_i is the unit cost of dike construction per meter of height and length,
- r is the maintenance cost

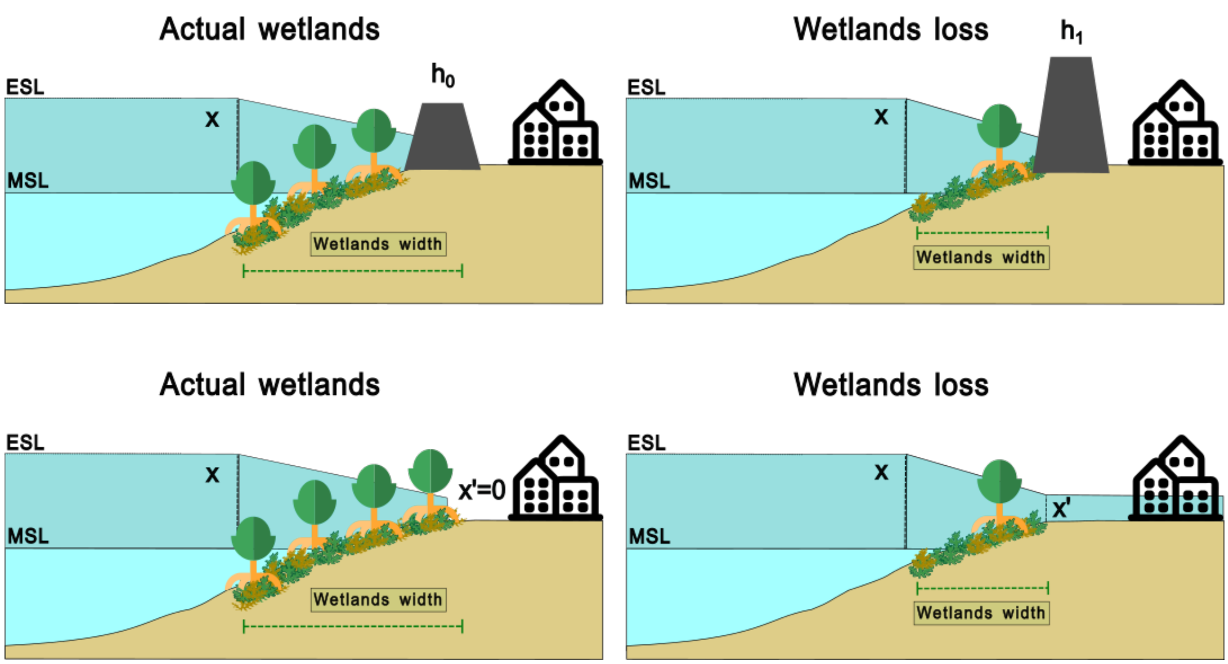

Figure C.1.2.3. Avoided damage (lower panel) and replacement cost (upper panel) biophysical production function methods used for coastal wetlands coastal protection service valuation. In avoided damage the coastal protection benefit is framed as a reduction in expected annual damages from coastal flooding due to the presence of coastal wetlands on the floodplain. In replacement cost the coastal protection benefit is framed as a reduction in cost of building lower sea-dikes (cost-saving) because the wetlands attenuate the water level.

<u>CS2.2 - Adaptation options for reduction of forest fire</u>

<u>Stakeholder:</u> Forest owner and management company (Miljö och Skog i Leksand Aktiebolag)

1. Input data

- Case study area: 25 ha (*Source:* reported by stakeholder)
- Average timber productivity: 106 m3/ha

According to Skogsstatistik, there is an average of 130 m3sk wood per hectare in Dalarna (forests of all ages) (Sveriges Lantbruksuniversitet [SLU], n.d.).

We convert m3sk (used for the volume of wood on a given area of forest) to m3fub (used when selling harvested timber) (Skogskunskap, n.d.; Skogskunskap, 2024d):

Specie	m3sk per ha	m3fub per ha
Pine	130	106,60
Spruce	130	105,30

In our calculations, we use the average number 106 m3fub.

- Average timber price pine/spruce: 815 SEK (*Source:* reported by stakeholder).
- Average timber price birch: 600 SEK (*Source:* reported by stakeholder).
- Average stem volume: 0,46 m3fub (*Source:* Skogforsk 2024c)
- Tree felling cost: 52 SEK per m3fub (*Source:* Lantmäteriet 2024)

The cost of felling trees depends on the stem volume of the trees (m3fub, i.e. the volume of wood without the bark and treetop (Skogskunskap, 2024d). The cost 52 SEK is for trees with the stem volume 0,45 m3fub (closest available value to 0,46 m3fub (average stem volume in the area)).

- Transportation of stems: 59 SEK/m3fub per 500 m

Source: the following costs for transporting stems are given by Lantmäteriet (2024):

SEK/m3fub per km	SEK/m3fub per 500 m	SEK/m3fub per 100 m
80	59	44

Given that the exact transportation distance is unknown, we use 500 m.

- Transportation of branches/treetops: 1684,8 SEK/hectare

  There is an average of 130 m3sk wood per ha (SLU, n.d.). Per 130 m3sk, the quantity of branches/treetops is as follows: ():

Region	Pine (tons of DS)	Spruce (tons of DS)
Southern Sweden	14	25
Northern Sweden	16	32

Source: Skogskunskap (2024b)

Note: DS means dry substance, i.e. content of timber when all water has been removed, in other words, wood content excluding moisture (Skogen, n.d.).

1 ha forest = 14-32 tons of dry substance branches/treetops.

14-32 tons of DS = 19,342-44,211 m3fub (SLU, n.d.).

Conversion to m3sk:

Specie	m3fub	m3sk
Pine	19,342-44,211	23,59-53,92
Spruce	19,342-42,211	23,88-54,58

Source: Skogskunskap (n.d.)

The average number for pine is 38,775 m3sk and the average number for spruce is 39,23 m3sk. We use the average number of 39 m3sk (average for both tree species).
Transportation of branches/treetops

SEK/m3sk per km	SEK/m3sk per 500 m	SEK/m3sk per 100 m
69	54	43

Given that the exact transportation distance is unknown, we use 500 m.
According to Skogforsk, only 80% of the total branches/treetops can be transported out of the forest.
0,8 * 39 m3sk = 31,2 m3sk.
54 SEK * 31,2 m3sk = 1684,8 SEK per 500 m, per felled hectare.

- Clearing forest: 1.400 SEK per ha (*Source:* Lantmäteriet 2024)
- Land preparation: 3.100 SEK per ha (*Source:* Lantmäteriet 2024)
- Indirect costs for felling trees: 1.378 SEK per ha

Indirect costs for felling of trees are 13 SEK/m3fub (± 5 SEK). For 13 ± 5 SEK, we use the average value 13 SEK. Using the number for average timber productivity: 13 SEK * 106 m3fub = 1.378 SEK per ha.
Source: Lantmäteriet (2024)

- Cost of construction and materials for building a road: 500.000 SEK per km (*Source:* Skogforsk 2024b)
- Cost for planting trees: 7.476 SEK per ha.

The cost for planting trees differs between seedings (sowing seeds directly on prepared ground) and planting (planting seedlings, typically seeded in nurseries at first):

	On own land (SEK per ha)		On others' land (SEK per ha)	
	Northern Sweden	Southern Sweden	Northern Sweden	Southern Sweden
Seeding	5.785	5.979	-	-
Planting	6.168	9.167	6.396	6.082

Planting costs: 5.785-9.167 SEK per ha. We use the average 7.476 SEK per ha. (*Source*: Skogskunskap 2024a)

- Cost for prescribed burning: 20.000 SEK per ha.

Prescribed burning, with all costs included, costs 10.000-30.000 SEK per ha. We use the average number of 20.000 SEK per ha. (*Source:* Skogforsk 2024a)

2. Expected wildfire damage costs and expected benefits from adaptation
2.1 Expected wildfire damage costs

The baseline (business-as-usual) cost represents the expected wildfire damage in the absence of any adaptation measures. The expected damage cost is calculated as follows:

$$E[WC(0)] = p \times \{area \times y \times \pi\} + \boldsymbol{c}$$

where $WC(0)$ denotes the expected wildfire cost at baseline, p denotes the probability of a fire occurrence, $area$ corresponds to the total burned area in hectares, y denotes the timber forest productivity (volume per hectare), π denotes the timber price.
The following average values are applied:
Case study forest area: 25 ha

Average timber productivity: 106 m3/ha
Timber price: 815 SEK
Cost at baseline: 25 ha * 106 m3 * 815 SEK = 2.159.750 SEK (196.800 euro)
The same equation is used when calculating the expected damage cost when the adaptation option a is implemented by adjusting the affected area, as seen below for the different measures, and by adding the costs ***c*** associated with adaptation, including investment (construction) costs, revenue losses attributable to adaptation options, and operational expenses as described below.

$$E[WC(a)] = p \times \{area \times y \times \pi\} + \boldsymbol{c}$$

To calculate the wildfire risk probability p a modular wildfire modelling framework was developed to assess wildfire risk in Europe under both historical and future climate conditions. The analysis is restricted to the fire season (June–October) and employs multiple climate datasets, including ERA5-Land reanalysis (2008–2023) for historical evaluation and bias-corrected CLIMEX2 projections (1991–2010 and 2021–2100) for future scenario analysis (Asselin, 2024) . Central to the framework is a machine learning (ML)-based fire probability model trained on wildfire observations from the EFFIS database and 23 predictors encompassing climatic, land cover, topographic, and anthropogenic variables. Among several algorithms tested, the Random Forest classifier demonstrated the highest predictive skill and was therefore selected. This model generates daily fire risk maps, from which the probability of wildfire occurrence is derived. This modelling approach was originally developed and applied within the ACCREU project (Deliverable D2.4: *Impacts on ecosystems and biodiversity*).

2.2 Expected benefits from adaptation

The expected benefits from the adoption of the adaptation option a are the difference between the expected damage costs at baseline and the expected damage costs when the adaptation option a is implemented:
$$E[B(a)] = E[WC(0)] - E[WC(a)]$$

3 Case study expected damaged costs and benefits for each adaptation option

3.1 Creating fire breaks

We calculate the costs of creating a fire break as follows.
<u>Width:</u>
When building a forest road, it is recommended to cut a path with a minimum width of 20 m through the forest (Skogskunskap, 2024c). The recommended width of a firebreak in a boreal forest is 30-60 m (Zong et al., 2021). Therefore, we use an average width of 40 m as the basis to calculate the cost per kilometer of building an evacuation route/a firebreak.

<u>Area:</u>
We calculate the cost per kilometre:
40 m * 1 km = 20.000 m2 = 4 ha
This implies cutting a path with a total area of 4 ha per km road.

<u>Wood per ha:</u>
To cut a path of 4 ha per km: 106 m3fub * 4 ha = 424 m3fub wood.
Where 106 m3fub represents the average timber productivity.

<u>Felling:</u>
52 SEK (felling cost) * 424 m3fub (wood per ha) = 22.048 SEK per km
Firebreak Option 1, 700 m: 0,7 * 22.048 SEK = 15.434 SEK
Firebreak Option 2, 2 km: 2 * 22.048 SEK = 44.096 SEK

Transportation of stems:
59 SEK (transportation cost/m3fub) * 424 m3fub = 25.016 SEK per 1 km road.
Firebreak Option 1, 700 m: 0,7 km * 25.016 SEK = 17.511 SEK
Firebreak Option 2, 2 km: 2 km * 25.016 SEK = 50.032 SEK

Transportation of branches/treetops:
1684,8 SEK (cost/ha for transporting branches and treetops) * 4 ha = 6739,2 SEK per km road.
Firebreak Option 1, 700 m: 0,7 km * 6.739,2 SEK = 4.717 SEK
Firebreak Option 2, 2 km: 2 km * 6.739,2 SEK = 13.478 SEK

Clearing forest:
Costs 1.400 SEK per ha (Lantmäteriet, 2024).
4 ha * 1.400 SEK = 5.600 SEK per km road.
Firebreak Option 1, 700 m: 0,7 * 5.600 SEK = 3.920 SEK
Firebreak Option 2, 2 km: 2 * 5.600 SEK = 11.200 SEK

Land preparation:
4 ha * 3.100 SEK (land preparation cost per ha) = 12.400 SEK per km road
Firebreak Option 1, 700 m: 0,7 * 12.400 SEK = 8.680 SEK
Firebreak Option 2, 2 km: 2 * 12.400 SEK = 24.800 SEK

Indirect costs for felling of trees:
Indirect costs for felling of trees are 13 SEK/m3fub (± 5 SEK) (Lantmäteriet, 2024). For 13 ± 5 SEK, we use the average value 13 SEK.
13 SEK * 106 m3fub = 1.378 SEK per ha.
4 ha * 1.378 SEK = 5.512 SEK per km road.
Firebreak Option 1, 700 m: 0,7 * 5.512 SEK = 3.858 SEK
Firebreak Option 2, 2 km: 2 * 5.512 SEK = 11.024 SEK

Construction and materials for building a road:
Costs 500.000 SEK per km (Skogforsk, 2024b).
Firebreak Option 1, 700 m: 350.000 SEK
Firebreak Option 2, 2 km: 100.000 SEK

Total cost
Firebreak Option 1: 404.120 SEK (36.700 euro)
Firebreak Option 2: 1.154.630 SEK (105.000 euro)

We exclude the costs of road maintenance, lost revenue for not planting new trees, management and administration costs for building a road.

Damage cost of creating a fire break
Firebreak Option 1, 10,86 ha burned: 10,86 ha * 106 m3fub * 815 SEK = 938.195,4 SEK (85.300 euro)
Firebreak Option 2, 0 ha burned = 0 ha * 106 m3fub * 815 SEK = 0 SEK (0 euro)

Benefits from creating a fire break
Benefits = baseline cost – total cost (i.e., adaptation option cost + damage cost)

Firebreak Option 1: 2.159.750 SEK – (404.120 SEK + 938.195,4 SEK) = 817.434,6 SEK (74.800 euro)

Firebreak Option 2: 2.159.750 SEK – (1.154.630 SEK + 0 SEK) = 1.005.120 SEK (91.800 euro)

3.2 Reducing tree density

We calculate the costs of reducing tree density as follows.
Thinned stands have 98-120 trees per ha (Brodie et al., 2024).
Before thinning: 1 ha of forest = 106 m3fub of wood.
After thinning: 1 ha of forest = 98-120 trees.
Average stem volume: 0,46 m3fub.
98-120 trees * 0,460 m3fub = 45,08-55,2 m3fub
This implies that for each hectare, the volume must be decreased from 106 m3fub to 45,08-55,2 m3fub, i.e. 50,10−61,52 m3fub of wood per hectare must be cut. We use the average number 56 m3fub to calculate the costs of reducing tree density.
52 SEK (average felling cost/m3fub) * 56 m3fub = 2.912 SEK per ha.
25 ha (total forest area) * 2.912 SEK = 72.000 SEK

<u>Transportation of stems:</u>
59 SEK (transportation cost/m3fub) * 56 m3fub = 3.304 SEK per ha.
25 ha * 3.304 = 82.600 SEK

<u>Transportation of branches/treetops:</u>
We cut down 56 m^3 fub of wood per hectare, starting from a total of 106 m^3 fub per hectare, which corresponds to approximately 53%.
In total, 1 ha = 14-32 tons of dry substance branches/treetops = 19,342-44,211 m3fub = 23,88-54,58 m3sk (spruce) / 23,59-53,92 m3sk (pine).
53% of 23,59-54,58 m3sk = 11,09-31,93. We use the average number of 21,5, i.e. we need to transport 21,5 m3sk of branches/treetops per ha.
80% of the total branches/treetops can be transported out of the forest:
0,8 * 21,5 m3sk = 17,2 m3sk
54 SEK (transportation cost for branches/treetops per m3sk) * 17,2 m3sk = 928,8 SEK per ha.
See section 1 on the input data for details on the given numbers.
25 ha * 928,8 SEK = 23.220 SEK

<u>Indirect costs</u>
13 SEK (indirect costs for felling trees/ha) * 56 m3fub = 728 SEK per ha.
25 ha * 728 SEK = 18.200 SEK

<u>Total adaptation cost:</u> 196.820 SEK (17.900 euro)
<u>Damage cost of reducing tree density</u>
25 ha * 106 m3fub * 815 SEK = 2.159.750 SEK (196.300 euro)
<u>Benefits from reducing tree density</u>
Benefits = baseline cost – total cost (i.e., adaptation option cost + damage cost) =

= 2.159.750 SEK – (196.820 SEK + 2.159.750 SEK) = -196.820 SEK (-17.400 euro)

3.3 Planting fire resistant tree species

We calculate the costs of planting fire resistant tree species as follows.
<u>Planting cost</u>
25 ha * 7.476 SEK (planting cost/ha) = 186.900 SEK (17.000 euro)

<u>Damage cost of planting fire resistant tree species</u>
16,44 (area burned) * 106 m3fub * 600 SEK = 1.045.584 SEK (95.000 euro)
<u>Benefits of planting fire resistant tree species</u>

Benefits = baseline cost – total cost (i.e., adaptation option cost + damage cost) =

= 2.159.750 SEK – (186.900 SEK + 1.045.584 SEK) = 927.266 SEK (84.800 euro)

3.4 Prescribed burning

We calculate the costs of prescribed burning as follows. In this case study, the strategy of prescribed burning is adopted for 7,5 hectares.
7,5 ha * 20.000 SEK (prescribed burning cost/ha) = 150.000 SEK (13.600 euro)

Damage cost of prescribed burning
17,52 (area burned) * 106 m3fub * 815 SEK = 1.513.552,8 SEK (137.600 euro)

Benefits of prescribed burning
Benefits = baseline cost – total cost (i.e., adaptation option cost + damage cost) =

= 2.159.750 SEK – (150.000 SEK + 1.513.552,8 SEK) = 496.197,2 SEK (45.100 euro)

4. Environmental co-benefits

Adaptation option	Area burned without adaptation	Area burned with adaptation (ha)	Avoided area burned (ha)
Fire break – Option 1	25 ha	10,86 ha	14,14 ha
Fire break – Option 2	25 ha	0 ha	25 ha
Reducing tree density	25 ha	25 ha	0 ha
Planting fire-resistant tree species	25 ha	16,44	8,56 ha
Prescribed burning	25 ha	17,52 ha	7,48 ha

4.1 Annual carbon sequestration by trees not burned

Swedish productive forest has "an average net carbon sequestration per year of 0,46–0,64 tons per hectare" (Backéus, Wikström, & Lämås, 2005, p. 9). The annual carbon sequestration by trees not burned is calculated by multiplying the average net carbon sequestration per year (0,46-0,64 tons/ha) by the avoided burned area:
Fire break Option 1: 14,14 ha * (0,46–0,64) tons/ha = 6,50-9,00 tons
Fire break Option 2: 25 ha * (0,46–0,64) tons/ha = 11,50-16,00 tons
Reducing tree density: 0 ha * (0,46–0,64)tons/ha = 0,00 tons
Planting fire resistant tree species: 8,56 ha * (0,46–0,64) tons/ha = 3,90-5,50 tons
Prescribed burning: 7,48 ha * (0,46–0,64) tons/ha = 3,40-4,80 tons

4.2 Avoided carbon emissions by trees not burned

A study regarding the 2014 Swedish wildfire estimated emissions by 145–160 tons of carbon dioxide per hectare burned (Granath et al., 2021; Koffmar, 2021). The avoided carbon emission by trees not burned was calculated by multiplying the estimated carbon emissions (145-160 tons/ha) by the avoided burned area:
Fire break Option 1: 14,14 ha * (145-160) tons/ha = 2.050,3-2.262,4 tons
Fire break Option 2: 25 ha * (145-160) tons/ha = 3.625-4.000 tons
Reducing tree density: 0 ha * (145-160) tons/ha = 0 tons
Planting fire resistant tree species: 8,56 ha * (145-160) tons/ha = 1241,2-1369,6 tons
Prescribed burning: 7,48 ha * (145-160) tons/ha = 1.084,6-1.196,8 tons

CS3.1b – Integrated adaptation decisions in managing the water-food nexus in Europe – Ebro river basin (Spain)

1. The Ebro Community Water Model (CWatM)

CWatM is a large-scale, distributed hydrological model suitable for implementation at global and regional scales (Burek et al., 2020). It is implemented in the Python programming language and is a fully open-source model (https://cwatm.iiasa.ac.at, last access: August 11, 2025). CWatM simulates the main hydrological processes and covers some aspects of the human–water interface, including reservoir operations, water transfers, and crop irrigation. In this project, we tailor CWatM to simulate river flows and irrigation requirements in the Ebro River Basin, Spain. High-resolution hydrological models often require updating model inputs with local datasets and adjusting the model to better account for key local human-hydrological processes (Hanasaki et al., 2022). Engaging stakeholders in the modelling process proves helpful (Hinton et al., 2025) and was also pursued in this project.

For the Ebro model, we enhance a five arc minutes calibrated global version of CWatM (available upon request), by focusing on the following key aspects:

1. Reservoir's operations and management: we update the reservoirs' input dataset, including reservoir operations, water transfer, and command areas.
2. Crops' water use: We simulate crop-specific irrigation requirements and yield loss associated with water deficit, following the FAO irrigation and drainage papers 56 and 33 (Doorenbos et al., 1979; Allen et al., 1998).
3. An irrigation efficiency map is created based on data collected for central irrigation districts (Causapé et al., 2006).

Below, we elaborate on the changes made to the model and data to capture these three key elements of the Ebro River Basin.

1a Reservoir's operations and management

Informed by stakeholders, we include 15 reservoirs with a total storage volume of 5,967 million m^3 into the model, located mainly along the northeastern tributaries, to support large-scale irrigated agriculture (see Figure 3.1b.1, main text). Each reservoir was provided with a data-driven downstream release function, expressed as the daily fraction of live-storage released during an average year (e.g., one value for every day between 1 and 366).

The Riegos del Alato Aragón (RAA) irrigation district is a focal point for this case study, used for exploring climate change impact and adaptation of the farming and hydrological system. The irrigation district covers 3,762 km^2 and receives its water from a complex system of reservoirs, canals, and ditches (Jlassi et al., 2016; Haro-Monteagudo et al., 2020).

El-Grado Reservoir

The El-Grado Reservoir is located on the Cinca River, at the northeastern corner of the RAA (see Figure 3.1b.1, main text), and has a storage capacity of 400 km^3. The Cinca canal distributes water from the headwaters into a network of secondary canals and irrigation ditches, posing limitations to the water supply. First, its capacity of 72 m^3 s^{-1} allows up to about 6.2 million m^3 to be delivered daily. Second, the canal's location in the mid-height of the El Grado reservoir limits its usable capacity to 240 km^3.

La Sotonera Reservoir

The Gállego River is another primary source of water to the RAA. Captured by the Ardisa reservoir, the water is transferred to the Sotonera reservoir, and then supplied to the Monegros Canal (with a capacity of

57 m^3 s^{-1}, based on its secondary canals) and the RAA. The Cinca Canal connects to the Monegros Canal, providing additional water to the western parts of the RAA.

We set up the CWatM model to simulate this distribution system, based on three main model components.

1) Water abstractions from the El Grado reservoir are restricted to 60% of the total storage volume, acknowledging the vertical location of the Cinca Canal.
2) Daily water withdrawal is limited to 6.2 million m^3 in the Cinca Canal (El Grado reservoir) and 4.9 million m^3 in the Monegros Canal (Sotonera reservoir).
3) Water transfers are set from the Ardisa and El Grado reservoirs to the Sotonera reservoir.

1b Crops' Modeling

The CWatM implements the FAO irrigation and drainage 56 (Allen et al., 1998) approach for calculating crop-specific irrigation requirements, and the FAO irrigation and drainage 33 (Doorenbos et al., 1979) to calculate crop yield loss associated with water deficit. Each crop is provided with a planting month, the duration (months) of four distinct growing stages, and a crop coefficient (Kc) for each growing stage. The crop irrigation requirements are calculated daily (Equation 13), where ET_c and Kc are the potential evapotranspiration (meters) and crop coefficients of crop *c* during any given day within growing stage *gs*, and ET_0 is the reference evapotranspiration (meters) on the same day, calculated using the Penman Montheith method and adjusted for changing concentration of atmospheric CO_2.

Equation 13: Calculating potential crop evapotranspiration.

$$ET_{c,gs} = ET_0 \times Kc_{c,gs}$$

The actual evapotranspiration is the minimum of the potential evapotranspiration and water available in the root zone, as simulated by the model. The growing stage yield loss due to water deficit is calculated using specific methods. Equation 14, where the relative yield ($\frac{Y_A}{Y_c}$) is a function of the yield coefficient (Ky) and the ratio between the actual and potential evapotranspiration. Crop-specific yield loss is calculated at the end of each growing season, after aggregating monthly evapotranspiration ratio values using the harmonic mean.

Equation 14: Calculating the yield loss due to water deficit.

$$1 - \frac{Y_A}{Y_c} = Ky_c \times \left(1 - \frac{ET_A}{ET_c}\right)$$

Key crops were selected based on their harvested area as provided in the hydrological River Basin Management Plan (CHE, 2023). Nectarines and Alfalfa are used as representatives of various orchards (e.g., cherries, apples, pears) and as fodder, respectively. The crop distribution maps are taken from the Spatial Production and Allocation Model (IFPRI, 2024) and the cropgrids dataset (Tang et al., 2024; Alfalfa). The parameters used for representing crops are taken from various sources and shown for the RRA in Table C.3.1b.1.

Table C.3.1b.1: Crop modeling parameters: crop calendar, crop, and yield coefficients. Regional crop coefficients are taken from García Vera and Martínez Cob (2004) and provided in the table as ranges. Yield coefficients are sourced from Steduto et al. (2012) and Khalifa and Taha (2023). Yields are not calculated for Alfalfa, since it was excluded from the economic assessment.

Crop	Planting Month	GS1	GS2	GS3	GS4	Kc1	Kc2	Kc3	Kc4	Ky
Maize	4	1	2	3	1	0.26-0.32	0.31-0.49	1.04-1.07	0.39-0.62	1.25
Wheat	10	3	2	2	2	0.83-0.84	1.04-1.08	1.16	0.56-0.66	1.15
Barley	11	1	2	3	2	0.83-0.94	0.89-1.00	1.13-1.15	0.46-0.56	1.15
Alfalfa	3	1	3	3	0	0.36-0.55	0.97-1.03	1.00-1.01	-	-
Nectarines	3	1	3	3	1	0.36	0.58-0.67	0.73-0.78	0.3-0.31	0.95
Olives	12	4	3	2	3	0.65	0.57	0.5	0.6	0.8
Citrus	1	2	3	4	3	0.66	0.64	0.65	0.74	0.95

1c Irrigation Efficiency Map

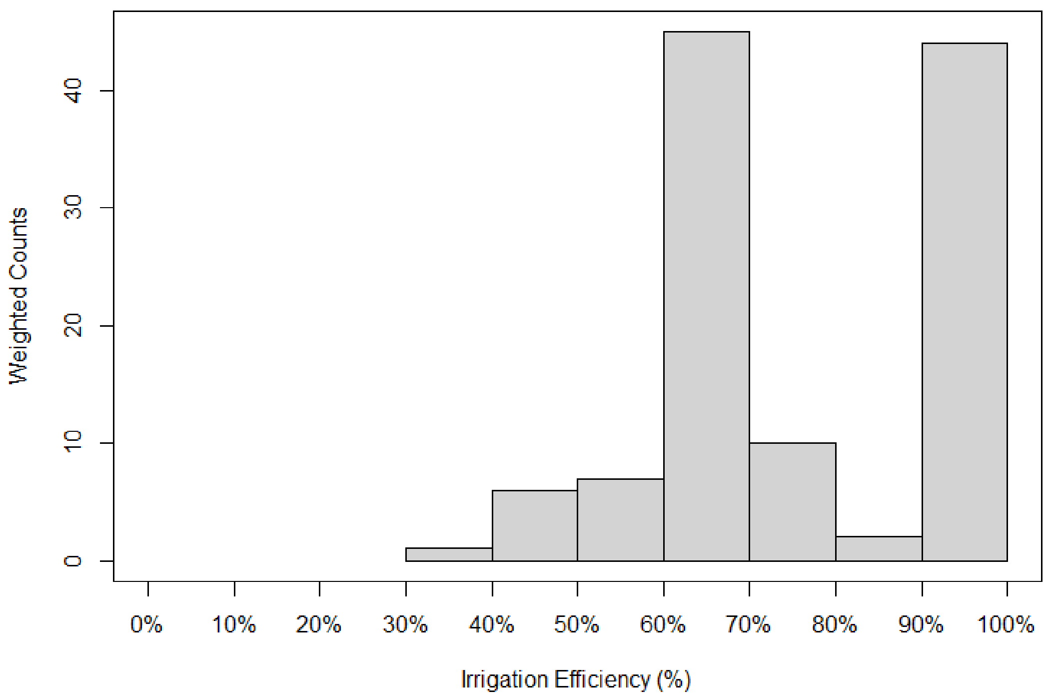

Figure C.3.1b.1: Histogram of irrigation efficiencies weighted by the documented area. Data is taken from Causapé et al. (2006).

We used data collected by Causapé et al. (2006) and randomly generated 50 maps based on the data histogram (Figure C.3.1b.1) using a Gaussian kernel. The data indicate an average irrigation efficiency of 76.5% ± 17%. The average map resulted in a normalized histogram with an average efficiency of 75.8% ± 2.3%. The average map compensates for the biased sampling (focused on central irrigation districts), allowing for spatial allocation and extrapolation of irrigation efficiencies across the entire Ebro River Basin—the Gaussian mask results in a clustered pattern of irrigation efficiency (Figure C.3.1b.2).

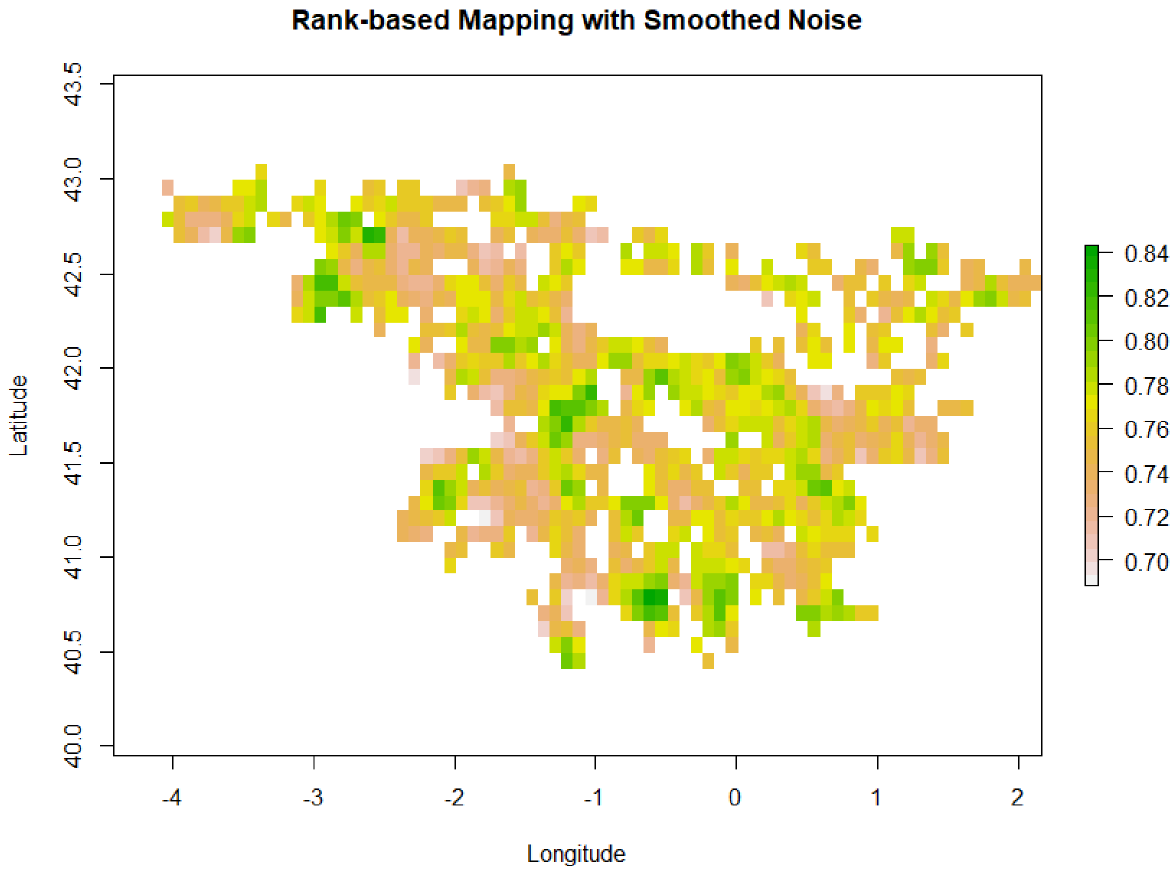

Figure C.3.1b.2: Average map of irrigation efficiency. The map is based on 50 random maps, generated with a Gaussian mask and based on the histogram of data collected by Causapé et al. (2006).

2. Economic Assessment

We use cost-benefit analysis to advance an economic assessment of the current state, climate change, and adaptation scenarios. For that purpose, we calculate and compare the net revenue (2015 €) and agricultural economic water productivity (2015 €/m^3). These indicators highlight the impact of climate change and adaptation on the local economy, as well as the extent to which water resources are being used efficiently. The revenues (R) from selling a crop c in time t are calculated following Equation 15, where Y and A are the crop's yield and area harvested, and p is the crop's producers' price in 2015 Euros (constant prices). The yield is calculated by multiplying the yield loss ratio by a maximum yield. The crop prices and maximum yields were taken from FAOSTAT. Yields were evaluated against data from the Global Agro Ecological Zones (GAEZ; FAO and IIASA, 2021), and found to be robust. The data is shown in Table C.3.1b.2. The revenue calculation assumes the Ebro production system does not affect the national producer prices, and that future prices are fixed to the 2015 price. It further simplifies the maximum yield input data by including only one national data point, though these values mostly align with the values provided in the GAEZ dataset.

Equation 15: calculating the revenues from selling a given crop in a given growing season/year.

$$R_{c,t} = Y_{c.t} \times A_{c,t} \times p_{c,t}$$

The costs section only includes annualized reservoir investment (for the local storage scenario) and ignores the production factors' costs, including land leasing, water costs, energy, machinery, labor, and chemicals and seeds. This simplifying assumption assumes that the crop-specific cost functions are not significantly different. The reservoir costs include an annualized investment component and an additional 10% operating and maintenance component, reaching 0.065 € m^{-3} ann^{-1}. Annualization is based on Equation 16, where ACT and I represent the annual investment (establishment cost) and the total investment, respectively, and n is the project's life-span (set to 50 years), and r is the interest rate (set to 5%). The data used to estimate the average total investment is displayed in Table C.3.1b.3.

Equation 16: Annualization of investment costs. For the reservoir, we have used a project's life span n=50 years, and an interest rate r=0.05. Source: Wiberg and Strzepek, 2005.

$$ACT_i = I_i \times \left(\frac{r \times (1+r)^n}{(1+r)^n - 1}\right)$$

Table C.3.1b.2: Crop-specific maximum yield and producers' prices. Annual prices are provided as a range and an average.

Crop	Maximum Yield (kg ha^{-1})	Price (€ 2015 ton^{-1}) Range (average)
Maize	12,833	131.5 -230.6 (165.3)
Wheat	4,253	119.2 -245.3 (173.4)
Barley	4,171	104.9 -221 (148.5)
Nectarine	21,369	407.9 -770.4 (572.6)
Olives	3,807	362.3 -716.8 (515.6)
Citrus	26,068	142.4 -245.2 (191.3)

Table C.3.1b.3: Total storage (million m^3) and construction costs (€ m^{-3}) for selected reservoirs in Spain.

Reservoir	Total Storage (million m^3)	Cost (€ m^{-3})	Source
Almudévar (Aragón)	169.7	0.67 -0.94	Sacyr (2024); CadenaSER (2025)
Mularroya (Jalón / Saragossa, Ebro basin)	103.3	1.49 -2.46	CHE (2007); Aragondigital (2022); Onda Cero (2025)
Malvecino	7 -7.23	1.2 -1.31	AcuaEs (2013); AcuaEs (N.D.)
Laverné	40	0.865	FNCA (2015); AcuaES (N.D.);
Los Campitos	4.2	0.53	El Dia (2021)

3. Modeling results: Current state and climate change scenarios

3a Model evaluation

The Ebro model was set up, run, and evaluated during the years 1997-2019. We have used the parameter set of the calibrated global model, and evaluated the model based on the Kling-Gupta efficiency (KGE), Nash Suttclife efficiency (NSE), and R^2. High model performance, in that sense, indicates that the simulated river discharge has a similar magnitude, trend, and variability relative to the observed discharge. Acceptable model performance is defined as a KGE > -0.41 (Knoben et al., 2019), NSE > 0.5, and R^2 > 0.6 (Moriasi et al., 2015). The model performance is high along the main channel (Figure C.3.1b.3), where KGE values are higher than 0.5 for almost all gauges, and are above 0.7 for almost half of them. Performance in the northeastern tributaries is lower, where all KGE values are above 0.1, but values of other metrics are below acceptable values.

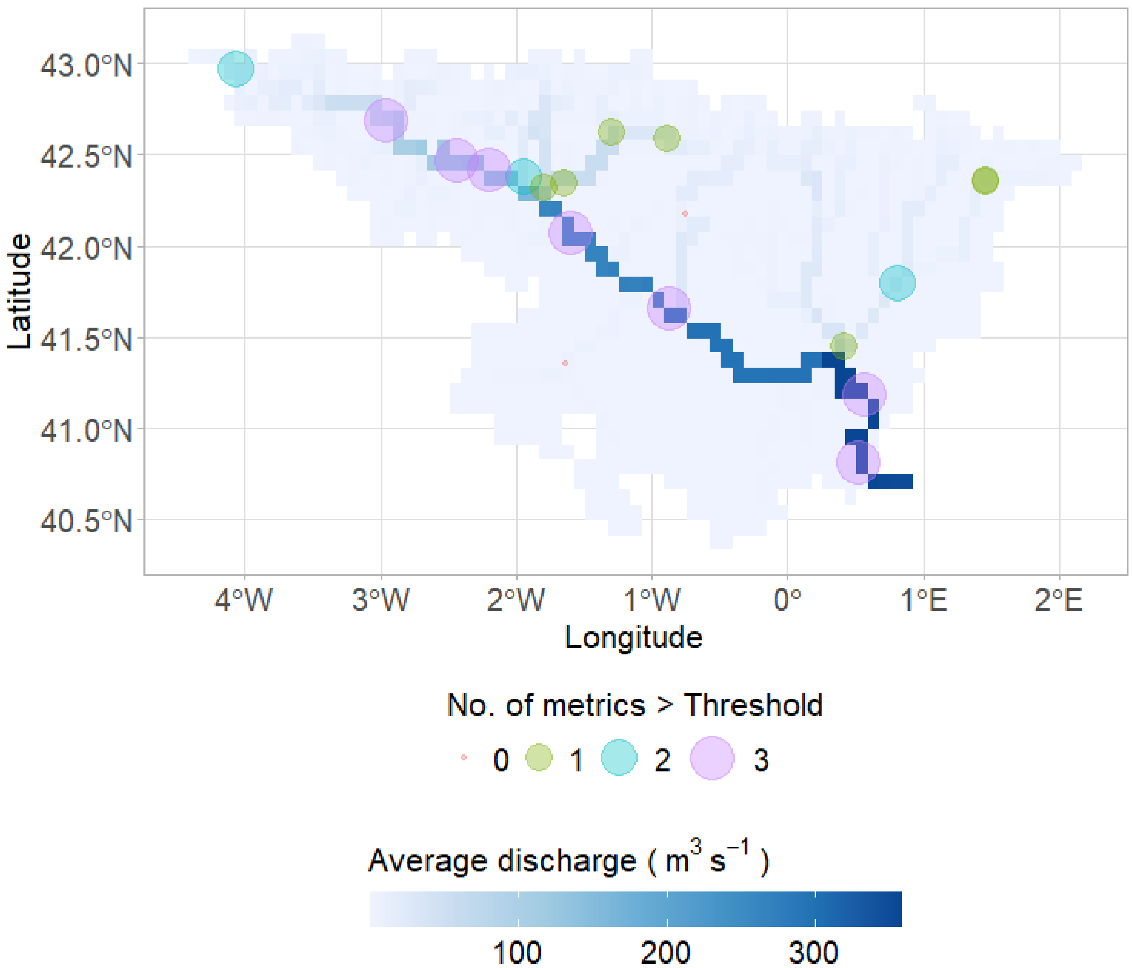

Figure C.3.1b.3: Average river discharge and the model performance as the number of evaluation metrics (KGE, NSE, R^2) with values higher than acceptable thresholds.

For model evaluation, we also compared the simulated irrigation withdrawals with those known for the key irrigation districts. The model indicates an annual irrigation withdrawal of approximately 4,000 million m^3 in the Ebro River Basin, which accounts for approximately 70% of the actual irrigation. In the RAA, as expected, irrigation is fed mainly by reservoirs' water, with a bit of pumping from the rivers, and insignificant use of groundwater. The river water source becomes vital in drought years, when reservoirs are not sufficiently replenished, thus restricting the total irrigation withdrawal (e.g., 2011-2012 in Figure C.3.1b.4).

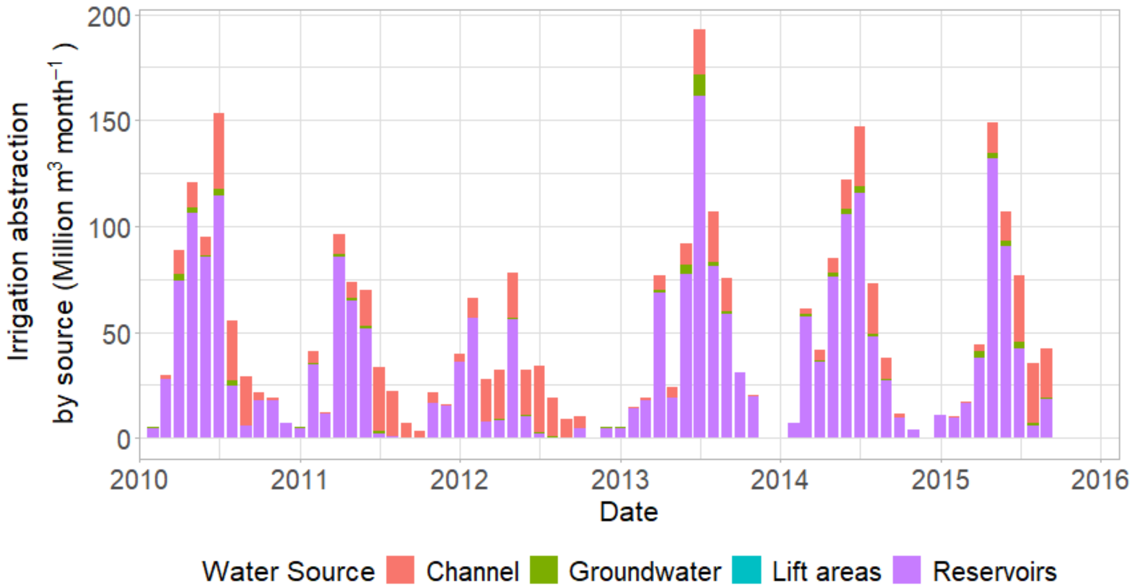

Figure C.3.1b.4: Monthly irrigation withdrawal by water source in the RAA between 2010 and 2016. Channel and lift areas both rely on river water. Lift areas are areas sharing the water from a given river segment, where channels indicate local channel water use (at a grid-cell level).

3c Current and future risk

Estimating the climate change impacts and adaptation requires consistent climatic and socio-economic forcings. The scenario protocol used by the ACCREU project is adopted for this assessment. It follows that the impact of climate change is estimated for three different representative concentration pathways (RCPs) 2.6, 4.5, and 7.0 (van Vuuren et al., 2011). The ACCREU scenario protocol proposes to use four global climate models (GCMs), which are used here (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM-1-2-HR, and UKESM1-0-LL), as well as MRI-ESM2-0, which aligns with the ISIMIP 3b protocol (https://protocol.isimip.org/).

Between 2000 and 2020, the average share of irrigation demand satisfied in the RAA ranged from 10% in drier years to 60% in wetter years. A consistent decrease is observed under climate change, reaching average irrigation shares of 17.2%, 19.8%, and 11.9% in 2050-2060 under RCP 2.6, 4.5, and 7.0, respectively (Figure C.3.1b.5). These reductions are associated with decreasing water availability in 2050 -2060, when inflows to headwater reservoirs under RCPs 2.6, 4.5, and 7.0 are expected to be 15.7%, 9.5% or 11% lower in Ardisa, and 14%, 12%, and 14.6% lower in El-Grado (Figure C.3.1b.6). A consistent increase in water demands (e.g., due to increasing evapotranspiration) is another dominant factor in the RAA (Figure C.3.1b.7), where irrigation water demands in 2050-2060 are expected to be 70%, 65%, and 80% higher under RCPs 2.6, 4.5, and 7.0, respectively.

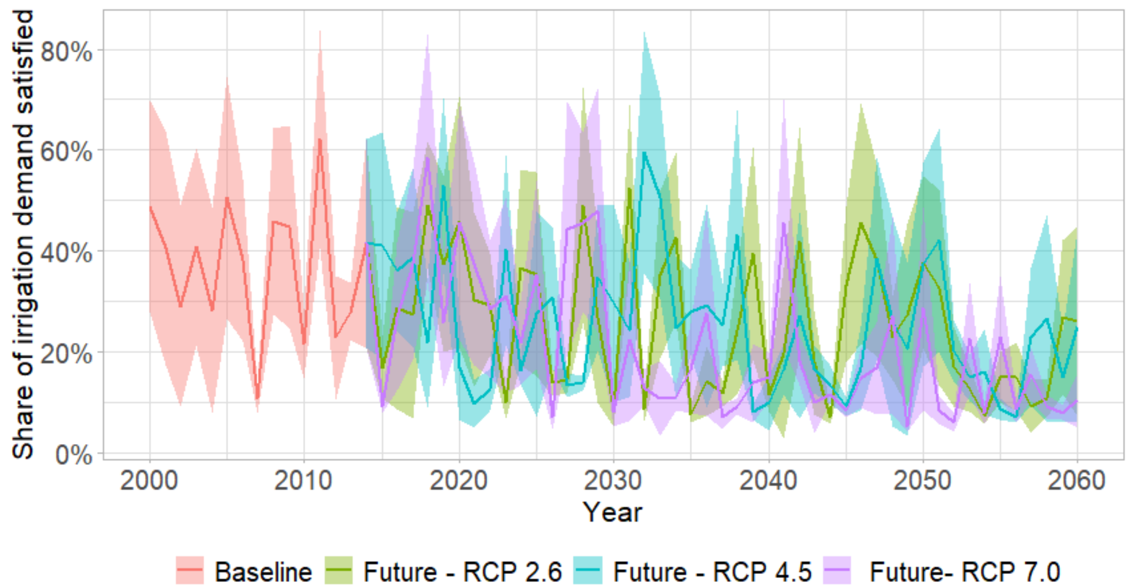

Figure C.3.1b.5: Annual share of potential irrigation satisfied in the RAA between 2000 and 2060 and based on different RCPs. The solid line represents the ensemble average, with the area indicating a half standard deviation distance around it. The future projections are between 2015 and 2060.

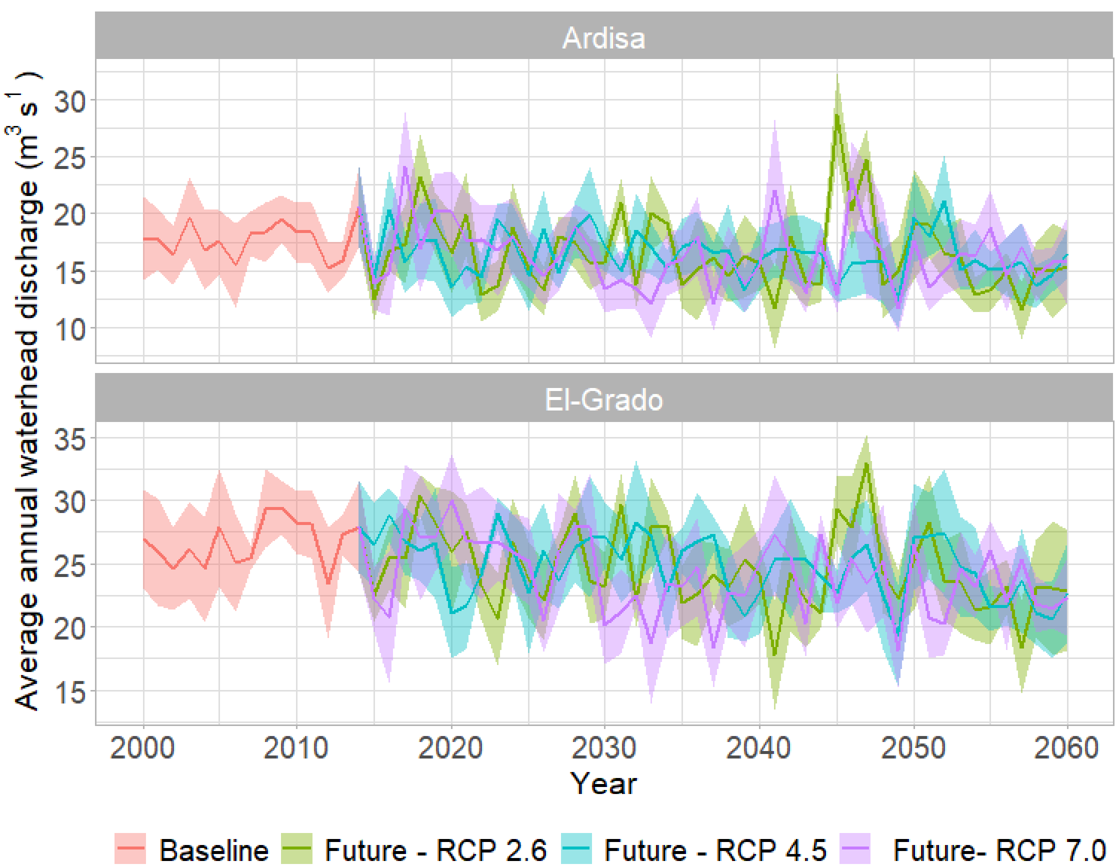

Figure C.3.1b.6: Annual average inflow into the waterhead reservoirs: Ardisa and El-Grado between 2000 and 2060 and based on different RCPs. The solid line represents the ensemble average, with the area indicating a half standard deviation distance around it. The future projections are between 2015 and 2060.

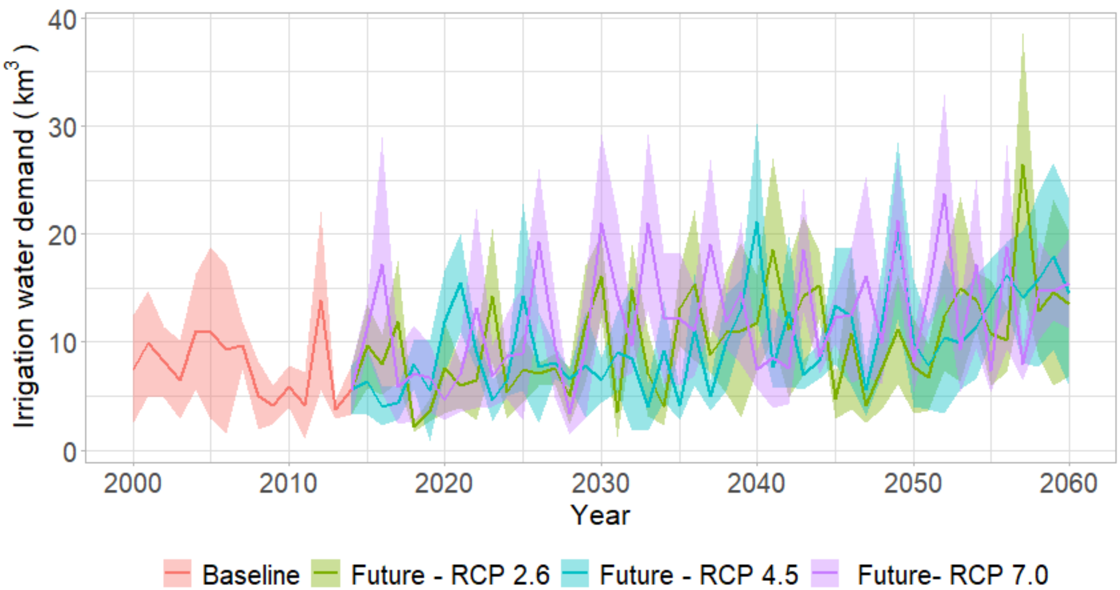

Figure C.3.1b.7: Annual irrigation water demand in the RAA between 2000 and 2060, based on different RCPs. The solid line represents the ensemble average, with the area indicating a half standard deviation distance around it. The future projections are between 2015 and 2060.

4. Modeling adaptation measures

4a Adaptation measure 1: Crop selection

The integrated assessment modeling framework linking CwatM and Global Biosphere Management Model (GLOBIOM; Havlík et al., 2018), as described in ACCREU D2.2, can account for either autonomous or planned adaptation measures. Autonomous adaptation measures refer to the adjustments made by households and firms (e.g., farmers) in response to changing economic conditions. Crop selection is an autonomous adaptation measure associated with climate change impacts. Since GLOBIOM does not cover all crops significant in the Ebro, we do not use its downscaled landcover and crop maps. Instead, we develop a crop selection narrative for the Ebro River Basin. Across all adaptation and mitigation scenarios, a relative shift is observed from Barley and Sunflower Seed towards Wheat cultivation, implying it is the most profitable choice, subject to the availability of water resources (Figure C.3.1b.8). This observed trend is consistent across RCPs, mitigation, and adaptation scenarios. The high adaptation scenario, which involves 63% ± 29% increase in irrigated cropland, also shows the highest increase in the relative share of wheat cultivation.

Inspired by the GLOBIOM scenario, we explore a crop selection by switching all nectarine and maize croplands to wheat, which in turn increases from 175 km^2 to 846 km^2.

4b Adaptation measure 2: Local Storage

The local storage adaptation measure relies on on-farm or regional storage infrastructure, such as ponds or small reservoirs, aiming to increase storage capacity and buffer against temporal water shortages. We implement this measure by simulating 57 reservoirs, one in each grid cell of the RAA. The reservoirs' volume ranges between 0.13 million m^3 and 3.12 million m^3, and averages at 1.4 million m^3. Overall, the adaptation measure adds storage volume of 28 million m^3 and 53.5 million m^3 in the area served by the Cinca canal and Monegros canal, respectively.

Water transfers from the headwater to the local reservoirs are limited based on Equation 17, where v is the volume of downstream reservoir j, q is the daily capacity of the canal associated with headwater reservoir i, and W is the maximum daily water transfer from headwater reservoir i to downstream reservoir j. Under this scenario, irrigation abstractions occur first from the headwaters reservoir, and from the local storage in case additional irrigation is required.

Equation 17: Calculation of the water transfer's daily limit.

$$W_{ij} = \min\left(v_j, q_i \times \frac{v_j}{\sum_{j \in i} v_j}\right)$$

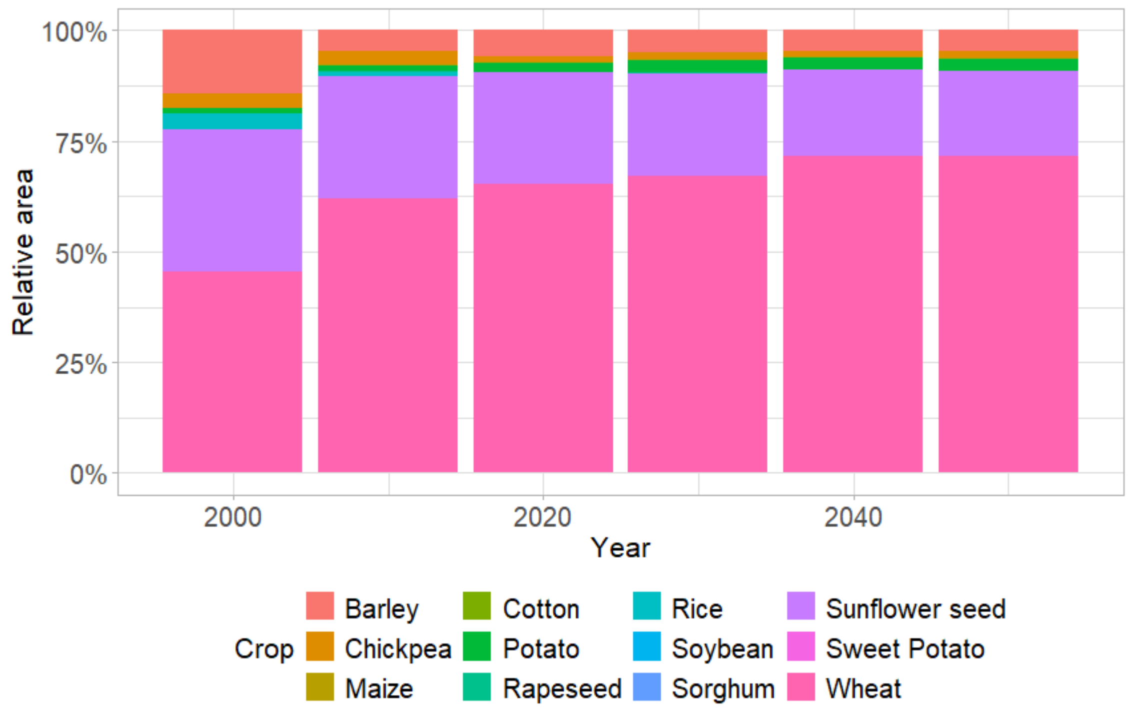

Figure C.3.1b.8: Average crop mix in the Ebro River Basin under different GLOBIOM simulations. Each simulation represents a decade, between 2000 and 2050. The future projections are between 2010 and 2050.

5. Climate change impacts and adaptations of the Ebro River Basin

The irrigation water withdrawal without adaptation ('No measure' in Figure C.3.1b.9) shows a slight increase under climate change, with a median of 740 million m^3 that increases to 758-768 million m^3. Both adaptation scenarios indicate lower water withdrawal levels, with medians around 500 million m^3 for the crop selection and local storage measures, respectively. Both adaptation scenarios show a slight reduction in water withdrawal, which is more apparent in the crop selection measure, which reduces from 499 million m^3 to 414-443 million m^3. The local storage adaptation measure shows a lower confidence interval around the mean, except for RCP 2.6, yet some years still present very low water use withdrawals.

The total crop production (in thousands of tons; Figure C.3.1b.10) reveals significant differences between the no-adaptation or the local storage scenarios and the crop selection measure. The median total production in the latter is 227 thousand tons, which is approximately 30% of the other measures (577 and 608 thousand tons for the local storage adaptation measure and without adaptation, respectively), primarily due to the replacement of high-yielding crops (e.g., nectarive and maize, see Table C.3.1b.2), with lower-yielding wheat. Unlike water use, in the case of production, the local storage measure demonstrates the highest variability. A slight decrease in production is observed under climate change, and is apparent primarily in the local storage measure.

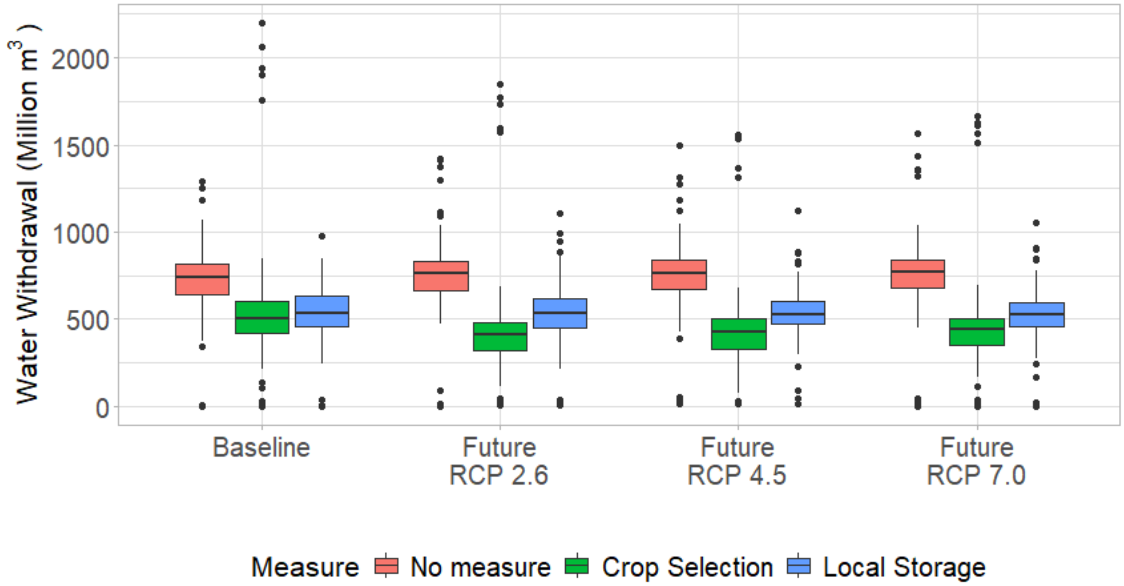

Figure C.3.1b.9: Current and future irrigation withdrawal in the RAA under different climate and adaptation scenarios. The boxes indicate the ensemble and temporal median, 25th and 75th percentile, and the whiskers and points indicate the confidence interval around the median, and extreme values. The baseline simulations and future projections are between 2000-2014 and 2015 -2060, respectively.

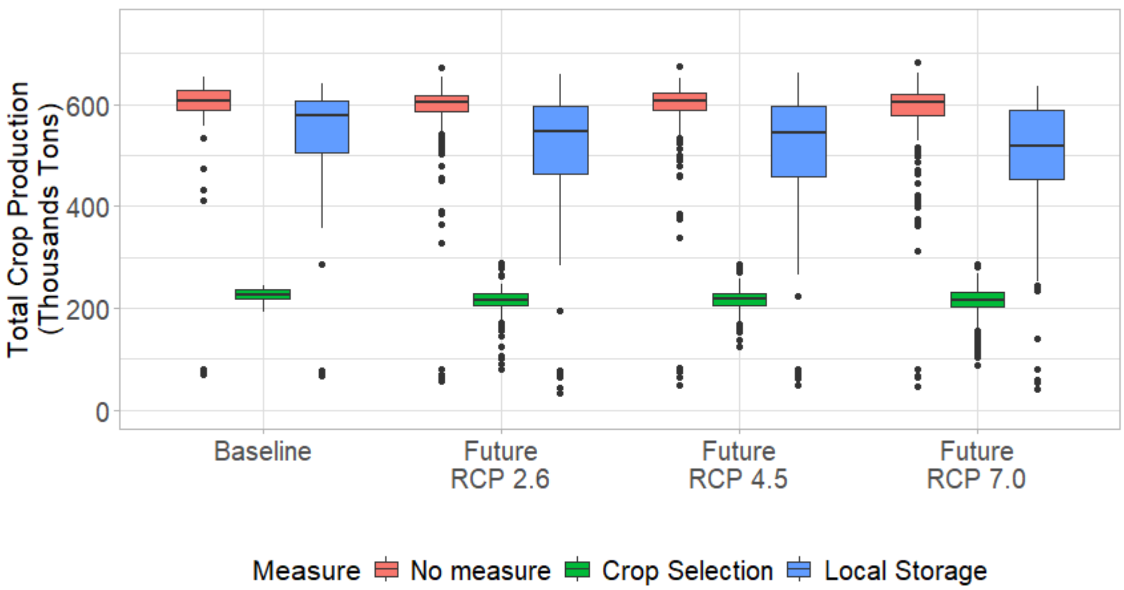

Figure C.3.1b.10: Current and future total crop production (thousands of tons) in the RAA under different climate and adaptation scenarios. The boxes indicate the ensemble and temporal median, 25th and 75th percentile, and the whiskers and points indicate the confidence interval around the median, and extreme values. The baseline simulations and future projections are between 2000-2014 and 2015 -2060, respectively.

The net revenue takes into account crop sales minus the annual infrastructure costs (for constructing local storage). Although we do not include any direct cost in the crop selection measure, a considerable opportunity cost is observed due to the loss of income associated with switching from high-yielding price crops to wheat. For example, on an average year, nectarine could generate up to 12,235 € ha^{-1} in 2015, compared to 737.5 € ha^{-1} from wheat. It follows that the net revenue gap between the no-adaptation scenario (220 € million) and local storage (194.5 € million) is slightly higher than the production gap (Figure C.3.1b.11), particularly when compared to the crop selection measure (36.6 € million). As the latter accounts for approximately 20% of the no-adaptation and local storage measures. Climate change impact indicates a reduction in the RAA's net revenue for the local storage (182–193 € million) measure, though it remains uncertain due to the significant temporal and model variability.

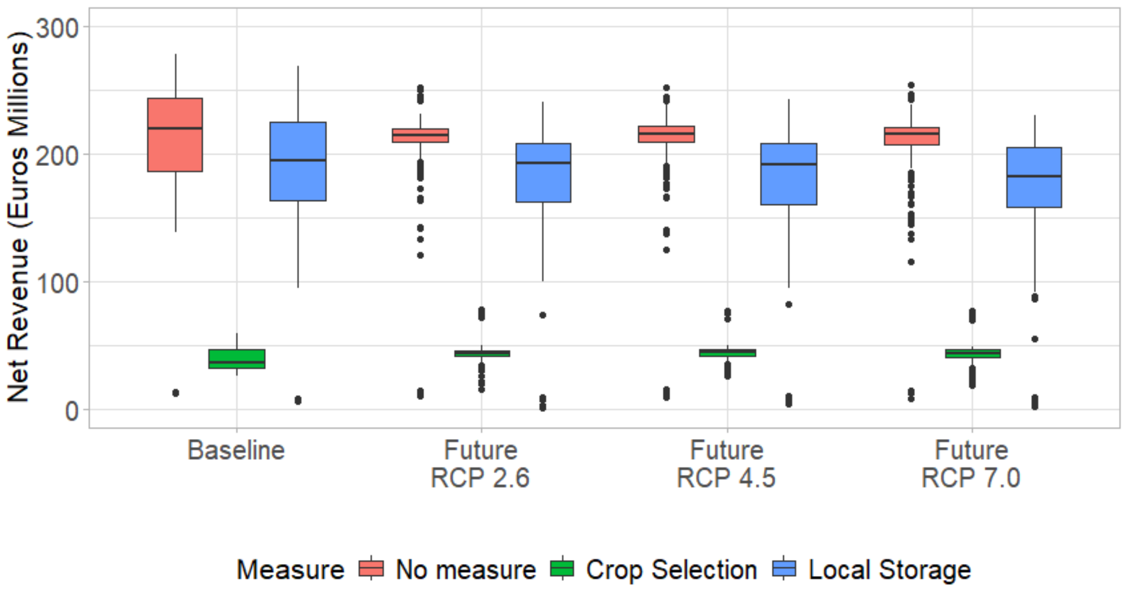

Figure C.3.1b.11: Current and future net revenues (€ millions) in the RAA under different climate and adaptation scenarios. The boxes indicate the ensemble and temporal median, 25th and 75th percentile, and the whiskers and points indicate the confidence interval around the median, and extreme values. The baseline simulations and future projections are between 2000-2014 and 2015 -2060, respectively.

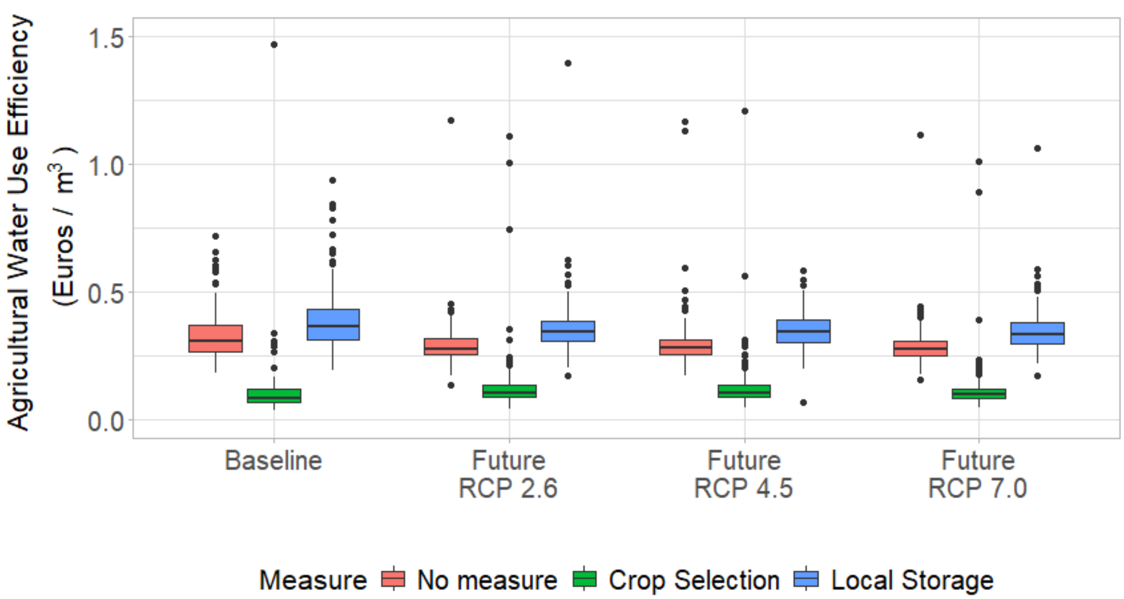

Figure C.3.1b.12: Current and future irrigation water used efficiency (€ / m^3) in the RAA under different climate and adaptation scenarios. The boxes indicate the ensemble and temporal median, 25th and 75th percentile, and the whiskers and points indicate the confidence interval around the median, and extreme values. The baseline simulations and future projections are between 2000-2014 and 2015 -2060, respectively.

The agricultural water use efficiency measures the net revenue generated by one unit of irrigation water. This metric proposes that the local storage measure uses water resources more efficiently relative to a no-adaptation option. Although there is some uncertainty regarding this gap, it is somewhat reduced across all future projections (Figure C.3.1b.12). With no adaptation, the median irrigation water use efficiency is 0.3 € m^{-3}, and it reduces to 0.27-0.28 € m^{-3}. The local storage adaptation measure results in water use efficiency of 0.36 € m^{-3}, which reduces to 0.33-0.34 € m^{-3}, and the crop selection measure shows the lowest irrigation water use efficiency of 0.08 € m^{-3}, but it increases to 0.1 € m^{-3} under climate change.

Climate change harms the riverine environment, as it increases the probability of exceeding environmental flows (Figure C.3.1b.13), a state in which river flows are lower than the flow required to maintain ecological integrity. The exceedance of the environmental flows increases mostly between July and September, peaking in August. It is much more pronounced in the midstream, which indicates the role played by irrigation and storage. The effect of the adaptation measures on the exceedance of environmental flows is more complex, showing both decreasing and increasing environmental flows exceedance associated with climate change adaptations. Both measures reduce the exceedance shares in the upstream location between July and September, primarily under RCPs 4.5 and 7.0. This segment of the Ebro receives water from the Gállego tributary, implying more releases from the Aridsa dam. However, in the midstream segment, a slight increase in the environmental flows exceedance is observed for both adaptation measures under RCP 2.6, and a slightly less increase or no change is evident under RCPs 4.5 and 7.0. Located downstream, this river segment also depends on significant return flows from less efficient flooding irrigation methods. Both adaptation measures result in reduced water withdrawals and return flows, but do not compensate for this with higher releases from the reservoirs.

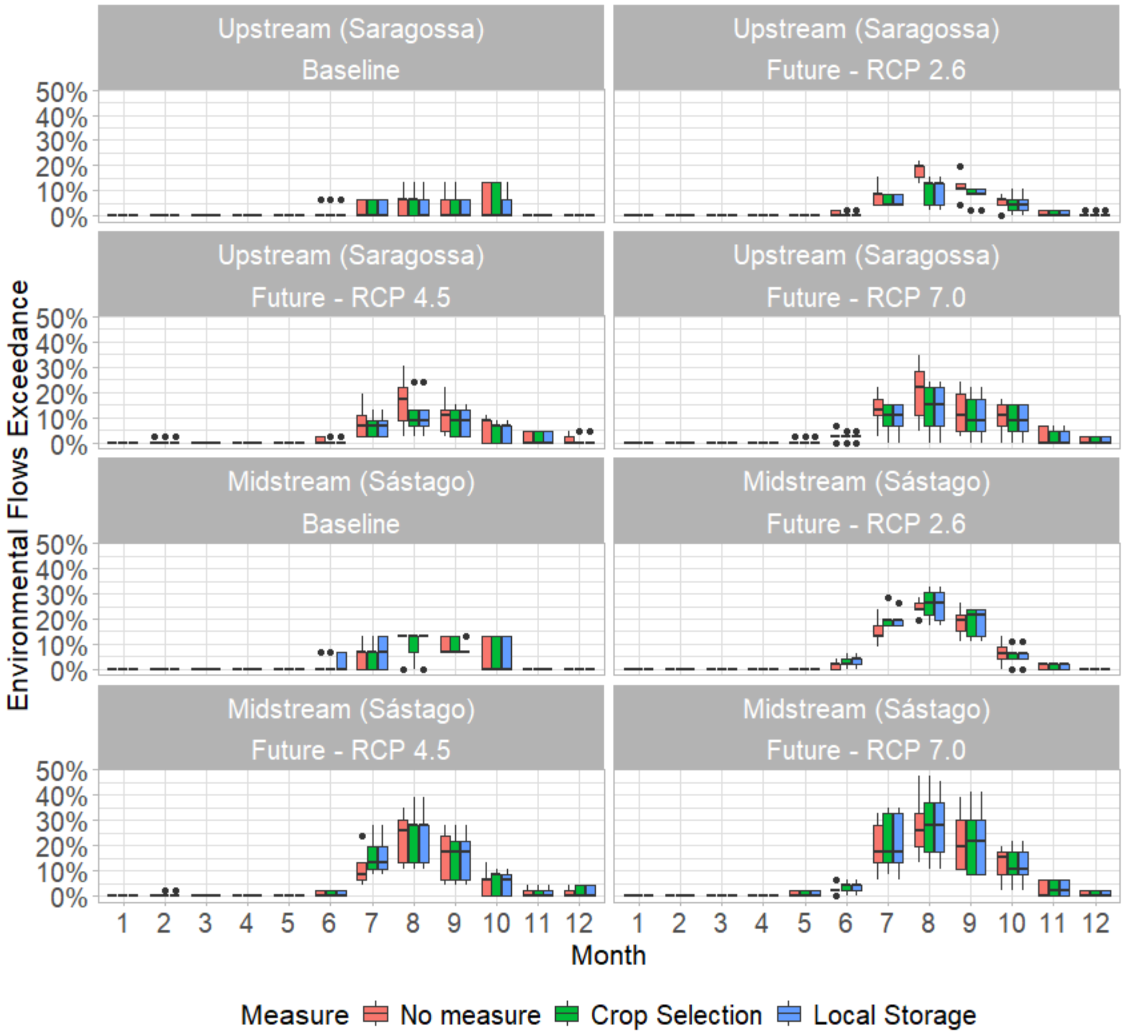

Figure C.3.1b.13: Current and future environmental flows' exceedance shares in the RAA under different climate and adaptation scenarios. An exceedance of the environmental flows is measured based on the monthly average discharge. The boxes indicate the ensemble and temporal median, 25th and 75th percentile, and the whiskers and points indicate the confidence interval around the median, and extreme values. The baseline simulations and future projections are between 2000-2014 and 2015 -2060, respectively.

CS5.2 – Stimulation of private sector adaptation through insurance arrangements

This case study makes use of the DIFI model (Hudson et al., 2019; Tesselaar et al., 2020a), which is a partial equilibrium model of supply and demand of flood insurance, which is integrated with a flood damage model that estimates flood damage over time. The DIFI model framework has three interlinked modules: (a) The risk module, which calculates the Expected Annual Damage (EAD); (b) the insurance module which uses this EAD to calculate insurance premiums for various insurance market forms; and (c) the demand module, which is used to simulate the insurance uptake by. Furthermore, the insurance module also simulates how insurance market schemes affect company-level adaptation effort and how insurance premiums can provide an incentive to implement adaptation measures.

5.1 Risk module

Flood risk is defined as the product of hazard, exposure, and vulnerability. Hazard refers to the frequency and intensity of floods, exposure denotes the presence of assets at risk in flood hazard areas and their values, and vulnerability represents the susceptibility of these exposed assets to potential losses (Botzen, 2021). In the Netherlands, two types of flood risk can be distinguished: flood risk that is deemed insurable and flood risk that is deemed non-insurable. Insurable flood risk arises from floods caused by breaches in non-primary flood defenses, which are located along small rivers or canals. In contrast, non-insurable flood risk stems from the failure of primary flood defenses, typically located along the coast or major rivers like the Rhine and Meuse.

In this paper, the risk model SSM (Slager & Wagenaar, 2017), version 2023, is used to estimate flood risk. The SSM is a model capable of calculating flood damages in the Netherlands using high-resolution inundation maps. The SSM model differentiates flood risk for seven different commercial sectors and is able to estimate flood damages for both direct damage and damages due to business interruption.

As input for SSM, LIWO inundation maps (LIWO, 2024) are used. These inundation maps have a resolution of 25m x 25m and are developed for the Netherlands only. LIWO classifies floods into four types: Type A, floods in unembanked areas; Type B, floods resulting from the failure of primary flood defenses; Type C, floods caused by the failure of secondary flood defenses; and Type D, floods originating from regional water bodies. Based on the definition of insurable and non-insurable flood risk in the Netherlands, Type A and Type B floods are considered uninsurable, while Type C and Type D floods are deemed insurable. Each flood type is associated with several inundation maps corresponding to different flood return periods (probabilities). The return periods are indicated as floods occurring once every x years and are depicted in Table C.5.2.1. The LIWO flood inundation maps are segmented per NUTS3 region. This allows SSM to estimate damages for each individual NUTS3 region, which is used to calculate risk-based insurance premiums later on.

Table C.5.2.1: Flood return periods per flood type

Flood type	Return periods
Type A	1/10, 1/100, 1/1000, 1/10000
Type B	1/100, 1/1000, 1/10000, 1/100000
Type C	1/100, 1/1000
Type D	1/10, 1/100, 1/1000

SSM internally processes exposure and vulnerability, based on Bruijn et al. (2015). To estimate flood exposure, data is derived from the BAG (PDOK, 2024), which is a registry that contains the m^2 and occupancy type of all buildings in the Netherlands. The m^2 and occupancy types of businesses are used in combination with maximum damages per m^2 derived from Bruijn et al. (2015) to estimate the exposure for each inundation map grid cell (25m x 25m) in the model. Vulnerability is operationalized via depth-damage curves that relate water depth to a percentage of the exposed asset value that is lost. The sectors for which damage is calculated correspond to the sectors included in the BAG: hospitality, healthcare, industry, office, education, sports, and retail. These seven sectors are categorized into three vulnerability curves: one for healthcare, office, and education; another for hospitality and retail; and a third for industry and sport (Slager & Wagenaar, 2017). For damages resulting from business interruption, one vulnerability function is used (Slager & Wagenaar, 2017). For each return period of each flood type, within each NUTS3 area, SSM calculates a direct damage estimate and a businesses interruption damage estimate for each aforementioned sector.

To calculate an insurance premium, the Expected Annual Damage (EAD) and volatility of damages (expressed through the standard deviation) are required. The EAD denotes the expected value of annual flood damage and is derived from a damage-probability curve. The volatility is consequently based on the standard deviation of flood damages. For each NUTS3 region, this damage probability curve is based on the estimated damage with the corresponding return period as derived from the SSM. Since the number of return periods from the LIWO inundation maps is different between the insurable and non-insurable flood types, the return periods with corresponding damages are converted into a piecewise linear system. This method allows for interpolation between return periods, resolving the issue of unequal numbers of return periods between insurable EAD and total EAD. This ensures consistent calculations for both EAD and the volatility of damages. The piecewise linear system takes the following form:

$$y(x) = \begin{cases} y_1 + \frac{(x-x_1)(y_2-y_1)}{x_2-x_1}, & \text{if } x_1 \le x < x_2 \\ y_2 + \frac{(x-x_2)(y_3-y_2)}{x_3-x_2}, & \text{if } x_2 \le x < x_3 \\ \vdots & \\ y_{n-1} + \frac{(x-x_{n-1})(y_n-y_{n-1})}{x_n-x_{n-1}}, & \text{if } x_{n-1} \le x \le x_n \end{cases}, \quad \text{for } x \in [0, \Omega] \tag{1}$$

where x_i represents the return period at which the damage y_i is observed for $i = 1, 2, \ldots, n$, y_i is the damage corresponding to return period x_i, and Ω is the largest return period. The function $y(x)$ gives the damage corresponding to the return period x, where x lies between two consecutive return periods x_i and x_{i+1}. The relationship between $y(x)$ and x is linear within each interval $[x_i, x_{i+1}]$, with the formula for $y(x)$ derived from linear interpolation between the points (x_i, y_i) and (x_{i+1}, y_{i+1}).

To estimate the EAD ($\bar{L}$) and the standard deviation (σ), the function $y(x)$ is interpolated over the interval $[0, \Omega]$ with a very small increment. This generates a dense set of return periods. The probability of no damage is defined as $1 - \Omega$. To normalize the probabilities, the interpolated return periods x_i are normalized by multiplying each return period in the interpolated interval by $\frac{\Omega}{\sum_{i=1}^{N} x_i}$. This ensures that the sum of probabilities does not exceed 1 including the probability of 0 damage. By running a Monte Carlo simulation the EAD is estimated as the expected value$^{i=1}$ of these interpolated values:

$$\bar{L} = \mathbb{E}[y(x)] = \frac{1}{N}\sum_{i=1}^{N} y(x_i), \tag{2}$$

where $\mathbb{E}[y(x)]$ denotes the expected value of the damage over the generated return periods. The standard deviation σ is calculated as the standard deviation of these observations:

$$\sigma = \sqrt{\mathbb{E}[(y(x) - \mathbb{E}[y(x)])^2]} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y(x_i) - \bar{L}\right)^2} \tag{3}$$

where $E[(y(x)-E[y(x)])^2]$ represents the expected value of the squared deviation from the EAD.
Using this system, $\bar{L}$ is estimated for both direct damage and business interruption damage for the baseline (insurable) risk (Type C, Type D) and the extended risk (Type A, Type B, Type C, Type D) for each NUTS3 region. Resulting in eight EAD types and eight σ types for each NUTS3 region (four for direct damage, four for business interruption damage).

Using the GLOFRIS model (Hessel et al., 2016; Ward et al., 2017), the average increase in EAD for the Netherlands was projected for 2050 and 2080 under the SSP2/RCP4.5 scenario. Multiplication factors derived from these projections were applied to the baseline EAD to estimate the EAD for 2050 and 2080.

5.2 Insurance module

The insurance module of the DIFI model translates the EAD and σ calculated in the risk module into insurance premiums for direct damage and insurance premiums for business interruption damage. Insurance premiums for both insurance policies are assessed separately for the current baseline insurance market system and three stylized alternative insurance market structures. The alternative insurance market structures differ in terms of their risk coverage (only flood Type CD, or flood type ABCD), and in terms of whether the reinsurance is arranged by private reinsurance companies or by a public reinsurance agent.

Insurance premium calculation

The insurance module follows a risk-layering approach, outlined by Paudel et al. (2015), in which part of the EAD is passed to the insured via a deductible and part of the EAD is passed to the reinsurer via an excess of loss reinsurance mechanism. This means that the EAD is split into three parts, indicated by D for the deductible part, P for the primary insurer share and R for the reinsurance share.

The (re)insurance industry charges a loading factor to cover the cost of providing (re)insurance and in some market forms an additional loading factor to generate a profit. The loading factors are adapted from Hudson et al. (2019) and have the following form:

$$\lambda = \begin{cases} \dot{\lambda} = C + \dot{P} & \text{if primary insurer} \\ \ddot{\lambda} = C + \ddot{P} & \text{if private reinsurer} \\ \dddot{\lambda} = C & \text{if public reinsurer} \end{cases} \tag{4}$$

Where C are the operating costs (for details on how this is determined, refer to Hudson et al. 2019), $\dot{P}$ is the profit loading factor for primary insurers which is assumed to be 0 due to Bertrand competition (Tesselaar et al., 2020a; 2020b), and $\ddot{P}$ is the profit loading factor for reinsurers which is assumed to be 0.5, reflecting the fact that there are relatively few reinsurers in the market (Hudson et al., 2019; Tesselaar et al., 2020a).

The pricing by the (re)insurance industry is influenced by a risk aversion parameter ρ. This parameter reflects the attitude of the (re)insurance industry towards high losses and acts as a surcharge on the premium. For private (re)insurers, the risk aversion is set to $\rho = 0.005$ (Kaas, 2008; Paudel et al., 2013). Because a public reinsurer is assumed to be risk neutral, the risk aversion parameter is set to $\rho = 0$ (Paudel et al., 2015). The full voluntary insurance market structure is characterised by fully voluntary uptake, risk-based premiums and risk-averse reinsurance. The premium of the full voluntary insurance market has the following form:

$$\pi_j = \frac{(1+\dot{\lambda})((\bar{L}_j * P) + (\rho * \sigma)) + (1+\ddot{\lambda})((\bar{L}_j * R) + (\rho * \sigma))}{N_j} \tag{5}$$

For NUTS3 region $_j$. Where N stands for the number of companies at risk (buildings that are located in a flood zone with a return period of at least 1/1000).
The solidarity insurance market structure is characterized by government mandated uptake and uses a flat premium structure. Therefore, the total EAD for all 40 NUTS3 regions in the Netherlands ($\bar{L} = \sum_{j=1}^{40} \bar{L_J}$) is equally distributed across all companies in the Netherlands. Consequently, the insurance premiums are fully detached from the actual flood risk. The reinsurance is arranged by private reinsurers, hence, the risk aversion factor $_\rho$ = 0.005 is applied (Kaas, 2008; Paudel et al., 2013). The premium of the solidarity insurance market has the following form:

$$\pi = \frac{(1+\dot{\lambda})((\bar{L}*P)+(\rho*\sigma))+(1+\ddot{\lambda})((\bar{L}*R)+(\rho*\sigma))}{N} \tag{6}$$

Where N stands for the total number of companies in the Netherlands. The full solidarity premium uses a flat premium structure and is therefore not subdivided into NUTS3 regions.

The Public Reinsurance voluntary insurance market follows the same principles as the full voluntary insurance market with the difference that the reinsurance is covered by a risk neutral reinsurer such as a government. Since a risk-neutral reinsurer does not include a risk aversion surcharge and a profit loading factor, the premiums in the RNRE voluntary system are lower than those in the fully voluntary system. The premium of the RNRE voluntary insurance market has the following form:

$$\pi_j = \frac{(1+\dot{\lambda})((\bar{L}_j*P)+(\rho*\sigma))+(1+\dddot{\lambda})(\bar{L}_j*R)}{N_j} \tag{7}$$

For NUTS3 region $_j$. Where N stands for the number of companies at risk in that region $_j$ (buildings that are located in a flood zone with a return period of at least 1/1000).

5.3 Uptake module

Company simulation

To simulate the uptake of insurance and the adoption of adaptation measures, an optimisation framework is used based on company data.

Data on current assets (CA), noncurrent assets (NCA), current liabilities (CL), and noncurrent liabilities (NCL) for the simulation are obtained from the Dutch Chamber of Commerce. A dataset containing deposited financial statements from fiscal year 2022 are categorized to match the 7 SSM sectors, totaling 491,742 financial statements. Judged by the Akaike Information Criterion and Bayesian Information Criterion, a lognormal distribution fits well for the current and non current assets and liabilities of all seven sectors. By definition, the log of a lognormally distributed variable is normally distributed. That is,

$$X \sim \text{Lognormal}(\mu,\sigma^2) \quad \Longleftrightarrow \quad \log X \sim N(\mu,\sigma^2)$$

This allows us to model, for each sector, the logarithms of CA, NCA, CL, and NCL jointly as a multivariate normal distribution.

By obtaining the 4 dimensional mean vector:

$$\boldsymbol{\mu}_i = \begin{bmatrix} \mathbb{E}\left[\ln(\mathrm{CA}_i)\right] \\ \mathbb{E}\left[\ln(\mathrm{NCA}_i)\right] \\ \mathbb{E}\left[\ln(\mathrm{CL}_i)\right] \\ \mathbb{E}\left[\ln(\mathrm{NCL}_i)\right] \end{bmatrix} \tag{8}$$

and covariance matrix:

$$\boldsymbol{\Sigma}_i = \begin{bmatrix} \mathrm{Var}[\ln(\mathrm{CA}_i)] & \mathrm{Cov}[\ln(\mathrm{CA}_i), \ln(\mathrm{NCA}_i)] & \cdots & \mathrm{Cov}[\ln(\mathrm{CA}_i), \ln(\mathrm{NCL}_i)] \\ \mathrm{Cov}[\ln(\mathrm{NCA}_i), \ln(\mathrm{CA}_i)] & \mathrm{Var}[\ln(\mathrm{NCA}_i)] & \cdots & \mathrm{Cov}[\ln(\mathrm{NCA}_i), \ln(\mathrm{NCL}_i)] \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{Cov}[\ln(\mathrm{NCL}_i), \ln(\mathrm{CA}_i)] & \mathrm{Cov}[\ln(\mathrm{NCL}_i), \ln(\mathrm{NCA}_i)] & \cdots & \mathrm{Var}[\ln(\mathrm{NCL}_i)] \end{bmatrix} \tag{9}$$

It becomes possible to estimate the multivariate normal distribution $N(\mu, \Sigma)$ for each sector i. This multivariate normal distribution can be used to simulate synthetic companies that each have a distinct balance sheet.

For each NUTS3 region, 10,000 companies are simulated, taking the actual sector composition of the NUTS3 region based on the BAG-registry into account. This generates a representative sample for each NUTS3 region without the need of location specific balance sheets. The resulting sample can then be used to analyze and draw conclusions about the behavior of companies within that region.

Furthermore, each business needs a building size in order for the costs of adaptation investment, premiums, and EAD to be scaled to the building size of the business.

The BAG-registry was used to obtain building sizes for each sector in the insurable 1/1000 floodplain. The building sizes in each sector follow a lognormal distribution. Using the parameters of these lognormal distributions and the percentage of each sector being present in a region, random sizes can be drawn. Next, the drawn building sizes are assigned to companies with controlled randomness, using the previously simulated balance sheet data. For each sector a fixed pool of n building sizes is drawn from the sector's log-normal distribution and sorted in ascending order. Next, the firms of the corresponding sector based on their noncurrent assets normalized to a $[0, 1]$ scale. Independent random ranks are also generated uniformly for each firm. Combining the noncurrent assets rank and the random rank, a blended rank is computed using:

$$r\text{blended} = w \cdot r\text{assets} + (1 - w) \cdot r\text{random} \tag{10}$$

Where $w = 0.6$ controls the influence of asset size ($w = 0$ meaning the sizes are assigned completely random, $w = 1$ meaning the sizes are perfectly correlated with the noncurrent asset size). Building sizes are assigned based on the blended ranks: the lowest rank receives the smallest building size from the pool, and so on in ascending order. This hybrid approach ensures that larger firms (by noncurrent asset value) are more likely to own a larger building, while still allowing for natural variability. The blending parameter w allows for sensitivity analysis, adjusting the weight given to deterministic versus random influences.

Uptake simulation

Each simulated company evaluates four possible actions: purchasing insurance, investing in flood risk reduction measures, doing both, or taking no action. The decisions are based on the company specific EAD, premium, and investment cost. As the true risk is often misperceived (Hudson et al., 2019; Tesselaar et al., 2020a; Ooms et al., 2024), the actual benefit of each measure is assumed to be misperceived. The framework uses three separate misperception distributions: one influencing the decision to invest in adaptation measures (i.e. the perceived risk and risk reduction from adaptation), and two others governing the insurance decision, conditional on the adaptation choice (i.e. the perceived risk and risk reduction from insurance after having implemented adaptation measures or not taking these measures). For each simulated company, a value is drawn from each of these distributions. The three distributions are modeled as gamma distributions and calibrated using survey data collected among companies in areas of the Netherlands affected by the 2021 flooding (Endendijk et al., 2024; Ooms et al., 2024). This dataset is useful because it contains information on the share of businesses that (1) took adaptation measures, (2) purchased flood insurance, (3) did both, or (4) did neither. The gamma distribution was chosen because it is strictly non-negative and flexible in shape, making it suitable for modeling misperception factors. The calibration was carried out using the differential evolution algorithm.

Furthermore, affordability is taken into account by measuring the level of financial health of each simulated company in combination with the ratio of the premium to current assets. The level of financial health is measured based on threshold levels on three financial ratios, which can be calculated based on the simulated balance sheets. It is first checked whether the current ratio is lower than one, indicating a low liquidity level. Next it is checked whether the working capital is negative, indicating a low liquidity level. As the third ratio it is checked whether the debt to equity ratio is larger than 2, indicating high leverage. If all three of the ratios exceed their thresholds, the company is assumed to be financially unstable and can therefore not afford the insurance premium or adaption investment. If one of the ratios is favourable, the company is either liquid enough to invest or solvent enough to borrow for investment. Furthermore, the premium and the investment costs cannot exceed the current assets.

After the initial affordability check, the decision framework has three stages:

Initial adaptation decision

$$\text{Subjective benefit adaptation - cost adaptation} = \sum_{t=1}^{25} \frac{\left((1-\epsilon)*\bar{L}\right)*X_1}{(1+r)^t} - I$$

Where X_1 denotes the adaptation misperception factor $X_1 \sim \text{Gamma}(\alpha_1, \theta_1)$, $\bar{L}$ denotes the EAD, I denotes the adaptation investment cost, r denotes the discount rate, ϵ indicates the adaptation effectiveness If the subjective benefit minus the cost of adaptation is greater than 0, the company chooses for invest in adaptation measures. The adaptation measure is assumed to cost €37 per square meter. This figure is based on cost data reported by Aerts et al. (2013) and Kreibich et al. (2015), and building size data from Federal Emergency Management Agency (2022). The costs of dry-proofing, wet-proofing, and their combination are averaged to calculate a single flood adaptation cost per square meter. Furthermore, given that businesses often have a larger building size than households and flood adaptation often includes fixed costs, economies of scale are incorporated into the adaptation investment cost. This is modelled using the following equation:

$$= 37 * \text{size}^{0.8}$$

Where $size$ refers to the building size. Moreover, the adaptation measure is assumed to have a lifetime of 25 years (Keeting et al., 2015; Aerts, 2018). Therefore, the costs and benefits of stage one and three are discounted over this period. Following Aerts et al. (2013) and Kreibich et al. (2015), the adaptation effectiveness is set at 0.65, meaning that the EAD gets reduced by 35% if an adaptation measure is present.

Insurance purchase decision

If chosen no adaptation in stage 1:

$$\text{Subjective benefit insurance} = \left((1-D)*\bar{L}\right)*X_2$$

$$\text{Cost insurance} = \pi$$

If chosen adaptation in stage 1:

Subjective benefit insurance = $\left((1-D)*(\epsilon*\bar{L})\right)*X_3$

Cost insurance = π

Where D denotes the deductible, ϵ denotes the fraction of the EAD that is left after the adaptation measure, $X2$ and $X3$ denote the insurance benefit misperception factor given adaptation and given no adaptation respectively $X_2 \sim \text{Gamma}(\alpha_2, \theta_2)$ and $X_3 \sim \text{Gamma}(\alpha_3, \theta_3)$, and π denotes the insurance premium. If the subjective benefit minus the premium cost is greater than 0, the company chooses to purchase an insurance policy.

Subsequent adaptation decision

If chosen no adaptation in stage 1 and if chosen insurance in stage 2:

Subjective benefit adaptation = $\sum_{t=1}^{25} \frac{((1-\epsilon)*(D*\bar{L})*X_1)+((1-\iota)*\pi}{(1+r)^t}$

Cost adaptation = I

If chosen adaptation in stage 1 and/or chosen no insurance in stage 2, stage 3 does not take place.
Stage 3 assesses the effect of an insurance incentive on the investment in adaptation measures. The purpose of this incentive is to encourage investment in such measures by offering a discount on the insurance premium if such investments are made. This premium discount is set to match the assumed effectiveness of the adaptation measure, thereby aligning the financial benefit with the expected risk reduction.

Insurance is assumed to be a yearly decision, hence, stage two considers a single period.

CS7.3 – Cross-sectoral economic analysis for adaptation

The annex to this case study is included separately as PDF file (AnnexC_7.3.pdf). The annex to this case study is included separately as PDF file (AnnexC_7.3.pdf). The table shows the individual measures per sector, their estimated costs, and whether they are currently budgeted for. The codes in the first column correspond to the different sectors identified in CS7.3, on page 160.

Annex D: Frameworks

This annex includes the complete PowerPoint frameworks for each case study. This annex is provided in a separate document as PDF file (AnnexD_Frameworks.pdf).

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
AGRI 1n	Ensure that the next Cyprus CAP strategic plans make most out of the EU programs to adapt the sector to climate change	Make the sector more resistant to climate change	High	*Very vague description; difficult to understand the breadth and scope of these measures. For the time being, we include measure A.A. 4.1.2 of the strategic CAP document, of €5 million, related to "Investments that contribute to environmental protection, climate resilience and animal welfare"*	5000	5000	Yes - the 5 million
AGRI 2n	Develop pilot projects on the use of desalinated water for irrigation with photovoltaic energy	Provide water to the sector from sustainable desalination	High	*Unknown if this is realistic, now that the Ministry of Agriculture is planning several new conventional desalination units.*			No
AGRI 3n	Encourage communities to adopt sound land management practices and change the use of soil, cultivation methods and varieties	Make agriculture more resilient	Low	*The national plan states that the cost is low because most of the measures have already been implemented.*	50	100	No
AGRI 4	Develop infrastructure that will facilitate the use of recycled water in agriculture and incentivize its use by farmers	Addressing the shortfall in water supply for irrigation purposes	High	*CAP strategic plan measure A.A. 4.5.1*	10000	10000	Yes
AGRI 5	Identify and promote the use of indigenous and other genetic material (plant and animal) adapted to the soil-climatic conditions that will be brought about by climate change	Addressing abiotic stresses (drought and high temperatures) and strengthening the resilience of agriculture and livestock to climate change	Low		50	100	No
AGRI 6	Improve efficiency in the use of water for irrigation by implementing rational irrigation planning, adopting more advanced irrigation systems and adequately maintaining existing systems	Addressing the shortfall in water supply for irrigation purposes	Medium		500	1000	Yes
AGRI 7	Promote research to study the effects of climate change on agriculture and livestock.	Addressing changes in crop yield and livestock farming	Medium		500	1000	Partly
AGRI 8	Development / improvement of early warning systems of extreme weather phenomena for agriculture	Increase of protection measures taken by farmers whose decision is based on timely and valid information on extreme weather events	High		1000	3000	No
AGRI 9	Provide site-specific advice and training on crop adaptation to climate change and create a forum for information exchange between the administration and agricultural professions	Upgrading the level and strengthening of the network of agricultural advice and training for adaptation of crops to climate change	Low		50	100	Partly

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
BIODIV 1	Create a database on the biodiversity of Cyprus with an emphasis on endemic, rare and vulnerable species and habitats	The purpose of this measure is to update and improve the current situation in Cyprus regarding biodiversity and trends of species and habitats and the effects of climate change to take the necessary adaptation measures for their conservation in a timely manner.	High	*"The database is currently under development in the framework of LIFE IP Physis "*	2000	3000	Yes
BIODIV 2n	Identify and develop contractual, regulatory and financial tools to enhance land use practices compatible with biodiversity conservation in the context of climate change adaptation	Create and maintain biodiversity-friendly habitats through working partnerships with private landowners.	High	*€1.305.000 according to CAP measure A.A. 4.3.3; € 302.700 + 1.200.000 + 1.020.000 + 13.440 according to CAP measures A.A. 1.3. Also, "Some first steps are underway through LIFE IP Physis (e.g. actions A.3, C.6, C.11). "*	4000	8000	Partly
BIODIV 3	Promote studies on the expected effects of climate change on Cyprus' flora, fauna and geological heritage, as well as on the structure and functioning of the terrestrial and marine ecosystems of which they form part.	Recording of all impacts on biodiversity & ecosystem services.	Medium - High	*"Measure is being implemented as part of Cyprus current NAS"*	1000	3000	Partly
BIODIV 4n	Improve water quality, preserve aquatic ecosystems and integrate water ecosystem resilience into public policies and sectoral plans	Fully implement the objectives of the WFD.	Medium	*"Measures are designed and partially being implemented"*	500	1000	Partly
BIODIV 5	Protection, conservation and proper management of the important natural wetlands of Cyprus	Addressing the risk of degradation of water-dependent ecosystems, due to reduced soil moisture and drying, drought episodes, reduced water quantity and increased demand of society in water, but also due to other projects, such as tourist facilities and activities, urbanization and related infrastructure (e.g. road network).	Medium		500	1000	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
BIODIV 6n	Preserve, restore and strengthen hydrogeomorphological and ecological continuities of river ecosystems	Restore hydro geomorphological continuity of river ecosystems	Medium - High		1000	3000	No
BIODIV 7	Action plans to protect species and their habitats threatened by climate change	Habitat and species protection considering the negative effects of climate change	Medium	*"Action Plans are being prepared for habitats and Species within the LIFE – IP Physis project. CCA is not being sufficiently considered in these plan".*	500	1000	No
BIODIV 8	Analysis of the vulnerability of ecosystems (structure and functions) and their services to climate change, with an emphasis on protected areas and the Natura 2000 Network	Protection at the level of ecosystems (habitats and species) and their functions, considering the negative effects of climate change	Medium		500	1000	No
BIODIV 9	Addressing the risk of invasive and alien species	Addressing increased risks from invasive alien species	High	*"It is an ongoing activity, things are being done, but there is room for improvement."*	2000	5000	Partly
BIODIV 10n	Promote the introduction of climate change adaptation criteria in the planning and management of protected areas	Promotion of adaptive planning and management of protected areas	Medium	*"Not much is being done in this area, but there is an acknowledgement that it is critical."*	500	1000	No
CULT 1n	Identify the elements of country's cultural heritage that are most vulnerable to climate change and define possible adaptation strategies	Gain a deeper, more localized understanding of the impacts of climate change to cultural heritage. Identify the elements of Cyprus' cultural heritage most vulnerable to climate change and identify adaptation strategies.	High		1000	3000	No
CULT 2n	Prioritize maintenance work on cultural heritage over restoration work	Ensure the conservation of cultural heritage in the context of climate change	Medium	*We assume higher than medium costs because periodic maintenance costs will be non-negligible.*	1000	3000	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
CULT 3n	Support reassessment and adjustments in all stages of heritage practice including inventorying, documentation and monitoring, impact assessments, conservation and management planning	Integrate the impacts of climate change into cultural heritage management plans and cultural heritage preservation actions and ensure that cultural heritage safeguarding plans are adapted to foreseeable climatic hazards.	Medium		500	1000	No
CULT 4n	Train professionals involved in the study and conservation of cultural assets to incorporate the climate change dimension into their professional activity	Enhance the incorporation of climate change considerations into cultural heritage conservation work.	Low		50	100	No
CULT 5n	Collect and transfer vernacular knowledge useful for climate change adaptation	Recognizing, collecting and enhancing the value of traditional vernacular knowledge useful for climate change adaptation.	Medium		200	500	No
CULT 6n	Develop climate change adaptation plans in heritage cities through the "green heritage" approach, which uses nature-based solutions that consider the specific requirements for the conservation of cultural heritage	Contribute to climate change adaptation in heritage cities using the "green heritage" approach: introducing nature-based solutions that take into consideration specific requirements of heritage buildings, streets, and public uses.	High		5000	10000	No
CULT 7n	Build synergies with other national policies and sectors to enhance the effective protection of cultural heritage and goods	Achieve coherence with other national policies by building synergies between the heritage sector and other sectors such as environment, urban and disaster risk management.	Low		50	100	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
CULT 8n	Encourage international cooperation in knowledge transfer to protect cultural and architectural heritage in the face of climate change	Enhance cooperation and exchanges of information and experiences for conservation of cultural heritage in the context of climate change.	Medium	*"Cyprus is already an active member in regional and international initiatives regarding cultural heritage protection in the face of climate change risks." "The EU promotes synergies with Europa Nostra for climate action and a Europa Nostra Hub has recently been established in Cyprus that may also facilitate such activities."*	500	1000	Yes
DRM 1n	Development and regular update of (wildfire/storm/heat) hazard maps	Strengthen the knowledge base on regional and local sensitivity regarding different risk typologies	Medium	*Coordination is probably what is needed for this measure. "The Forest Department, based on Vegetation maps has Fire Risk Maps. WDD has Flood Risk Maps, The Fire Service has archives of all incidents that was involved, from which Hot spot areas per risk can be retrieved. Local Authorities have knowledge of where Illegal dumping sites exist, which are a major source of wildfires, etc."*	300	1000	No
DRM 2n	Review Cyprus' national DRM and civil protection system with updated climate change projections and scenarios	Incorporate the latest knowledge on climate related risks into DRM and civil protection policies and plans	Medium	*To be based on a study of DG Reform*	300	1000	No
DRM 3n	Secure financial resources for adapting essential networks and critical infrastructure providing basic services (e.g. electricity, water, health) from climate-related disasters, emphasizing on alternative solutions (e.g. nature-based solutions)	Ensure financial resources are available for climate-risk proofing critical infrastructures	Medium	*To be based on a study of DG Reform*	300	1000	No
DRM 4n	Support and reinforce disaster risk preparedness: Observation, early warning, communication and education with climate change adaptation criteria	Instruments related to disaster risk preparedness (observation, early warning, communication and education) incorporate climate risks and response.	High	*There seem to be various data collection and early warning mechanisms in the government, which would need to be upgraded.*	2000	5000	Partly

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
DRM 5n	Encourage the consideration of risk analyses associated with climate change in the study, analysis and definition of self-protection measures and promote self-protection for the different disaster risks related to climate change	Promote the consideration of climate projections in the study, analysis and definition of self-protection measures and the promotion of their development for the different disaster risks related to climate change.	Medium		300	800	No
DRM 6n	Review post-disaster recovery action plans to incorporate climate change adaptation considerations	Incorporate climate change adaptation into recovery actions aimed at restoring normality to the affected area after the immediate response to the emergency has been completed	Medium		300	1000	No
DRM 7n	Apply the *Pluvial Hazard, Risk Assessment and Adaptation Tool* to assess pluvial flood risk hotspots and prioritize areas for adaptation solutions	Provide a quick assessment of pluvial flood risk hotspots and support the prioritization of areas for adaptation solutions, focused on nature-based approaches.	Low		50	100	No
ECON 1n	Conduct specific sectoral foresight studies to identify vulnerabilities of Cyprus' industry to climate change, develop sectoral adaptation strategies and revise Cyprus' 2019-2030 Industrial Policy accordingly	Improve knowledge of adaptation needs of climate-vulnerable industrial sectors and develop appropriate adaptation strategies.	Medium		200	500	No
ECON 2n	Develop a framework for projects and investments assessment that include climate vulnerability evaluation criteria to help inform investment decisions and redirect investments when necessary	Avoid investments whose profitability would be significantly reduced due to climate change and redirect investments.	Low		50	100	No
ECON 3n	Promote the use of the DERRIS climate risk self-assessment tool for Small and Medium Enterprises (SME) to Increase the climate risk awareness of local SMEs	Increase the climate risk awareness of local SMEs. Encourage the private and public sector/business entities to adapt to climate change.	Low		50	100	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
ECON 4n	Promote frameworks for collaboration and coordination on adaptation among the different agents involved in the financial system, with special attention to insurance activity, and strengthen adaptation capacities in the sector.	Mobilise all actors involved in the financial system, especially in the insurance business to develop frameworks for collaboration and coordination on climate change adaptation between public institutions, private entities, academic institutions and other key agents to promote, among other things, the exchange of information and knowledge.	Low		50	100	No
ECON 5n	Capacity building on adaptation in the financial system and insurance business	Promote the generation of knowledge and capacities on the impacts of climate change on the financial system and insurance activities, as well as on the identification of opportunities to contribute to climate change adaptation	Medium	*Considered to be primarily a private intiative.*	100	400	No
EDU 1n	Integrate climate change adaptation into the revised curricula of Education for Sustainable Development and formal education curricula at all educational levels	Raise awareness among young people about climate change and enhance their capacity to act through the integration of climate change adaptation into the revised curricula of Education for Sustainable Development at all educational levels.	Low	*"Initiatives are under way"*	50	100	Yes

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
EDU 2n	Provide non-formal education programs for climate change adaptation	Utilize the Governmental Network of Environmental Education Centres to provide specialized programs on climate change adaptation and education for sustainable development for students, educators, professionals, and the wider civil society,	Low		50	100	No
EDU 3n	Update professional education and training programs for teachers and education staff taking into consideration the content of the revised National Adaptation Strategy	Expand and strengthen professional education and training programs for teachers and education staff on teaching and learning approaches that connect climate change with the social, environmental, economic, political, and cultural dimensions of sustainability	Low		50	100	No
EDU 4n	Produce educational and informational material on climate change adaptation	Increase awareness by improving access to educational and informational materials on climate change adaptation by generating materials available online	Low		50	100	No
EDU 5n	Strengthen the climate resilience of educational institutions through targeted actions and programs to adapt infrastructure and school environments to new climate conditions	Reduce the vulnerability of educational infrastructures to new climate conditions	High	*Existing budget: €20 million for energy renovations in public schools (funded by the European Regional Development Fund) + €21 million for the new Technical Scool (funded by the Just Transition Fund). Maximum budget is a very rough estimate, assuming that a large fraction of the existing school buildigns will undergo energy renovations and creation of green spaces.*	41000	150000	Partly

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
EDU 6n	Strengthen and leverage international collaboration networks related to climate and environmental education	Formation of the international policies and regional policies by infusing also Cyprus policies and priorities in the field and exchange of good practices and expertise with other countries and regions enabling the implementation of national policies more effectively	Low		50	100	No
ENER 1n	Improve knowledge on the (potential) impacts of climate change (including extreme events) on: (i) the production potential of renewable energies and translate the results into energy planning; (ii) the functionality and resilience of energy generation, transmission, storage and distribution systems; (iii) energy demand and develop a strategy to avoid or limit spikes in demand, especially those associated with heat	Improve knowledge on the (potential) impacts of climate change on the energy sector and incorporate results into energy planning to increase resilience of the sector and avoid or limit spikes in demand.	Medium		100	500	No
ENER 2n	"Energy efficiency – Upgrade Homes" program	Incorporate the latest knowledge in updates of long-term climate change adaptation strategies, protect buildings from extreme temperatures and relevant material deterioration and apply adequate funding mechanisms	High	*Here we consider only potential additional costs, beyond those already foreseen for energy renovations of buildings.*	10000	20000	No
ENER 3	Good maintenance and possible upgrade of electricity transmission lines to account for climate adaptation. Promoting smart networks with the aim of minimizing losses in the transport system.	Management related to transmission line overheating and adapt existing transport system to identified climate risks.	High		5000	20000	

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
ENER 4	Increase Cyprus energy security by increasing interconnection with international energy transmission networks	Interconnection of Cyprus with the Trans-European energy, electricity and gas networks as defined by European regulation 347/13. CSR contributes to: diversification of the country's energy mix; eliminate energy isolation; energy security; completion of the internal energy market.	High	*This is only indirectly an adaptation measure. We will not consider it further.*			
ENER 5n	Promote new renewable energy technologies that are robust under changing climatic conditions incorporating waste to energy technologies	Enhance the energy sector's sustainability, ensure energy security, and support the transition toward a low-carbon economy (i.e., limit fossil fuel use and dependency) while adapting to climate change impacts such as extreme temperatures, fluctuating weather patterns, and water scarcity and contribute to improving the management of organic waste.	High	*This is only indirectly an adaptation measure and involves the update of an existing funding scheme. We will not consider it further.*			
FISH 1	Protection of breeding habitats	Secure the sustainable production of fish	High	*"Even though a lot has been or is being implemented, as there is always room for improvement, or adapt to new changes."*	1000	3000	Partly
FISH 2n	Improve enforcement of fishing legislation and monitor fishing activity	Secure sustainable fisheries by controlling the activity of professional and recreational fisheries.	Medium		200	1000	No
FISH 3n	Strengthen adaptation to climate change in the Common Fisheries Policy (CFP), national management and recovery plans and the aquaculture sector	Strengthen adaptation to climate change in Cyprus national fisheries policy in line with the revised CFP	Medium		300	1000	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
FISH 4n	Value Chain Development	Secure and increase the added value of local fisheries and aquaculture product while ensuring social, ecological, and economic sustainability.	Medium		200	500	No
FISH 5n	Promote fishing and consumption of invasive alien species	Control invasive fish species and protect marine biodiversity	Medium	*"This is being done at the moment for certain IAS fish and should be continued with additional funds."*	300	1000	Partly
FOR 1n	Competent authorities aim to support forestry through tourism tax and stakeholder networks to develop sustainable tourist offers	Generate a funding mechanism	Medium	*It is unknown if such a measure is considered appropriate by the government. It will probably be rejected by the Ministry of Finance. "Ministry of Finance does not allow to establish Special Local Taxation Systems with local management units to manage the collection of this tax."*			No
FOR 2n	Increase firefighting staff in the Department of Forests	Reduce the impacts of forest fires	Medium	*Additional due to climate change*	300	1000	Partly
FOR 3	Coping with increased forest fire risk	Reduce the risk of forest fires occurring and spreading. Protect important forest ecosystems and their dependent species of flora and fauna.	High	*€3.045.000 are foreseen for forest fire prevention and restoration in measure A.A. 4.3.2 of the Strategic CAP document. This is not necessarily related to adaptation.*	10000	20000	Partly
FOR 4n	Integrate fire risk into regional planning and harness the potential of nature-based solutions in a context of climate change adaptation	Contribute to reducing the risk of fires and increasing resilience to this risk, as fires have a very negative effect on the carbon balance of forests and the resilience of ecosystems	Medium		200	500	No
FOR 5n	Model fire-climate relationships to identify areas sensitive to forest fire risk	Reduce the risks of forest fires and their impacts.	Low		50	100	No
FOR 6n	Promote the recultivation of abandoned agricultural land	Reduce forest fire risk in abandoned agricultural lands	Low	*It might include measure A.A. 4.3.4 of the strategic CAP document related to Afforestation, with a budget of €650.000, plus measure A.A. 1.9 for the maintenance of afforested areas (€296.000)*	1000	2000	Partly
FOR 7	Develop and implement a Strategic Plan for the adaptation of Cyprus' forests to climate change	Adaptation of forest ecosystems to climate change	High	*Plan "to be developed". Its financing is stated to be "Ongoing under the Department's annual budget"*	1000	3000	Partly

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
FOR 8	Research, data collection and systematic monitoring of the effects of biotic and abiotic factors related to climate change in forests/ selection and use of suitable forest species with high resistance to adverse climatic conditions (e.g., drought)	Address the increased risk of drought damage/forest productivity decline and improve knowledge on the impact of climate change on forests	High	*It seems to be "ongoing" but with "low" financing*	1000	3000	Partly
FOR 9	Pest population monitoring for early detection of potential pest and disease epidemics	Addressing the increased risk of pest infestations, insect pathogens (diseases), etc. endemic to the forests of Cyprus or belonging to the category of quarantine organisms.	High	*Additional due to climate change*	1000	3000	No
FOR 10n	Develop forest management plans and strategies for Cyprus that take into account climate change adaptation to ensure the continued provision of ecosystem goods and services and the improvement of forest resources	Better and more holistic forest management	High	*To be based on a Technical Support study funded by DG Reform. Part of it is included in Strategic CAP document measure A.4.3.3 with a budget of €1.305.000, already included in measure BIODIV 2n*	1000	3000	Partly
GOV 1n	Expand and update knowledge on the impacts and risk of climate change on the different sectors (update CRV)	Generate updated information to assess the impacts and risks of climate change on the different sectors according to the latest available climate models and scenarios.	Low		50	100	No
GOV 2n	Training and capacity building on adaptation to climate change	Improve understanding of the implications and impacts related to climate change to enhance the implementation of climate adaptation actions at the regional and local level, and the resilience of individuals and communities to climate change risks.	Low		50	100	No
GOV 3n	Communication and social outreach on climate change adaptation	Increase the general understanding of the implications and impacts related to climate change	Low		50	100	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
GOV 4n	Promote the development of regional and local climate adaptation plans in coordination with the National Adaptation Strategy	Promote DLGO and municipalities implement climate change adaptation measures within their respective areas of competence that are aligned with and contribute to Cyprus' National Adaptation Strategy goals	Low		50	100	No
GOV 5n	Develop an IT monitoring and reporting system for climate change adaptation	Facilitate monitoring and evaluation of implementation of the National Adaptation Strategy	Low		50	100	No
GOV 6n	Create an Intergovernmental Working Group on Adaptation to Climate Change and designate focal points for adaptation in competent ministries, District Local Government Organizations and municipal representatives	Strengthen the consideration of climate change in all ministries and competent authorities and ensure a coordinated and effective implementation of the National Adaptation Strategy	Low		50	100	No
GOV 7n	Develop legislation for mandatory reporting requirements of public administrations on implementation of adaptation measures	Facilitate the collection the information regarding the implementation of the National Adaptation Strategy to inform the Biennial Progress Reports to be shared with the Council of Ministers, the Intergovernmental Working Group on Adaptation to Climate Change, and the public on MARDE's website.	Low		50	100	No
HEAL 1n	Identify the risks of climate change on human health and develop the most effective adaptation measures by integrating climate change into national health plans.	Reducing the health risks posed by climate change	Medium		200	500	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
HEAL 2n	Improve the governance of heat waves to reduce their impacts on human health	Act upon state-of-the-art heat-health action plans fed by scientifically sound data monitoring and evaluation and monitor compliance with existing safety legislation.	Medium		200	500	No
HEAL 3	Operation of community centres in each municipality/community (e.g., town halls, schools, Open Elderly Protection Centres, etc.) to provide protection (air conditioning, shade, fluids) to the population at risk	Climate change impact management on mortality and morbidity	Medium	*The national adaptation report estimates this as a low-cost measure but we believe the costs will be higher.*	300	1000	No
HEAL 4	Empower and prepare medical/nursing and municipal staff to deal with climate change emergencies and serve an increased number of patients/incidents related to climate change	Manage impacts of climate change in relation to mortality and morbidity.	Low		50	100	No
HEAL 5n	Develop a national strategy to prevent the health risks from vector-borne and non-vector-borne infectious and parasitic diseases favoured by climate change	Prevent the health risks from vector-borne and non-vector-borne infectious and parasitic diseases favoured by climate change and have the best available knowledge at hand to appropriately react to emerging health risks if required	High		1000	2000	No
HEAL 6	Establish an effective multilevel governance system that identifies a lead agency, defines clear roles and responsibilities of the various health and social care services, and facilitates intersectoral and intergovernmental coordination to manage climate change impacts on public health	Improve the health care system response to climate related health-risks, improve the flow of information and enhance capacities of competent authorities and communities to respond to climate-related health risks	Medium		500	1000	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
WAT 1	Periodic reviews of progress and priorities of water policies and plans, and adaptation of objectives, instruments and resources, considering climate change.	Integrate climate change adaptation into water policy and planning - RBMPs, FMPs, DMPs - giving special priority to the management of extreme events (droughts and floods).	Medium - High	*"There are a lot of measures but there is always room for improvement. Partly covered by the 6-year periodic reviews of the WFD-RBMP and the FRMP. Climate change is considered in these reviews."*	500	1000	Partly
WAT 2	Improve, upgrade, modernize and repair the water supply and distribution networks and related infrastructure to reduce water losses	Water savings to address water scarcity / high water costs due to increased demand for desalination / energy from water suppliers	High	*"WDD's Infrastructure is well maintained. Now probably this has been transferred to Local and Regional Authority. This measure is considered of high priority; however, its implementation depends on the availability of human and financial resources." These projects are already included in the national Investment Plan of Water Works, therefore we do not consider them as strictly adaptation measures.*			No
WAT 3	National Investment Plan for Water Works considers the revised National Adaptation Strategy and addresses the identified strategic and specific objectives	The targeted allocation of resources for the implementation of infrastructure projects for water protection and the sustainable satisfaction of water needs taking into consideration climate change adaptation.	High	*The cost has been estimated at 1.17 billion Euros - see "Εθνικό Επενδυτικό Πλάνο Υδατικών Έργων" of September 2024. But this involves all measures related to water works, regardless of climate change adaptation or not.*			Yes
WAT 4	Create an early leak detention tool and a digital platform (app) to inform consumers about their consumption, submit applications and pay bills.	Early detection of leaks in domestic water supply systems. Behavioural change of consumers in relation to water protection, resulting in water savings. Consumer facilitation. Upgrading of services. Increased reliability of the water supply operator.	High	*This is largely implemented in some or all cities through RRP / Cohesion Fund investments, and are included in WDD's National Investment Plan of Water Works. We do not consider them to be adaptation measures.*			Partly
WAT 5	Expand the use of water meters	Supply deficit of irrigation. Improve monitoring of consumption patterns and reduce overall water use.	Low	*No cost assessment is provided in the national adaptation report. It is stated that costs will be borne by consumers."It has been implemented to a significant extent in some regions."*			Yes

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
WAT 6	Implementation and regular reviews of the Drought Management Plan (DMP) incorporating information on climate change impacts on water resources and integrate contingent drought risk management into water planning and management	Implementation and regular revisions of Drought Management Plan	Medium - High	*The national adaptation report mentions that costs will depend on the measures to be included in the DMP.*	800	5000	Partly
WAT 7n	Improve application of the polluter pays principle to improve water quality	Reduce pollution and improve water quality	Medium		200	500	Yes
WAT 8	Reuse of treated urban wastewater after strict control of its suitability; and provide incentive schemes for sectoral uptake of water reuse (farming, livestock, other uses)	Reuse of treated urban wastewater with strict control of their suitability in compliance with existing regulations	High	*How does this relate to measures AGRI 4 and WAT 3? This is probably included in other measures.*			
WAT 9n	Protect groundwater resources from pollution and overuse and promote the reduction of groundwater abstractions where sustainability limits are exceeded	Improve status of groundwater bodies	Medium		500	1000	No
WAT 10n	Reduce flood risks through river ecosystem restoration and rewilding in rural and urban areas	Adapt planning practices so that ecological and hydrological continuities and ecosystem functionality inform spatial planning (regional, urban), the approval of projects impacting inland waters and strengthen the resilience of territories to the impacts of climate change	Medium - High	*The national adaptation report estimates medium costs but the description of the measure indicates several investments that will lead to higher costs. "Some actions are completed, underway or planned. Needs are assessed on a systematic basis." It is likely that several measures are included in the Revised Flood Risk Management Plan - see https://www.moa.gov.cy/moa/wdd/wfdf.nsf/All/0BC29ADF9EABFDD4C2258A6E0042266B/$file/%CE%92_3_FRM%20PoM_CY_f.pdf?OpenElement*	1000	10000	Partly
WAT 11	Enhance the efficient use of water in buildings, industry and agriculture	Water savings to address water scarcity / high water costs due to increased demand for desalination / energy from water suppliers.	Medium		200	500	No
WAT 12	Control and limit intensive water demands activities (e.g., golf courses, tourist facilities, water-intensive crops) in water-scarce areas	Water savings to address water scarcity and high-water costs due to increased desalination demand	High	*The national adaptation report mentions that costs will be borne by the private sector.*	1000	3000	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
WAT 13n	Develop future water availability and demand scenarios (for 2050, 2070) under climate change projections and develop strategic plans to adapt demands to projections	Generate updated information to assess the effects of climate change on water resources, extreme events, water uses and the status of water bodies and associated aquatic ecosystems, according to the latest available climate models and scenarios. Develop plans to adjust current and future water demands to available resources in a climate change context in consultation with affected sectors and actors.	Medium - High	*"It is being implemented now through a Contract awarded to Private Consultants"*	500	2000	Yes
INFR 1n	Adapt the different building codes towards climate change adaptation	Increase the resilience of infrastructures	Medium		500	1000	No
INFR 2	Create and maintain urban parks and other green spaces to reduce the urban heat island effect	Management of urban heat island effect	Medium	*"There are already green spaces planned in the urban areas by the town planning, nonetheless there are issues during the implementation and the maintenance of them"*	200	500	Partly
INFR 3	Develop flood relief projects in cities to complement existing and new flood relief solutions	Reduce flood risk: insurance premiums for flood risk; flooding of transport infrastructure, critical utilities and archaeological sites; number of persons exposed to significant flood risk; number of owners to significant flood probability	High	*It is questionable whether these are additional measures due to climate change. The extent of such projects is also unknown.*	20000	50000	Partly
INFR 4n	Change public procurement practices to incorporate climate change adaptation criteria in the development of call for tenders and the establishment of allocation criteria	Incorporate climate change adaptation criteria in infrastructure public procurement processes	Medium		100	300	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
INFR 5	Extensive tree planting	Shading and temperature reduction; Aesthetic improvement and urban landscaping; CO2 absorption; Improved conditions for walking and cycling	Medium - High	*The national adaptation report estimates medium costs but the description of the measure indicates several investments that will lead to higher costs. "Financing options via the CAP need to be elaborated"*	1000	10000	Partly
INFR 6n	Incorporate climate change adaptation criteria into the strategic planning of the transport sector, including the support and strengthening of climate change adaptation capacities in public administrations and other key sectors and actors	Improve climate resilience of transportation sector	Medium	*"This measure causes administrative cost (time, personnel, expertise) and has indirect impact (not directly to the public); thus it arises risk not to be a priority".*	200	400	Partly
INFR 7n	Improve public transport adapting it to new climatic conditions, especially heat stress	Reduce the heat stress in public transport	High		5000	20000	No
INFR 8n	Review maintenance protocols for the transport infrastructure considering the risks arising from climate change	Increase the lifetime of infrastructure	Medium	*"This measure causes administrative cost (time, personnel, expertise) and has indirect impact (not directly to the public); thus, there is a risk that it will not be considered a priority."*	100	400	Partly
INFR 9	Grant Scheme for adaptation to climate change of communities' infrastructures	Mitigation of climate change impact to communities' infrastructure	Medium - High	*The national adaptation report estimates medium costs but the description of the measure indicates several investments that will lead to higher costs. Especially for communities, a RRP-funded scheme of 2.9 million Euros is under implementation - see https://communities-adapt.cea.org.cy/*	3000	20000	Partly
INFR 10n	Provide training and capacity building to staff from competent authorities – planning department, municipalities, new regional organizations – on the benefits of green spaces and nature-based solutions for climate adaptation	Improve the resilience of cities and communities to climate related risks by training staff on available measures.	Medium		100	300	No
SEA 1	Elaboration of a study to identify coastal areas vulnerable to climate change	Protection of tourist assets at risk of flooding due to sea level rise / impacts on coastal development.	Medium	*The national adaptation report estimates low costs but the description of the measure includes several studies that may lead to higher costs.*	100	300	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
SEA 2n	Develop adaptation initiatives and promote nature-based solutions for stabilising and enhancing the coastline resilience against climate risks	a. Maintain and restore the natural capacity of the coast to adapt to changes by increasing the application of nature-based solutions aiming for: protection of land affected by coastal erosion and wave action; addressing impacts on coastal development; preventing loss of bottom marine habitat. b. Reduce the negative impact of existing hydro-technical facilities – for instance dams – that prevent the natural flow of sediments to the coast causing a change of hydrodynamic conditions in the adjacent area and siltation of the bottom habitats.	High		20000	50000	No
SEA 3n	Implementing a coastal contract for integrated wetland management in the context of climate change	Protecting coastal (wet-)lands for climate change adaptation and environmental protection	Medium		100	300	No
SOIL 1	Continuation and increase of interventions through the implementation of the CAP Strategic Plan 2023-2027	Addressing increased soil erosion/ desertification	Low		50	100	No
SOIL 2	Improve management of extensive livestock farming and control of illegal grazing	Addressing increased soil erosion/ desertification. Prevent desertification, prevent soil erosion and promote the restoration of degraded land	High		10000	30000	No
SOIL 3	Promote the practice of incorporating compost to reduce desertification and degradation of agricultural soils	Reduction of desertification and degradation of agricultural soils	Medium	*"Research and pilot implementation already done under the LIFE – AgrOassis. Need to increase implementation to whole country".*	400	1000	No
SOIL 4	Promote the practice of installing plant barriers to reduce soil erosion	Limitation of soil erosion	Low		50	100	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
SOIL 5n	Limit land occupation and soil sealing by applying various tools (e.g. spatial planning etc.)	Limit land occupation and soil sealing	Medium		200	500	No
SOIL 6n	Include soil erosion prevention measures in remediation requirements after mines are abandoned	Prevent soil erosion	Low		50	100	No
SOIL 7n	Reuse of excavated soil from construction industry waste depending on their specifications for soil improvement	Prevent loss of good quality soil	Low	*Low public costs, low to medium private costs*	100	500	No
SPAT 1n	Integrate climate change adaptation into territorial and urban planning, by climate proofing according to specific guidelines	Improved integration of climate adaptation into spatial and urban planning is supported through the analysis and monitoring of the spread of urbanised land in the territory from a climate change perspective	Medium	*"The measure is already partially implemented, maybe indirectly, but can be improved"*	200	500	Partly
SPAT 2n	Create a forum for information exchange between local authorities	Enhance the exchange of information and best practices on climate change adaptation.	Medium		100	300	No
SPAT 3n	Map land and soil reserves, and secure crucial areas (e.g. for air corridors, ecologically relevant areas)	Prepare the ground for spatial planning decisions and in particular for measure SPAT 4.	High	*"This is being done"*	1000	2000	Partly
SPAT 4n	Develop, in collaboration with local and regional authorities, medium- and long-term balanced land strategies that limit the consumption of natural, agricultural and forestry areas to achieve the objective of zero net artificialisation	Limit the consumption of natural, agricultural and forestry areas to achieve the objective of zero net artificialisation and minimize soil sealing.	High		2000	5000	No
SPAT 5n	Apply the Climate Resilience City (CRC) tool to elaborate adaptation options in urban planning	Support the collaborative planning of climate adaptation measures for a more resilient and attractive cities.	Low		50	100	No

Code	Measure	Goal	Cost*	*TZ Comments*	Min. Cost (k€)	Max. Cost (k€)	Budget planned?
TOUR 1n	Conduct study of the regionalized impacts of climate change in the tourism sector and integrate adaptation into plans, programmes and strategies in the field of tourism	Actively promote the adaptation of the tourism sector in Cyprus, maintaining its competitiveness and utilizing the opportunities and potential that result from climate change.	Low		50	100	No
TOUR 2n	Promote tourism models that are more resilient to the impacts of climate change	Reformulate current tourism model, seeking models that are sustainable, diversify away from the dominating “sea, sun, sand” model, and consider sector specific climate change risks and vulnerabilities. Contribute to the overhaul of tourism in areas affected by obsolescence, as well as to its revaluation and innovative projection.	Low		50	100	No
TOUR 3n	Promote the resilience of tourist resources - including natural and cultural resources - and infrastructures to climate change impacts	Identify, plan and develop adaptation initiatives to protect tourism destinations and resources, as well as promote the resilience of infrastructures and facilities.	Medium		100	300	No

* Classification of costs: Low: €100,000 or less; Medium: €100,000 – €1,000,000; High: over €1 million

__Note:__ The first four columns of the table come from the National Adaptation Strategy. The rest are estimates of the ACCREU study team.

	187950	**533200**

CS1.1 – Sub-national adaptation investments for coastal floods

Deltares

FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU – CS1.1

Case study: 1.1 Sub-national adaptation investments for coastal/riverine floods
Representative for Decision Type: 1 (Flood risk)
Stakeholders: Province of North-Holland and Water Board HHNK
Where: City of Den Helder

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation?
No adaptation: Flood risk exceeds social- and economic acceptability (and legal) thresholds.
Business-as-usual adaptation: reduction in the attractiveness and spatial quality of the area; high land pressure, as space needs to be reserved for future dike reinforcements.

Policy question of stakeholder
How to adapt to flood risk such that spatial attractiveness is increased, on the short and long term?

The role of the stakeholder in the decision-making process
Water board: responsible for safeguarding flood risk. They are responsible for maintaining the dikes in this area and reviewing the dikes and reinforcing the dikes if needed. They hence also make the final decision on the superdike adaptation option.
Province: responsible for spatial planning. There is a large housing crisis in the Netherlands, including in this province; so they are interested in finding locations where houses can be built.

Relation to local, national, and European initivaties/policies
National: HWBP flood directives/standards (specifies flood protection standards)
National: WBS spatial planning directive / Delta programme / national adaptation strategy (emphasis on long-term)
Provincial: adaptation strategy
Municipal: adaptation strategy

Uncertainties (U)

What are the external factors?

Climate Scenarios
Socioeconomic Scenarios (SSPs)

- RCP2.6 (17th & 83rd percentile)
- RCP8.5 (17th & 83rd percentile + three high-level sea-level scenarios)
- SSP1-5 (two variations for 1 & 5, with lower and higher population, respectively)

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Economic methods
- CBA

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
Urban scale	200 years	Flood risk management & Spatial planning

Adaptation options (O)

What adaptation options are considered in the case study?	Are the options more incremental or transformative? Incremental	Transformative
Grey • Dike reinforcement following HWBP protection standards	X	
Large dike reinforcement (3.5m SLR) combined with housing development (either in small area 700m long, or larger area, 1400m long)		X
Green		
Soft		

Appraisal criteria (C)

What appraisal criteria are considered?	Qualitative	Quantitative	Monetised
What direct costs are considered?			
Dike construction and planning costs			X
Housing costs (construction; demolition; planning; dispossession etc.)			X
Maintenance costs housing			X
What direct benefits are considered?			
Reduction in expected annual flood damages			X
Reduction in expected annual flood fatalities			X
Reduction in expected annual people affected by floods			X
House sale income			X
Rent income			X
What co-benefits and co-costs are considered?			
<u>Economic</u>			
• Spatial trade-offs of housing			X
<u>Social</u>			
• Place attachment loss			X
• Value of trees for residents			X
• Value of water view for residents			X
<u>Environmental</u>			
• Tree costs			X
• Emission costs of dike and housing			X

Are you considering general welfare effects? If so, how? **YES**/NO	Social	Temporal	Spatial
• Take a lock-in perspective for the superdike measure and monetise these lock-in/regret costs • Disaggregate effects across generations • Use multiple discounting principles • Use multiple time horizons		X	

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1	Continuation of BAU – incrementally strengthening dikes and no new coastal development	Inner dike improvements around 2080/2100	Incremental
2	Transformative dike reinforcement with integrated spatial planning	3.5 and/or 5.0 m SLR proof dike + housing development	Transformative
3			
4			
…	…	…	
n	…	…	

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or goverannce and institutional (G).

#	Barriers	Cat
1	1A – Competing local planning objectives 1B – Availability of future resources 1C – Availability of land for future reinforcements	G F F
2	2A – unsuitable financing institutions (not nationally funded) 2B – Acceptability of expropriating home owners 2C – uncertain effect housing on dikes 2D – acceptability of overtopping 2E – acceptability of overinvestment 2F – place attachment	F S K S S S
…	…	…
n		

Assessment of strategies (SA)

#	Path-dependencies	Transfer costs	Timing	Financing of strategies	Distributive effects	Direct costs & benefits	Co-costs & -benefits
	Do you encounter path-dependencies in the identified strategies? If yes, how?	**What are the transfer costs like?**	**What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?**	**Who will finance the strategy?**	**What are the main distributional effects of the strategy?**	**Will be you be able measure the direct costs and benefits qualitatively, quantitatively, or monetised?**	**For which co-costs and co-benefits could you provide an order of magnitude?**
1	Path-dependency and lock-in of BAU (hard protection approach)	High when transferring to NBS; low when transferring to other types of strategies	~decade lead time; current situation	Public (national and water boards)	Equal protection of individuals;	Direct costs: monetised Direct benefits: monetised/quantitatively	Spatial quality (CS level, not general stategy level)
2	Lock-in if SLR is more or is less than expected (little flexibilty in this strategy). It locks-out alternatives, by reducing the benefits of the alternative options	high – requires expropriation of home owners and relocation of renters – loss of place attachment	~a decade lead time; current or longer-term option.	Public (water boards and regional/local)	Possible gentrification; regressive effect. Low-income households pay for protection high-income households	Direct costs: monetised Direct benefits: monetised/quantitatively	Housing values; gentrification;Spatial quality (only CS-level; not general strategy level)
3							
4							
…	…	…					
n	…	…					

CS1.2 – Large scale and long-term coastal nature-based solution policies for rural regions in Europe and the German Baltic coast

Global Climate Forum (GCF)

XLRM FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: 1.2 Large scale and long-term coastal policies for regions in Europe and the German Baltic coast
Representative for Decision Type: 1 (Flood risk)
Stakeholders: European Agencies, National/regional planning, nature conservation organisations
Where: Coastal European regions

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation)?
No adaptation: Flood risk exceeds social- and economic acceptability (and legal) thresholds.
Business-as-usual adaptation:
- Northwestern Europe: reduction in the attractiveness and spatial quality of the area.
- Southern-Europe: Flood risk exceeds social- and economic acceptability (and legal) thresholds.

Policy question of stakeholder
- Where and when would it be beneficial to switch between "hold the line" policy to planned retreat?

The role of the stakeholder in the decision-making process
National adaptation planning of coastal protection and involvement of different parties in decision making process
Nature conservation organizations promote the green adaptation
Regional planning and coastal protection agencies protect local interest (infrastructures)

Relation to local, national, and European initiatives/policies
National: flood directives/standards (specifies flood protection standards)
National: spatial planning directive / national adaptation strategy (emphasis on long-term)
Regional/local: adaptation strategy

Uncertainties (U)

What are the external factors?

Climate Scenarios
Socioeconomic Scenarios (SSPs)

- Sea level rise (+ rate of SLR)
- Representative storm surge conditions
- Morphological development of the seabed
- Spatial claims for developing infrastructures (i.e., future housing demand nationally and locally)
- Developments in future (income) inequality
- Demographic development
- Discount rate
- Risk aversion

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models
- DIVA
- Wetland change model
- Environmental economic valuation models

Economic methods
- Cost and benefits analysis
- Expected damages
- Sensitivity analysis

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

Trade-off between grey and green adaptation strategies and hybrid strategies (managed realignment and coastal restoration)

Case study delineation (CS)

Spatial scale	Temporal scale / time frame	Sector / discipline
European regions	2020-2100	Economic assessment; Coastal

Adaptation options (O)

What adaptation options are considered in the case study?	Are the options more incremental or transformative? Incremental	Transformative
Grey		
• Dike reinforcements	✓	
• Building new dikes		✓
Green		
• Wetlands restoration (using sediment nourishment)		✓
• Managed realignment		✓
Soft		

Appraisal criteria (C)

What appraisal criteria are considered?	How are the criteria measured? Qualitative	Quantitative	Monetised
What costs are considered?			
•Operational costs			✓
•Investment costs			✓
What direct benefits are considered?			
• Reduction in expected annual damages from floods and SLR		✓	✓
• Protection cost reduction			✓
What co-benefits?			
Economic			
•Carbon sequestration			✓
Social			
Environmental			
•Natural capital, Ecosystem services			✓
Are you considering distributional effects? If yes, how? Yes/No			

CS2.1 – Multi-sectoral adaptation to wildfire risk in a densely populated region with high natural values

Technical University of Denmark (DTU)

XLRM FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

***Case study:** 2.1 Multi-sectoral adaptation to wildfire risk in a densely populated region with high natural values*
Representative for Decision Type:
***Stakeholders:** (STRESS-SCARL*) Sorrento and neighbouring municipalities in the Campania region, other local stakeholders*
*(*Engineering consortium,, public-private partnership)*
***Where:** Sorrento municipality and part of the Campania region*

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation)?
No adaptation: Wildfire risk exceeds social- and economic acceptability (and legal) thresholds (including legislation regarding protected nature, high-value agriculture, tourism).
Business-as-usual adaptation: Focus on preparedness and BAU forest management. Preparedness activities linked to monitoring and prediction of fire weather index (e.g., restrictions of fire usage).

Policy question of stakeholder
What are the risks under current and future scenarios? How to adapt to increasing wildfire risks in a holistic way such that the impacts on human and natural systems, e.g. buildings, infrastructure, (high-value) agriculture, and protected forests are minimized. What are the costs and benefits of different practices under current and future conditions?

The role of the stakeholder in the decision-making process
Municipality (Sorrento is the main city, neighboring municipalities are smaller and look for Sorrento for leadership): responsible for information, land management, planning, connected to emergency management services
Regional (Campania): responsible for, e.g., transport infrastructure

Relation to local, national, and European initiatives/policies
Local/municipal + regional: adaptation strategy and disaster risk management, local regulations for wildfire prevention and forest management; Civil Protection
National: Protection of natural areas, Civil Protection
European: European Commission Wildfire Prevention Action Plan

Uncertainties (U)

What are the external factors?

Climate Scenarios
Socioeconomic Scenarios (SSPs)

Increasing levels of warming, e.g., SSP1-2.6, SSP2-4.5 and SSP3-7.0.

Representative land surface and land use scenarios with adaptation.

Other factors:

Risk preferences and time preferences

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models

A multi-scale probabilistic fire spread model, combining the ForeFire-Climate model with the Fire Weather Index (FWI) system

Economic methods

- Cost-benefit analysis
- Environmental impact assessment
- Qualitative interviews

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

- *Fire risk prevention*

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
Ca. 10 x 10 km (or higher) Regional, municipal	2030, 2050, 2100	Fire risk prevention, disaster risk management, planning

Adaptation options (O)

What adaptation options are considered in the case study?	Are the options more incremental or transformative? Incremental	Transformative
Grey		
• Increased physical protection of assets		
Green		
• Optimized forest management (e.g. reduced tree density, replanting more suitable tree species).		
• Fire belts		
• Land use change		
Soft		
• Improved risk assessment - improved fire risk management (prevention, preparedness, response)	✓	
• Enhanced monitoring programmes & technologies	✓	
• Insurance schemes	✓	
• Restriction of access to risk-prone areas (e.g. tourists are prohibited to enter protected natural areas under high-risk fire conditions to prevent a fire starting)	✓	

Appraisal criteria (C)

What appraisal criteria are considered?	How are the criteria measured? Qualitative	Quantitative	Monetised
What costs are considered?			
- Operational costs (emergency management, forest management)			✓
- Investment costs (land use change, physical protection)			✓
What direct benefits are considered?			
• Reduction in expected annual risk damages (e.g. infrastructure)			✓
• Reduction in tree & agriculture loss		✓	
• Reduction in biodiversity loss	✓	✓	
What co-benefits?			
Economic			
• Resilience	✓		
Social			
• NA			
Environmental			
• NA			
Are you considering distributional effects? If yes, how? No			

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1	Fire risk prevention	1. Wildfire monitoring and early warning systems: UAVS	Incremental (1,2,3,4) and transformative (5)

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governance and institutional (G).

#	Barriers	Cat
1	The region's challenging physical features – steep terrain, dense vegetation , and a complex urban-wildland interface-further reduce the effectiveness of drone operations	K, P, B
	Drone performance is also influenced by weather conditions and constrained by operational factors such as battery life and flight range	K, P, B
	Effective deployment depends on the availability of skilled personnel, supporting infrastructure, and sophisticaled data processing capabilities.	F, H, G
	Regulatory issues particularly those concerning emergency response and airspace restrictions, must be addressed to enable	S, G

Assessment of strategies (SA)

#	Path-dependencies	Transfer costs	Timing	Financing of strategies	Distributive effects	Direct costs & benefits	Co-costs & -benefits
	Do you encounter path-dependencies in the identified strategies? If yes, how?	What are the transfer costs like?	What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?	Who will finance the strategy?	What are the main distributional effects of the strategy?	Will you be able to measure the direct costs and benefits qualitatively, quantitatively, or monetised?	For which co-costs and co-benefits could you provide an order of magnitude?
1	Given the complex land-use patterns in Campania, the local authorities have resolved to implement soft-adaptation measures through the use of UAVs.	The associated costs include the initial investment in technology, the cost of training personnel for its effective use, and the ongoing costs related to system operation and maintenance.	Long-term strategy but also short-term	Regional/ local government budget	Areas that are accessible and monitored through drone surveillance tend to exhibit a higher level of protection	Monetised	The private sector also benefits since it plays a role in providing safeguards.

CS2.2 – Adaptation options for reduction of forest fire

Technical University of Denmark (DTU)

XLRM FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: 2.2 Adaptation options for reduction of forest fire
Representative for Decision Type:
Stakeholders: Forest owner and management company (*Miljö och Skog i Leksand Aktiebolag*)
Where: Leksand (Sweden)

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: W hat happens without adaptation (and with business-as-usual adaptation)?
No adaptation: fire risk and damages exceed social and economic acceptability levels.
The number of days with warm weather has increased the likelihood of forest fires. One event that can cause a forest fire is using vehicles when cutting and carrying trees from the stump to the landing. In the former case, the vehicle used is a harvester, and in the latter case, a forwarder. Vehicles can cause sparks when driven, especially when metallic boggy hits bare rock or larger stones. The driver of the vehicle, especially in the case of a forwarder, does not remain in the same spot. Usually, travel about two Km with the logs to take them out of the forest to be carried on the truck. Since there is a lag from a spark to fire, the vehicle may already be at another location when the fire starts and the damages occur.

Business-as-usual adaptation: reduction in fire risk damages by checking an index of fire risk; avoiding working in the forest during the days with high risk of wildfire.

Policy question of the stakeholder
What are the costs and benefits of different adaptation options to reduce the likelihood of forest fires and forest fire damage?

The role of the stakeholder in the decision-making process
Responsible for reducing the likelihood of fires.
Information provision on the risk of fire to forest owners and advising them on adaptation options to reduce fire risk and damage.

Each day, the operator of the forest machines needs to inform herself about the weather and fire risk, which is graded on a six-point scale (https://www.msb.se/sv/om-msb/informationskanaler/appar/brandrisk-ute/). If the index is above three, the principal (the agent who ordered the forest to be cut, typically the forest owner) needs to contact the operator to tell the option to be followed, and the operator has to confirm this, typically via email. If the index is three or above, additional fire extinguishers have to be brought with the vehicle. This is in addition to the extinguishers already onboard. If the index is four or above, fireguards are needed. A problem for operators is to find guards at short notice. Since the vehicles are large investments, operators often prefer to cut back on other activities rather than have the vehicles not operate.

Relation to local, national, and European initiatives/policies
Local: Local regulations for wildfire prevention and forest management; Civil Protection Act
National: Ordinance on Emergency Preparedness; Swedish Civil Contingencies Agency
European: European Commission Wildfire Prevention Action Plan

Uncertainties (U)

What are the external factors?

Climate Scenarios
Socioeconomic Scenarios (SSPs)

Increasing levels of warming, e.g., SSP1-2.6, SSP2-4.5 and SSP3-7.0.

Representative land surface and land use scenarios with adaptation.

Other factors:

Risk preferences and time preferences

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models

A multi-scale probabilistic fire spread model, combining the ForeFire-Climate model with the Fire Weather Index (FWI) system

Economic methods

- Cost-benefit analysis
- Environmental impact assessment
- Qualitative interviews

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

- *Forest management*
- *Fire risk prevention*
- *Capacity building*
- *Financial strategies*

Case study delineation (CS)

Spatial scale	*Temporal scale / time frame*	*Sector / discipline*
10x10 km forest scale	Near Future (2021-2040) Mid Century (2041-2060) Far Future (2061-2080) Distant Future (2081-2100)	Fire risk prevention and forest management

Adaptation options (O)

What adaptation options are considered in the case study?	Are the options more incremental or transformative? Incremental	Transformative
Grey		
• Creating firebreaks		✓
Green		
• Reducing tree density	✓	
• Planting fire resistant tree species		✓
• Prescribed burning	✓	
Soft		
• Using fire risk app to improve knowledge and readiness	✓	
• Training programmes for fireguards and other stakeholders	✓	
• Employing fire guards for surveillance	✓	

Appraisal criteria (C)

What appraisal criteria are considered?	How are the criteria measured? Qualitative	Quantitative	Monetised
What costs are considered?			
- Operational costs			✓
- Investment costs			✓
What direct benefits are considered?			
• Reduction in expected annual risk damages		✓	✓
• Reduction in forest tree loss		✓	
What co-benefits?			
Economic			
NA			
Social			
NA			
Environmental			
• Air quality improvement (less carbon emissions)		✓	
Are you considering distributional effects? No			

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1	Forest management for damage risk reduction in case of a fire	1. Creating firebreaks 2. Reducing tree density 3. Planting fire resistant tree species 4. Prescribed burning	Transformative Incremental Transformative Incremental
2	Fire risk prevention	Using fire risk app	Incremental
3	Capacity building	Training programmes for fireguards and other stakeholders	Incremental

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governance and institutional (G).

Strategy	Barriers	Cat
Forest management	Not all tree species suit all terrains; costly; forest owners may be unaware of options or unwilling due to habits and traditions	K; B; F; S
Fire risk prevention	Unavailability of trained staff; costly to hire fireguards; unawareness of fire risk app	K; H; F; C
Capacity building	Training is costly and time-consuming	F

Assessment of strategies (SA)

#	Path-dependencies	Transfer costs	Timing	Financing of strategies	Distributive effects	Direct costs & benefits	Co-costs & -benefits
	Do you encounter path-dependencies in the identified strategies? If yes, how?	What are the transfer costs like?	What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?	Who will finance the strategy?	What are the main distributional effects of the strategy?	Will you be able to measure the direct costs and benefits qualitatively, quantitatively, or monetised?	For which co-costs and co-benefits could you provide an order of magnitude?
1	Forest owners are used to grow certain species, not clearing the forest, not creating firebreaks, or not implementing prescribed burning	Costs of switching to less profitable species but more resistant to fires; costs of reducing tree density and creating firebreaks	Long-term strategy but also short-term	Forest owners but also forest managers	Richer forest owners will protect themselves more	Monetised	Environmental co-benefits in terms of carbon emissions
2	No, using the fire app is mandatory	-	Short-term	The Swedish Contingency Agency (MSB)	-	-	-
3	No, the training programs are mandatory	Relocation of workers	Short-term	collaborative initiative between forest companies, forest owner associations, and forest research groups	-	-	-

CS3.1a – Integrated adaptation decisions in managing the water-food nexus in Europe – Thaya river basin (Czech Republic)

International Institute for Applied Systems Analysis (IIASA) &
Czechglobe

FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: 3.1 Integrated adaptation decisions in managing the water-food nexus in Europe
Representative for Decision Type: Integrated adaptation decisions in managing the water-food-biodiversity
Stakeholders: River Basin authorities and Ministry of Agriculture of Czech Republic
Where: Thaya river basin – Czech Republic / Austria

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation?

- No adaptation: decrease in agricultural production in the region and sub-utilization of agricultural land and productivity potential
- Business-as-usual adaptation: there is low uptake of irrigation as an adaption measure and increased risk of water competition among users leading to unsustainable agricultural production.

Policy question of stakeholder

- How to adapt for sustainable use of water resources and water management concerning the provision of water services, especially those of the supply of drinking water and large-scale irrigation?

The role of the stakeholder in the decision-making process

- Povodi Moravy (Regional Water Authority): provides management, operation, and maintenance of water courses and water management facilities in the Morava basin (e.g., planning activities according to the Water Act and managing and influencing water management within the water management system)
- Ministry of Agriculture: define and mutually harmonize the public interests of water protection as a component of the environment, the reduction of the adverse effects of floods and droughts, and the sustainable use of water resources, especially the drinking water supply.

Relation to local, national, and European initivaties/policies

National; Water Act (No. 254/2001 Coll.) and Water Supply and Sewerage Act (No. 274/2001 Coll.)

European: Directive 2000/60/EC of the European Parliament and of the Council - Water Framework Directive and Danube River Protection Convention

Uncertainties (U)

What are the external factors?

Climate Scenarios

- CMIP6 climate scenarios – 30 GCMxRCP combinations
- Climate Scenarios: SSP2-RCP4.5, SSP3-RCP7.0, SSP5-8.5
- Climate models:GCM – UKESM1-0-LL, IPSL-CM6A-LR, MRI-ESM2-0, GFDL-ESM4, MPI-ESM1-2-HR

Socioeconomic Scenarios (SSPs)

- SSP1, SSP2, SSP3, SSP5

National Adaptation strategies

- Business as usual (BAU)
- Holding the ground (HTG)
- Make the best of climate change (TBC)
- Outside the limits (OTL)

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models

- GLOBIOM
- CWATM

Economic methods

Global- consistent partial equilibrium

Integrated Impact Assessment

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
NUST2, National and Thaya River Basin	10y/2100	Agriculture and water management

Adaptation options (O)

What adaptation options are considered in the case study?	Incremental	Transformative
Grey • Planned and sustainable irrigation expansion and transformation from rainfed- to irrigate management systems		X
Green • location of the production, by changing the optimal crop shares at the local level		X
Soft • trade, by changing trading quantities and relative importance of different trading partners • management, by increasing or decreasing fertilizers and irrigation use in agriculture • consumption, by changing the amount and the structure of food consumption	X X X	

Are the options more incremental or transformative?

Appraisal criteria (C)

What appraisal criteria are considered?	Qualitative	Quantitative	Monetised
What direct costs are considered? • Production cost • Investment cost			X X
What direct benefits are considered? • Increased sustainable agricultural production		X	
What co-benefits and co-costs are considered? Economic • Agricultural yield • Agricultural production • Agricultural producer prices • Agricultural value added		X X X X	 X X
Social • Food security		X	
Environmental •GHG emissions •Water availability and environmental flows •Land use change		X X X	

How are the criteria measured?

Are you considering general welfare effects? If so, how? YES/NO	Distributive	Temporal	Spatial

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1	BAU: Agricultural production based on the SSP2 socio-economic development	Unplanned irrigation expansion, improved irrigation efficiency based on SSP2, no constraint in water use for irrigation, autonomous crop allocation and gradual increase in international trade, increase meat demand	Incremental
2	HTG: maintaining the current level of provision services and maximizing comparative advantages offered by climate change	Planned irrigation expansion, increased irrigation efficiency based on national adaptation strategies, constraints in water use for irrigation based on national adaptation strategies, autonomous crop allocation, and gradual increase in international trade, increased meat demand	Incremental
3	TBC: a balanced supply of provision, regulating, and cultural ecosystem services	Planned sustainable irrigation expansion, increased irrigation efficiency based on national adaptation strategies, constraints in water use for irrigation-based regulating services, autonomous crop allocation, and decrease in imports by 2050, decrease meat demand	Transformative

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or goverannce and institutional (G).

#	Barriers	Cat
1	1A – Extreme events and economic crisis 1B – Political disparities among stakeholders 1C – Water competition with other sectors	E G P, E
2	2A - Limited knowledge about sufficient adaptation measures 2B - Bad public opinion about agriculture's impact on the environment 2C - Limited amount of water for irrigation	K S P
3	3A - Requires advanced governance structures 3B – Can require large investments 3C-	G F
4	4A- Large uncertainty in technology 4B – Implementation require national and subnational governance 4C – Dependance of Czech comperative advantage in the EU market	K G E
…		
n	…	…

Assessment of strategies (SA)

#	Path-dependencies	Transfer costs	Timing	Financing of strategies	Distributive effects	Direct costs & benefits	Co-costs & -benefits
	Do you encounter path-dependencies in the identified strategies? If yes, how?	**What are the transfer costs like?**	**What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?**	**Who will finance the strategy?**	**What are the main distributional effects of the strategy?**	**Will be you be able measure the direct costs and benefits qualitatively, quantitatively, or monetised?**	**For which co-costs and co-benefits could you provide an order of magnitude?**
1	Little adoption of irrigation as an adaptation measure, path-dependency on keep current agricultural management systems	Low transfers cost but increase input cost such as fertilizers	Yearly/ Short-term low regret	Private	Impacts on producer and consumers equally	Direct costs: monetised Direct benefits: quantitatively	Agricultural production, GHGs, land use
2	Unsustainable expansion of irrigation and strategy lock-in. Large investment, the need to guarantee water even unsustainably facing low acceptance	High transfer costs are driven by infrastructure investment and maintenance, low when just upgrading irrigation tecnologies	Decadal/ Longer-term	Public (Regional and National Water Authority) and Private	Low-income farms may not benefit due to large investment cost	Direct costs: monetised Direct benefits: quantitatively	Agricultural production, GHGs, land use
3	Decrease the risk of strategy lock-in by increase the acceptance of the strategy under sustainability practices	Transfer cost is driven by infrastructure investment, upgrade of technologies, and maintenance, low when just upgrading irrigation tecnologies	Decadal/ Longer-term	Public (Regional and National Water Authority) and Private	Opportunity for cooperation between farms and regional authorities	Direct costs: monetised Direct benefits: quantitatively	Agricultural production, GHGs, land use
4	Higher competition with other adaptation strategies such organic farming, and other management practices that provide other co-benefits such as NBS	Low transfer cost when using NBS instead of irrigation, and High transfer cost when changing from irrigation to NBS	Decadal/ Short-term low regret and long-term	Public (Regional and National Water Authority) and Private	Policy makers benefit from alignment of practices with policies, farmers require higher preparation and infrastructure,	Direct costs: monetized Direct benefits: quantitatively	Agricultural production, GHGs, land use

CS3.1b – Integrated adaptation decisions in managing the water-food nexus in Europe – Ebro river basin (Spain)

International Institute for Applied Systems Analysis (IIASA)

FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: 3.1 Integrated adaptation decisions in managing the water-food nexus *in Europe*
Representative for Decision Type: Integrated adaptation decisions in managing the water-food-biodiversity
Stakeholders: Confederación Hidrográfica del Ebro
Where: Ebro River basin, Spain

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation?
No adaptation: Increase water stress, particularly due to seasonal variability, reduced inflows to headwater reservoirs and increasing water demands. Alleviated drought risk, and increased water pollution.

Business-as-usual adaptation: Increased water use efficiency maybe offset by increasing demands from the agriculture and energy. Supply-side measures have limited effect and may create tension between water users/mangers.

Policy question of stakeholder
What are the costs and benefits of adaptive measures considering climate change, allowing to maintain the pivotal role of water in the regional economy and ecological systems?

The role of the stakeholder in the decision-making process
Ebro Hydrographic Confederation (EHC; river basin authority): water management and planning for the whole basin (an administrative body of the Ministry for Ecological transition and demographic challenge).

Relation to local, national, and European initivaties/policies
European: Water Framework Directive (2000/60/EC), Groundwater Directive (2006/118/EC), Floods Directive (2007/60/EC), Nitrates Directives (91/676/EEC)

National: Water Law, Environmental Impact Assessment Law, Nature Conservation Law, National Climate Change Adaptation Plan.

Local: Third River basin management plan (Approved January 2023); The river basin stretches across provinces, and nine autonomous communities.

Uncertainties (U)

What are the external factors?

Climate Scenarios
CMIP6 climate scenarios: 5 GCMs for each SSP-RCP combinations

e.g., SSP_RCP: SSP1-RCP2.6, SSP2-RCP4.5, SSP3-RCP7.0
e.g., GCM – UKESM1-0-LL, IPSL-CM6A-LR, MRI-ESM2-0, GFDL-ESM4, MPI-ESM1-2-HR

Socioeconomic Scenarios (SSPs)
SSP1, SSP2, SSP3

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models
GLOBIOM
CWATM (Community Water Model)

Economic methods

Global- consistent partial equilibrium
Integrated Impact Assessment
Cost Benefit Analysis

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
NUTS2, National and Ebro River Basin	10y/2060	Agriculture and water management Urban supply and hydropower important in economic terms

Adaptation options (O)

What adaptation options are considered in the case study?	Incremental	Transformative
Grey		
• Irrigation expansion and modernization – Change rainfed – irrigated and reduce the share of flood irrigation	X	
• Waste water treatment and reuse	X	
• On-farm storage to reduce the effect of seasonality and limit overall water abstraction	X	
Green		
• Land allocation (preserving the delta's paddy fields)	X	
• Higher environmental flows would be needed in the future, specially during drought periods.		X
Soft		
• International trade		X
• Water saving crops selection		X
• Water allocation schemes	X	

Are the options more incremental or transformative?

Appraisal criteria (C)

What appraisal criteria are considered?	Qualitative	Quantitative	Monetised
What direct costs are considered?			
• Production cost		X	X
• Investment cost		X	X
What direct benefits are considered?			
• Increased sustainable agricultural production		X	
What co-benefits and co-costs are considered?			
<u>Economic</u>			
• Agricultural yield		X	
• Agricultural production		X	
• Agricultural producer prices		X	X
• Agricultural value added		X	
<u>Social</u>			
• Food security		X	
<u>Environmental</u>			
• Water availability and environmental flows		X	
• Land use change		X	

How are the criteria measured?

Are you considering general welfare effects? If so, how?	Distributive	Temporal	Spatial
NO			

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1	BAU: Agriculture intensification and modernization	Expand irrigated agricultural areas and replace flood-irrigation wirth sprinklers/drip irrigation. Increase stoarge capacity to cope with seasonal water stress.	Incremental
2	Demand-side measures to restrict water use	Maintain regional productivity and economic value while optimizing water use, via international trade and crop selection.	Transformative

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or goverannce and institutional (G).

#	Barriers	Cat
1	1A: Financing of irrigation and storage infrastructure is costly	F
	1B: Restricting water abstraction is politically challenging; without it the river flows may become lower.	G
	1C: Large dams would reduce flows and sediment delivery to the protected downstream delta.	B
2	2A: Agricultural/land use policies are not (fully) managed by the River Basin Authority.	G
	2B: Shifting from traditionally cultivated crops may encounter knowledge gaps.	K
	2C: Transformation of traditional practices.	S

Assessment of strategies (SA)

	Do you encounter path-dependencies in the identified strategies? If yes, how?	What are the transfer costs like?	What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?	Who will finance the strategy?	What are the main distributional effects of the strategy?	Will be you be able measure the direct costs and benefits qualitatively, quantitatively, or monetised?	For which co-costs and co-benefits could you provide an order of magnitude?
#	**Path-dependencies**	**Transfer costs**	**Timing**	**Financing of strategies**	**Distributive effects**	**Direct costs & benefits**	**Co-costs & -benefits**
1	Path-dependency of BAU due to planned and approved irrigation expansion and modernization.	High due to required invsetments at the irrigation region level (e.g., canal), expansion at the farm level is slightly less costly	Decade lead time	Self investement supported by state subsidies (slowly reducing).	Catious planning of water allocation is required to keep just and efficient water resource use	Investment costs and crop sales are monitized.	Crop production, environmental flows.
2	Medium path-dependency due to regional agricultural legacy, traditions, and knowledge.	Medium, incluidng knowledge & technology transfers, increasing social acceptability, resoruce redistribution, and manageing conflict between stakeholders.	Long term	Governmental subsidies to incentivized transition water-saving crops.		Crop sales due to crop selection.	Crop production, environmental flows.

CS3.2 – Integrated species distribution model for estimating potential economic impacts of conservation and impact mitigation preservations

Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)

FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: 1.1 Sub-national adaptation investments for coastal/riverine floods
Representative for Decision Type: 1 (Flood risk)
Stakeholders: Province of North-Holland and Water Board HHNK
Where: City of Den Helder

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation?

No adaptation: The protected area will gradually loose its biodiversity and the characteristic dune system will erode. This includes a decline in attractivity for nature-oriented beach tourists. Flood risk in the settlement behind the dune ridge will increase.

Business-as-usual adaptation: with low efforts for adaptation, the dune system will lose biodiversity and functionality, including higher frequency of flooding in the areas behind the dunes due to sea level rise.

Policy question of stakeholder

How to conserve the dune system so to allow for its adaptation to the risk of rising sea levels and extreme events? Specifically: how to best manage a coastal natural area (site of the “Habitat” Directive 92/43/EEC), in a way that biodiversity of the site and its capacity to adapt to rising sea levels are conserved while allowing for touristic activities and for flood protection of the areas behind the dunes.

The role of the stakeholder in the decision-making process

The Stakeholder. a local section of the NGO (WWF) is in charge of short term management of the Oasis: Environmental education and information activities; Awareness raising and information for visitors on biodiversity and climate change issues; Creation of informational and didactical signage; Manual cleaning of the beach; Environmental management activities and territory control; Environmental monitoring and ecological analysis of flora and fauna; Delimitation of priority areas for habitat conservation; Environmental improvement interventions for the purpose of increasing biodiversity; Delimitation and signage of nesting area of a target species blest (Charadrius alexandrinus); Assistance in the activity of recovery and care of sea turtles.

Relation to local, national, and European initiatives/policies

Management support of the ZSC/ZPS site - IT 3250023 Biotopi litoranei di Venezia - località Alberoni, according to Habitat Directive 92/43/EEC; 2) Participation in LIFE Project: i) LIFE DUNE - Concerted action for biodiversity on the Veneto coast; ii) LIFE URCA (URgent Conservation Actions pro Emys orbicularis in Italia e Slovenia) PROEMYS; (URgent Conservation Actions pro Emys orbicularis in Italia e Slovenia)

Uncertainties (U)

What are the external factors?

Climate Scenarios
Socioeconomic Scenarios (SSPs)

Sea level rise;
- Increasing of number, seasonality and intensity of coastal storms;
- Increasing risk of alien flora and fauna species' invasion.
- Changes in coastal sediment supply and dune capacities of timely adaptation to SLR

- Spatial claims for local new beach resorts;
(high economic pressure for intensification of touristic exploitation of beaches with new bathing establishments), coastal squeeze in a limited space between sea and lagoon

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models used:

DIVA model scenarios of Sea Level rise,

Needed:
IBIS model (biodiversity losses due to SLR

Economic methods

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
Urban scale	2030 / 2050	Biodiversity conservation / cosastal protection

Adaptation options (O)

What adaptation options are considered in the case study?	Are the options more incremental or transformative? Incremental	Transformative
Grey		
• Installation of physical measures for limiting/channelling access to beaches, protecting the major part of the beach	x	
Green		
Reinforcing/restoring dunes/sand deposition for dune growth	x	x
Soft		
• Awareness raising among beach users and residents of the Lido island is key for supporting conservation measures	X	
• Involvement of residents and volunteers in the protection measures and in monitoring	X	x
• Enforcement of land use / protection plans,	x	
• Change of land use plans to enhance protection		x

Appraisal criteria (C)

What appraisal criteria are considered?	Who benefits?	How are the criteria measured? Qualitative	Quantitative	Monetised
What direct costs are considered? Costs for enforcing surveillance, installation (opportunity costs for foregone beach uses/installation of beach establishments)	Local authority		x	x
What direct benefits are considered? Increase of biodiversity, conservation of a rare habitat and species	society	x		
What co-benefits and co-costs are considered? Economic: ecosystem services:	Whole society		X	
carbon sequestration of dune vegetation	Residents and establishments			
Flood protection for the residential area	in Alberoni,		x	x
Social: • biodiversity (cultural, recreation)	Lido/Venice residents tourists	X		x
Environmental: • Value of biodiversity and coastal habitats	society	x		

Are you considering general welfare effects? If so, how?	Distributive	Temporal	Spatial
no			

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy
1	Forest management (regional forest agency)	Conversion of the pine-wood into autochtonous mixed dune forest (reduction of fire risk, protection of the dune system, implemented by the regional forest agency)
2	Dune protection and management (WWF)	a) Delimitation of pathways crossing dune areas channel the accessibility of the beach area for tourists. Installation of fences, and wooden pathways). b) Intensification of awareness rising among residents and visitors and stronger surveillance of visitors' behaviours c) Surveillance of nesting areas and emergency interventions during storm surges, thinning and elimination of invasive vegetation
3	Dune reconstruction (Lagoon authority, Local authority)	a) Reconstruction and revegetation of missing parts of the dune system (recreation of parts of the dune habitat). b) (1) cancellation of unused concession (2) closure of existing establishments at expiry of existing concessions
4	Reduce urbanization (local authority)	Closure of roads accessing to the beaches, creating space for dunes (demolition of buildings and other sealed surfaces)
5	Governance	Competences for actions are split between different authorities, coordination needed

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governance and institutional (G).

#	Barriers	Cat.
1 Forests	Forest management is on-going as a slow transformation process, forest surface is limited by urbanization	P/B
2 Dune protection	(a) Costs of physical infrastructures for dune protection (b) Costs of surveillance and awareness raising (c) Manpower for protecting hatching sites from flooding during storm surges	P/F/G
3 dune reconstruction	Public opposition to limitation of new concessions, eventual indenisations High costs of dune reconstruction	B
4 urbanization	Public opposition to limits to urbanization, costs of demolition and indenisation of owners	S
5 governance	The split of competences between urban planning, beach and forest management and nature conservation would require some coordination.	G
		…

Assessment of strategies (SA)

	Do you encounter path-dependencies in the identified strategies? If yes, how?	What are the transfer costs like?	What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?	Can this strategy increase risk to other hazards?	What effects does this strategy have on regions outside the project area?	Who fill finance the strategy?	What are the main distributional aspects of the strategy?
#	**Path-dependencies**	**Transfer costs**	**Timing**	**Risk substitution**	**Risk transfers and spillovers**	**Financing of strategies**	**Distributional aspects**
1	*(not sure: could the forest transformation strategy block the forest in the place where it is now rather than allowing for dune growth and migration?)*	Forest management is ongoing, extension needs to interact with private owners (golf club, residences) medium-low	long term, low regret	None	none	Part of on-going forest management strategies (Regional admin.)	Reduction of fire risk for residents
2	Trade-off with eventual planning of long-term (hard) protection measures for higher levels of SLR at the cost of dune systems and biodiversity	a) low-to medium (installation and maintenance of wooden pathways across dunes) b,c) need to motivate volonteers for emergency interventions in case of storm surges out of season	a) Medium term low regret b) Short term, no regret	Dunes might not be fit for long-term protection strategies, scarce (physical) space for combining hard protection with NBS strategies	none	Voluntary work with public support (monitoring, awareness raising etc.)	Free use of beaches is an attractive option for residents, limitation to uses may be perceived as deprivation of traditional rights
3	Trade-off with eventual planning of long-term (hard) protection measures for higher levels of SLR at the cost of dune systems and biodiversity	High costs for dune reconstruction and for compensation of highly remunerative and popular establishments, conflicts with owners of buildings and concession holders, compensation costs	Long term	Dunes might not be fit for long-term protection strategies, scarce (physical) space for combining hard protection with NBS strategies	Establishments could move to other non protected beaches	Public investments for dune reconstruction and maintenance,	Free use of beaches is an attractive option for residents, limitation to uses may be perceived as deprivation of traditional rights
4	no	conflicts with owners of buildings and concession holders, compensation costs	Long term,	**no**			none
5	Low, institutional settings and territorial competences can change	Interaction in the given governance system causes high transaction costs	Mid term	No	No	Low costs	none

CS4.1 – Adaptation policy assessment, focus on health and distributional aspects

Basque Centre for Climate Change (BC3)

FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: 4.1 Adaptation policy assessment, focus on health and distributional impacts (BC3)
Representative for Decision Type: 4 Securing good health and social justice in regional and urban adaptation
Stakeholders: **Lead contact:** Direction of Natural Heritage and Climate Change, Department of Economic Development, Sustainability and Environment and Ihobe Basque Environmental Agency (Basque Government)
Where: Basque Autonomous Community (NUTS 2)

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation)?
No adaptation: Heat risks to health lead to increased morbidity and mortality and costs for the health sector
Business-as-usual adaptation: differential dimensions of vulnerability and exposure to heat are not accounted for, compounding or exacerbating social injustice as a result of adaptation.

Policy question of stakeholder
Concerning heat impacts on health:
- What are the economic and financial implications of climate risks for the health sector (and beyond)?
- What are the differential effects and social justice dimensions of adaptation options for different groups?
- What are the costs and co-benefits of adaptation options?

The role of the stakeholder in the decision-making process
The department involved is in charge of climate policy planning. The Environmental Agency is the operative arm of the department in many environmental issues, including climate change adaptation. It hosts the climate change office which coordinates with other departments, including public health and social affairs.

Relation to local, national, and European initivatives/policies

Regional policies:
- Basque Climate Change Strategy 2050
- New obligations arising from the implementation of the Basque law on energy transition and climate change
- Basque Health Plan 2030
- Environmental Framework Programme 2030

Regional / National: Ongoing health monitoring activities
Regional / National: National heat action plans
Local: local climate adaptation plans

Uncertainties (U)

What are the external factors?

Climate factors:
- Climate scenarios: regionalised scenarios overall foresee an increase in max. temp., heat waves duration but the magnitude depends on the scenario.
- Effects of other variables (e.g. humidity, air pollution)

Sociodemographic factors:
- Changes in population and ageing processes.
- Natural acclimatization processes

Economic factors:
- GDP and population projections, but not under CC.
- Discount rates
- Attitudes towards climate risks and adaptation

Other:
- Effectiveness of adaptation
- Accounting green adaptation measures (local)
- Assessing vulnerability (in a way that can be used for quantification).

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models

Economic approaches
- Health impact assessment: econometric model to assess regional mortality and morbidity
- Cost-benefit analysis

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
Regional (autonomous community) (NUTS 2)	2050	Health sector Cross-sectoral adaptation to heat

Adaptation options (O)

What adaptation options are considered in the case study?	Are the options more incremental or transformative? Incremental	Transformative
Grey		
• Cooling in health sector infrastructure / buildings	x	
Green		
• Development of green infrastructure	X	(X)
Soft		
• Early warning systems	X	
• Heat-related communication and information (general public, specific vulnerable groups, workplaces)	X	
• Actions of health and social service professionals, especially with different risk groups	X	
• Investments in energy efficiency	X	

Appraisal criteria (C)

What appraisal criteria are considered?	How are the criteria measured? Qualitative	Quantitative	Monetised
What direct costs are considered?			
- Cost of mortality		X	X
- Cost of morbidity		X	X
- Cost of health and adaptation options	X	X	X
What direct benefits are considered?			
- Avoided mortality and morbidity		X	X
- Reduced healthcare costs		X	X
- Reduced social inequality	X		
What co-benefits and co-costs are considered?			
Economic			
• Effects on productivity		(x)	
Social			
• Social justice	X		
• Well-being	X		
Environmental			
• Biodiversity			

Are you considering general welfare effects? If so, how?	Distributive	Temporal	Spatial
Yes	x	x	x

We will consider the distributional and wider social justice effects of heat impacts and how this is integrated in adaptation policy and related measures with relevance for the health sector. This includes analysis of vulnerable groups' residence, work context and access to health services.

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1	Communication campaigns	Heat warning and information plan; online portal, awareness campaign for vulnerable groups, training of personnel working with vulnerable groups	Incremental
2	Heat Action Plan (emergency plan)	Early warning systems Heat-related communication and information (general public, specific vulnerable groups, workplaces) Actions of health and social service professionals, especially with different risk groups.	Incremental
3	Long-term resilience building strategy for heat events	Development of green infrastructures Investments in energy efficiency in buildings (public and private)	Potential transformational effect
4			

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governannce and institutional (G).

#	Barriers	Cat
1	1 A Difficulties to reach specific vulnerable groups (e.g. due to language barriers) 1 B Lack of training time to skill up personnel or lack of trained personnel 1 C Limited effectiveness	S H G
2	2 A Lack of funding to implement strategies 2 B Difficulty in addressing vulnerable groups e.g. homeless people	F S
3	3 A Lack of funding to implement strategies 3 B Low support from relevant stakeholders in planning, implementation and maintenance of measures 3 C Vulnerable groups not prioritised despite higher impacts (e.g. gentrification processes, distributional effects of energy efficiency measures…)	F G S
…		
n		

Assessment of strategies (SA)

	Do you encounter path-dependencies in the identified strategies? If yes, how?	What are the transfer costs like?	What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?	Who will finance the strategy?	What are the main distributional effects of the strategy?	Will be you be able measure the direct costs and benefits qualitatively, quantitatively, or monetised?	For which co-costs and co-benefits could you provide an order of magnitude?
#	**Path-dependencies**	**Transfer costs**	**Timing**	**Financing of strategies**	**Distributive effects**	**Direct costs & benefits**	**Co-costs & -benefits**
1	Low. Change possible without locking the system.	Low transfer costs	Short-term, low regret strategy	Public funds (regional government)	Progressive if adapted to different vulnerable groups (language, format…)	Yes, direct costs estimated on CBA; benefits only of the overall HAP. Low-regret measure (co-costs).	Not assessed. Potential co-benefits: avoided impact, risk literacy. Potential co-costs: information fatigue.
2	Low. Procedures can be updated and measures such as EWS are in place for other extreme events as well.	Low	Annual plan, low regret strategy	Public funds (regional government)	Progressive when targeting vulnerable groups (elderly,…).	Yes, direct costs estimated on CBA; benefits in terms avoided mortality and morbidity. Low regret measure.	None.
3	Unknown, but probably low path-dependency in cases such as green infrastructure.	Overall, low transfer costs, except for measure with high upfront investments (e.g. energy retrofitting)	Long-term but some of them could be no regret (e.g. green infrastructure or promoting healthy lifestyles)	Public funds (regional government)	Progressive if targeting vulnerable and high-exposure groups and areas. Risk of regressive outcomes (amenity/gentrification, energy efficiency subsidies without equity lens).	No monetary costs and benefits were measured. Measures were included as overarching strategies.	None.
4							

CS4.2 – Qualitative assessment of social justice dimensions of climate policy

Ecologic & Basque Centre for Climate Change (BC3)

FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: 4.1 Adaptation policy assessment, focus on health and distributional impacts (BC3) and 4.2 Qualitative assessment of social justice dimensions of climate policy (Ecologic)
Representative for Decision Type: 4 Securing good health and social justice in regional and urban adaptation
***Stakeholders:* Lead contact** Ministry for Environment, Climate and Science of the Free Hanseatic City of Bremen - Directorate for Climate adaptation (Landeszentrale Klimaanpassung), **in coordination with** Ministry for health, Women and Consumer Protection of the Free Hanseatic City of Bremen and the Health Authority ("Gesundheitsamt").
Where: Bremen City (NUTS 3) and Federal (City) State (Bremen and Bremerhaven) (NUTS 2)

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation)?

No adaptation: Heat risks lead to increased morbidity, mortality, reduced quality of public spaces and lowered economic productivity during heatwaves as well as higher costs for health sector.
Maladaptation: differential dimensions of vulnerability and exposure to heat are not accounted for, compounding or exacerbating social injustice as a result of adaptation.

Policy question of stakeholder

Concerning heat impacts on health:
- What are the economic and financial implications of climate risks for the health sector?
- What are the differential effects and social justice dimensions of adaptation options for different groups?
- What are the costs and co-benefits of socially-just adaptation options?

The role of the stakeholder in the decision-making process

The Ministry for Environment, Climate and Science is responsible for municipal planning and monitoring, developing and implementing the state level Adaptation Strategy, mapping of climate impacts including areas with higher social vulnerability or heat stress. The Ministry led the design and development phase for the Heat Action Plan (HAP) with additional roles foreseen for different actors in the implementation.

The Ministry for Health, Women and Consumer Protection is responsible for public health services and the running of public health offices, responsible for hospital planning and investments, as well as medical education. The "heat action plan coordination unit" will be integrated in the health authority ("Gesundheitsamt") which is not directly a part of the Ministry but a subordinated authority.

Relation to local, national, and European initivaties/policies

Municipal / state: Update of climate adaptation strategy
Municipal / state: Analysis of climate impacts (every 5 years)
Municipal / state: Ongoing health monitoring activities
National / State level: Heat action plan (encouraged by new Federal initiative)

Uncertainties (U)

What are the external factors?

Climate factors:
- Climate scenarios
- Effects of other variables (e.g. humidity, air pollution)

Sociodemographic factors:
- Changes in population and ageing processes.
- Natural acclimatization processes

Economic factors:
- GDP and population projections, but not under CC.
- Discount rates
- Attitudes towards climate risks and adaptation

Other:
- Effectiveness of adaptation
- Accounting green adaptation measures (local)
- Assessing vulnerability (in a way that can be used for quantification).

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Economic methods

- Health impact assessment: econometric model to assess regional mortality and morbidity
- Cost-Benefit-Analyses

Qualitative methods for policy assessment

- Social justice policy assessment, probably based on Adaptation Justice Index (AJI)

Case study delineation (CS)

Spatial scale	*Temporal scale / time frame*	*Sector / discipline*
Local (city) (NUTS 3) and regional (federal state) (NUTS 2)	2030	Health sector Cross-sectoral adaptation to heat

Adaptation options (O)

What adaptation options are considered in the case study?	Incremental	Transformative
Grey		
• Cooling in health sector infrastructure / buildings		
• Identification of potential rooms that provide cooling	X	
• Drinking water provision either through wells or through water bottles, esp. for vulnerable groups in focus areas		
• Provide seasonal shading		
Green		
• Nature-based transformation of public spaces (long-term)		X
• Planting and maintenance of city trees and green spaces	X	
• Provide seasonal shading options through trees		
Soft		
• Heat information / awareness-raising of vulnerable groups	X	
• Creation of an online portal on heat	X	
• Training of staff in social and healthcare facilities	X	
• Exchange and networking on climate adaptation at state level	X	
• Communication regarding options for cooling	X	

Appraisal criteria (C)

What appraisal criteria are considered?	Qualitative	Quantitative	Monetised
What direct costs are considered?			
- Cost of mortality		X	X
- Cost of morbidity		X	X
- Cost of health and adaptation options		X	X
	X		
What direct benefits are considered?			
- Avoided mortality and morbidity		X	X
- Reduced healthcare costs		X	X
- Reduced social inequality	X		
What co-benefits and co-costs are considered?			
Economic			
• Effects on productivity		(X)	
Social			
• Social justice	X		
• Well-being	X		
Environmental			
• Biodiversity	X	(X)	

Are you considering general welfare effects? If so, how? Yes	Distributive	Temporal	Spatial
We will consider the distributional and wider social justice effects of heat impacts and how this is integrated in adaptation policy and related measures with relevance for the health sector. This includes analysis of vulnerable groups' residence, work context and access to health services.	X	X	X

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1	Communication campaigns	Heat warning and information plan; online portal, awareness campaign for vulnerable groups, trainining of personell working with vulnerable groups	Incremental
2	Management of extreme events	Enhanced information flow in case of extreme heat, drinking water provision in public spaces, preparation and communication of availability of cooler spaces for vulnerable groups, care for homeless and drug-consumers, provision of immediate cooling options in areas with a high proportion of vulnerable groups	Incremental
3	Long-term resilience building strategy for heat events	Climate-resilient green area management, reduction of heat island effects in public urban spaces, cooling of buildings used by vulnerable groups and for public and private social care facilities, planting and maintenance of city trees	Incremental

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governannce and institutional (G).

#	Barriers	Cat
1	1 A Lack of long-term funding to implement strategies 1 B Difficulties to reach specific vulnerable groups (e.g. due to technical barriers or cultural ones, limited accesibility via different media) 1 C Lack of staff in social care and high workload of existing ones	F S H
2	2 A Lack of long-term funding to implement strategies 2 B Lack of ability to induce behavioral change among vulnerable groups e.g. homeless people 2 C Governance of cross-sectoral measures given sectoral organization of Senate	F S G
3	3 A Lack of long-term funding to implement strategies 3 B Low support from relevant stakeholders in planning, implementation and maintenance of measures 3 C Vulnerable groups not prioritised despite higher impacts 3 D Lack of training time to skill up personell or lack of trained personell	F G S

Assessment of strategies (SA)

#	Path-dependencies	Transfer costs	Timing	Financing of strategies	Distributive effects	Direct costs & benefits	Co-costs & -benefits
	Do you encounter path-dependencies in the identified strategies? If yes, how?	What are the transfer costs like?	What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?	Who will finance the strategy?	What are the main distributional effects of the strategy?	Will be you be able measure the direct costs and benefits qualitatively, quantitatively, or monetised?	For which co-costs and co-benefits could you provide an order of magnitude?
1	Lack of skilled personell in urban and transport planning	High, requiring adjustment	Long lead-time and longer-term strategy	Mostly public (education funding)	Potentially more social cohesion as focus shifts to less-advantaged neighborhoods	Direct benefits: More holistic planning; higher adaptive capacity of the overall urban area, reduced heat island effect through improved shading and greenery. Strategy 1 was costed as part of the overall HAP.	Increased biodiversity; improved air quality through less car traffic and integration of nature-based solutions in traffic planning
2	Structural lock-in in health sector (lack of funding)	High, requiring adjustment of funding streams and priorities	Long lead-time and longer-term strategy	Public	More funding available for disadvanted groups in health sector can enhance their protection against heat-related risks.	Overcoming lock-in would allow to focus more on heat-related vulnerabilities of marginalized groups Strategy 2 costed as part of the overall HAP.	
3	Mental lock-in / dominating paradigms in urban and transport planning and social planning	High, requiring adjustment of funding streams and priorities	Long lead-time and longer-term strategy	Public	Potentially more social cohesion as focus shifts on less-advantaged neighborhoods.	Direct benefits: Overcoming lock-in would allow to focus more on heat-related vulnerabilities of marginalized groups; More holistic planning; higher adaptive capacity of the overall urban area, reduced heat island effect through improved shading and greenery. No measurement of costs possible.	

CS5.1 – Adaptation options for enhancing financial stability

Deltares

FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: *5.1* Adaptation options for enhancing financial stability
Representative for Decision Type: 5. Financial and private sector adaptation decisions
Stakeholders: De Nederlandsche Bank (Central Bank of the Netherlands)
Where: The Netherlands

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation)?
Without adaptation, flood risk and other climate hazards might possibly develop into risks with substantial adverse impacts on the stability of the financial system, in particular for banks that have exposures to areas vulnerable to climate risks.

Policy question of stakeholder
Are climate hazards a substantial threat to financial stability? What are relevant transmission channels? What can be done to adapt to this? How would adaptation to climate hazards interact with macroprudential policy?

The role of the stakeholder in the decision-making process
DNB has different roles and mandates. For this project financial stability monitoring and developing macro-prudential policy is relevant:

- Identifying financial vulnerabilities related to climate change
- Filling of existing data and analytical gaps on climate-related financial risks.
- Raising awareness, e.g. among financial institutions.
- Research regarding options for macroprudential policy.

Relation to local, national, and European initiatives/policies
At this moment, each central bank in Europe is starting to work on climate risks. In NL: the choice to start with flood risk is natural given the large exposure to floods in NL. On the European level, climate-related risks are being addressed by the ECB and national central banks, for instance in the form of climate stress tests.

Uncertainties (U)

What are the external factors?

Climate Scenarios
- dike breach locations -> leading to different flood events; climate change is reflected in the probability

Socioeconomic Scenarios (SSPs)
- not assessed

Socio-economic characteristics:
- reflected by looking into different parts of the country with different real estate characteristics.

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models
A train of models consisting of:

- Flood hazard models (retrieved from LIWO)
- Flood damage models for real estate (SSM)
- Financial risk models, in particular on credit risk.

Economic methods

- Models used to assess financial vulnerabilities, for instance by testing if adverse flood scenarios could cause substantial capital depletion through a real estate damage channel

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

- Business-as-usual adaptation strategy: fully relying on strengthening flood defences to keep risk at acceptable levels.
- Reduced lending standard for properties exposed to flooding: LTV's capped to 90% of real estate taxation value (see Endendijk et al., 2024)

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
The Netherlands	Now, 2050, 2100	Banks, possibly also other types of financial institutions.

Adaptation options (O)

What adaptation options are considered in the case study?	Are the options more incremental or transformative? Incremental	Transformative
Grey		
• Strengthening flood defences	✓	
Soft		
• Differentiate pricing or lending standards based on degree to which collateral is at risk from floods		✓
• Climate risk information provision	✓	

Appraisal criteria (C)

What appraisal criteria are considered?	How are the criteria measured? Qualitative	Quantitative	Monetised
What direct costs are considered?			
Direct construction costs (see case 1.1)			✓
What direct benefits are considered?			
Flood risk reduction (reduced expected annual damage)			✓
Individual mortality risk		✓	
Group mortality		✓	
What co-benefits and co-costs are considered?			
<u>Economic</u>			
Maintaining an attractive investment climate in NL	✓		
Financial stability – impacts on lenders		✓	✓
LTV cap may drive up prices in flood-safe areas, and reduce house prices in flood-prone areas, with associated household wealth and housing market accessibility effects	✓		
<u>Social</u>			
Accessibility of the housing market			✓
<u>Environmental</u>			
Are you considering general welfare effects? If so, how? YES/NO			
Reclection on the distributional impact of LTV-cap on households with different wealth, notably younger first-time buyers vs older, wealther owners of existing homes.			✓

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1	Fully relying on physical flood adaptation options	Dike and storm surge barrier strengthening	Incremental
2	Active steering with financial adaptation instruments	Various macroprudential policy options, **reduced lending standards in flood prone areas***, concentration limits	Transformative (because application in climate domain is new)
3	Provision of climate risk information, leaving adaptation to the market	Climate label at asset level, private flood insurance system, mortgage provision conditional on climate risk.	Transformative (in the Dutch context, would be incremental in UK/USA)

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governance and institutional (G).

#	Barriers	Cat
1	Seems feasible up till 5 m sea level rise Saltwater intrusion Affordability with extreme sea level rise	T P E
2	Technical limits in reliability of climate risk data **Interference with other macroprudential policy objectives such as accessibility of the housing market** **May reduce credit availability**	T E,F F,G
3	Technical limits to reliable climate labels at asset-level At tension with culture of solidarity in Dutch water governance	T S,G

Assessment of strategies (SA)

#	Path-dependencies	Transfer costs	Timing	Financing of strategies	Distributive effects	Direct costs & benefits	Co-costs & -benefits
	Do you encounter path-dependencies in the identified strategies? If yes, how?	What are the transfer costs like?	What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?	Who will finance the strategy?	What are the main distributional effects of the strategy?	Will be you be able measure the direct costs and benefits qualitatively, quantitatively, or monetised?	For which co-costs and co-benefits could you provide an order of magnitude?
1	Risk of lock-in and maladaptation on the long-term (> 5 m sea level rise). Levee-effect: May encourage further developments in risky areas. Further fuelling the agglomeration forces in the flood-prone Randstad area.	Very large, see case study 1.1	0 year, this already is the strategy	Public (taxes)	Principle of solidarity: people in safe areas pay for people in high-risk areas	Not done by us, but this is the principle behind the CBA on which flood protection standards in NL are based.	n.a.
2	Counter levee-effect: (Slightly) discourages developments in risky zones.	Lower	A decade?	n.a. (relatively cheap)	Risk of climate adaptation gentrification **Wealth impacts on existing home owners**	Qualitatively	**LTV-cap: benefits for credit impacts on lenders**
3	Risk of market failures			Left to the market.	Like 2.	No	None

* Bold adaptation options and effects are discussed in the case study, some of the other effects will be discussed in the deliverable on Adaptation Decision Types.

CS5.2 – Stimulation of private sector adaptation through insurance arrangements

Vrije Universiteit Amsterdam (VU)

FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: Stimulation of private sector adaptation through insurance arrangements
Representative for Decision Type: *5 (finance and private sector)*
Stakeholders: Dutch association of insurers
Where: *The Netherlands*

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation)?

Businesses are (indirectly) affected by floods and suffer long-term business-interruptions, causing societal disruptions, e.g., unemployment, shortages in products.

Policy question of stakeholder

Can insurance effectively encourage adaptation by businesses to increasing flood risk? How could such a policy look like? (e.g. conditional insurance, premium discounts, business-interruption insurance)

The role of the stakeholder in the decision-making process

The stakeholder advises insurance companies on effective business strategies. Therefore, it has a considerable impact on insurance operations. The stakeholder represents its members (i.e. 97% of Dutch insurance market).

Relation to local, national, and European initivaties/policies

NatCat Insurance is a relevant topic in all European countries. E.g., EIOPA has set a specific goal to reduce the European NatCat insurance protection gap. Also to increase risk awareness and stimulate risk-conscious behaviour. Regarding indirect business impacts, this is under-researched. Climate Resilience Dialogue (EC) – Insurance Europe.

Uncertainties (U)

What are the external factors?

- Flood risk
- Flood protection standards
- Insurance system/availability
- Adaptation effectiveness
- Climate scenarios (RCPs)
- Socioeconomic scenarios (SSPs)

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models

DIFI
SSM
GLOFRIS

Economic methods

- Partial-equilibrium modelling
- Utility maximization
- Cost-benefit analysis

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
Municipality/1x1km Building level	**Current-2050-2080**	Private sector Industrial/commercial Small/medium/large businesses

Adaptation options (O)

What adaptation options are considered in the case study?	Incremental	Transformative
Grey - Policyholder-level adaptation (wetproofing/dryproofing)	✓	
Green		
Soft • Incentivizing policyholder-level adaptation via insurance • Insurance policies • Insurance system change	✓	✓

(Are the options more incremental or transformative?)

Appraisal criteria (C)

What appraisal criteria are considered?	Qualitative	Quantitative	Monetised
What direct costs are considered? **Damages (direct and indirect)** **Adaptation costs**			✓
What direct benefits are considered? Reduced risk Increased adaptation effort			✓ ✓
What co-benefits and co-costs are considered? Supply risk (decreased business interruption)			✓
Social			
Environmental			

(How are the criteria measured?)

Are you considering general welfare effects? If so, how?	Distributive	Temporal	Spatial
No			

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1	Policyholder adaptation	Wetproofing/dryproofing	Incremental
2	Incentivizing policyholder adaptation via insurance	Insurance premium discounts	Incremental
3	Insurance policies	Coverage for direct damage or business interruption	Incremental
4	Insurance system change	Moving from private to public reinsurance	Transformative
5			
n	…	…	

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governance and institutional (G).

#	Barriers	Cat
1	Adaptation needs to be possible, it has to be cost-effective.	E/F/ H/K
2	It needs to be cost-effective, insurers have to be willing, adaptation investment needs to be verified.	E/F/ H/G
3	Damage needs to be calculated accurately, businesses need to be willing to insure.	E/F/ H/G
4	Legislative framework, government needs to be willing, needs to be politically feasible.	H/S/ G
…		
n	…	…

Assessment of strategies (SA)

#	Path-dependencies	Transfer costs	Timing	Financing of strategies	Distributive effects	Direct costs & benefits	Co-costs & -benefits
	Do you encounter path-dependencies in the identified strategies? If yes, how?	What are the transfer costs like?	What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?	Who will finance the strategy?	What are the main distributional effects of the strategy?	Will be you be able measure the direct costs and benefits qualitatively, quantitatively, or monetised?	For which co-costs and co-benefits could you provide an order of magnitude?
1	Protection standards are hard to revert. Potential lock-in.		Long-term strategy	Policyholders	Risk of disproportionally benefitting higher socioeconomic classes	Monetised (reduced risk)	-
2	Protection standards are hard to revert. Potential lock-in.		Long-term strategy	Policyholders	Increased difference in risk between insured and uninsured businesses	Monetised (reduced risk), increase in adaptation effort	-
3	Individualization of the risk through the insurance systems might prevent more collective or systematic approaches.		Short-term strategy (yearly)	Policyholders	In case of risk-based premiums, certain areas can have insurance premiums that are not affordable for the local businesses	Monetised (reduced risk)	-
4	Fundamentally changing the insurance market form in a country is difficult		Long-term strategy	Government/insurers/policyholders	May increase or decrease distributive solidarity depending on policy change	Monetised (reduced risk), increase in insurance uptake	-
…	…	…					
n	…	…					

CS6.1 – Adaptation to minimize the risk of disruptions of trade corridors

Deltares & University of Graz

FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: 6.1 Adaptation to minimize the risk of disruptions of trade corridors (road and rail network)
Representative for Decision Type: 6 (Transport and supply chains)
Stakeholders: **Federal** Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK)
Where: Austria

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what are the costs without adaptation, and with different adaptation strategies?
Without adaptation: changing flood hazard could lead to increased transportation time / restriction of travel corridors and the cutting off of regions from the rest of the transport network. This could lead to additional impacts on businesses relying on just-in-time production/warehousing, restriction of movement, tourism losses etc.
With business-as-usual adaptation: Lack of transformative adaptation could lead to costly options being pursued / lack of awareness of alternatives e.g. improving resilience of transport network via creation of additional links / nodes

Policy question of stakeholder
How can adaptation options and strategies be prioritized with respect to identifying areas with highest co-benefits and synergies to other adaptation goals (e.g. Disaster risk reduction) in a rigorous operationalized framework?

The role of the stakeholder in the decision-making process
The BMK focuses on national adaptation strategy, e.g. drafting the Austrian Strategy for Adaptation to Climate Change and providing periodic updates. The Ministry sets strategic goals for (among others) transport e.g. safeguarding a functioning transport system, and recommends strategies e.g. “reduction in the growth of permanently sealed roadways as flood protection.“ BMK is also responsible for assessing progress towards achieving these strategies (qualitatively, expert judgement)

Relation to local, national, and European initivaties/policies
Local: defines national strategy in some cases to be implemented at local level (roadways could fall in this area, as rail focus is national level)
National: Collaboration with other Ministries (e.g. Finance for adaptation funding, Interior who has jurisdiction over disaster risk reduction etc.)
EU: Ensure compliance with reporting of national adaptation plans, incorporation EU Green Deal goals into strategy etc.

Uncertainties (U)

What are the external factors?

Climate Scenarios

- We use hazards with return periods of 30-100 and 300 year events
- We use RCP 4.5 and RCP 8.5
- The flood model itself has its limitations (frequency/intensity)

Socioeconomic Scenarios (SSPs)

- Sensitivity analysis includes different discount rates and accounting periods for benefits.
- Costs for adaptation are estimated at 400EUR per km, in the sensitivity analysis lower bounds and upper bounds are used.

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models

- Deltares RA2CE-tool for assessing damage to road and rail network
- Use output of SWAN hydrological model of the University of Köln
- Explorative analysis of ERA-5 climate data (precipitation)

Strategic appraisal

- Use MIRACA conceptual framework that describes adaptation at 4 levels

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
National	We look at current resilience of infrastructure, 2050 and 2100. Looking at flood events with return periods of 30, 100 and 300 years. Investment to infrastructure in discounted in 25 years.	Transport- road and rail network

Adaptation options (O)

What adaptation options are considered in the case study?	Are the options more incremental or transformative? Incremental	Transformative
Grey • Increasing road height	X	
Green		
Soft		

Appraisal criteria (C)

What appraisal criteria are considered?	How are the criteria measured? Qualitative	Quantitative	Monetised
What direct costs are considered?			
Investment costs of measures, including discount rates		X	X
Damages to infrastructure		X	X
What direct benefits are considered?			
Reduction in infrastructure impacts		X	X
What co-benefits and co-costs are considered?			
<u>Social</u>			
• Change in accessibility of regions	X		
• Adaptation priorization for regions with lowest GDP	X		

Are you considering general welfare effects? If so, how?
Yes, we take three different adaptation strategies based on either utilitarian, egalitarian or prioritarian principles,

Distributive	Temporal	Spatial
X		X

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1			
2			
3			
4			
…	…	…	
n	…	…	

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or governannce and institutional (G).

#	Barriers	Cat
1	Transformative adaptation likely too difficult, due to political aspects – incremental adaptation generally much easier	G
2	Example of raumordnung (spatial planning) – key issue of stepping on rights, responsibility for planning can be at state / local level, rather than national – any aspect / bringing up of rights leads to a closing down of discussion	G
3	Limited financing available; only what is budgeted, a major barrier to transformative adaptation; new projects outside of typical spending have to be approved by Parliament	F/G
4	Issue of jurisdiction / Ministerial responsibility, e.g. Spatial planning typically falls to Land ministry, rather than Climate	G
…	Relocation also difficult due to EU-level governance	G
n	…	…

Assessment of strategies (SA)

Do you encounter path-dependencies in the identified strategies? If yes, how? | **What are the transfer costs like?** | **What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?** | **Who will finance the strategy?** | **What are the main distributional effects of the strategy?** | **Will be you be able measure the direct costs and benefits qualitatively, quantitatively, or monetised?** | **For which co-costs and co-benefits could you provide an order of magnitude?**

#	Path-dependencies	Transfer costs	Timing	Financing of strategies	Distributive effects	Direct costs & benefits	Co-costs & -benefits
1							
2							
3							
4							
…	…	…					
n	…	…					

CS6.2 – Supply chain resilience analysis for individual businesses

University of Graz

FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: 6.2 Supply chain resilience analysis for individual businesses
Representative for Decision Type: 6 (Transport and supply chains)
Stakeholders: AT&S and Fronius
Where: Headquarters in Austria

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation)?

No adaptation: Increasing intensity and frequency of supply chain disruptions
BAU adaptation: May reduce some but not all climate-induced supply chain risks

Policy question of stakeholder

How to adapt to physical climate risks transmitted through supply chains and how to embed climate risk considerations into broader decision-making processes?

The role of the stakeholder in the decision-making process

Fronius: responsible for managing supply chain risks; (general) risk management
AT&S: responsible for managing supply chain risks; CSR division

Relation to local, national, and European initivatives/policies

European: Corporate Sustainability Reporting Directive (CSRD) guidelines for physical risk reporting
National/European: financial reporting duties

Uncertainties (U)

What are the external factors?

Climate Scenarios
Socioeconomic Scenarios (SSPs)

Geopolitical risks, conflicts along supply chains

Protectionism vs open trade

Increased demand for sustainable resources & raw materials (from other sectors)

Changing market demand

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Expert Judgement

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
Firm-level	Prinarily 3-5 years (for operational decisions), 5+ years for strategic considerations	Supply chain management / economics

Adaptation options (O)

What adaptation options are considered in the case study?	Incremental	Transformative
Grey		
• Increasing inventory buffers (I)	x	
Green		
Soft		
• Diversification of suppliers (I)	X	
• Regionalization/localization (I)	X	
• Scenario planning & stress testing / climate risk assessment (I)	X	
• Forecasting/early-warning systems (I)	X	

Are the options more incremental or transformative?

Appraisal criteria (C)

What appraisal criteria are considered?	Qualitative	Quantitative	Monetised
What direct costs are considered?			
Costs of implementing monitoring system			x
Costs for supplier switching			x
Operational costs	x		
What direct benefits are considered?			
Reduction in supply chain disruptions	x		
What co-benefits and co-costs are considered?			
Sustainability			
Economic			
• Effects on upstream suppliers (increasing their resilience) and downstream markets (market stability)	x		
• Legitimate CSRD reporting can increase attractiveness for investors and customers	x		
Social			
Environmental			
• CSRD reporting is an important signaling to costumers; adding physical risks to that; indirectly contribution to environmental goals	x		
	Distributive	**Temporal**	**Spatial**
Are you considering general welfare effects? If so, how? YES/NO			

How are the criteria measured?

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

#	Strategy description	Individual options that are part of the strategy	Is the strategy transformative or incremental?
1	Diversify and monitor	Climate risk assessment, monitoring, supply chain diversification. inventory management, operational flexibility	incremental
2			
3			
4			
…	…	…	
n	…	…	

Barriers to adaptation (B)

What are the barriers to adaptation for each strategy? Please describe them briefly and categorize them as either knowledge, awareness, technology (K); physical (P); biological (B); economic (E); financial (F), human capital (H), social and cultural (S); or goverannce and institutional (G).

#	Barriers	Cat
1	1A – weather & disaster forecast is still in its infancy, information therfore maybe not be reliable	K
	1B – lack of in-house expertise/capacity/financial means	K, F
	1C – in-house responsibilities not cleary defined	G
	1D – market maybe too concentrated to allow for risk-reducing diversification	E, (P)
	1E – additional financial burden (classification & certification) associated with new/additional suppliers	F
2		
3		
4		
…		
n		

Assessment of strategies (SA)

Do you encounter path-dependencies in the identified strategies? If yes, how? **What are the transfer costs like?** **What are the lead times of the strategy? Is it a short-term low-regret strategy, or one for the longer-term?** **Who will finance the strategy?** **What are the main distributive effects of the strategy?** **Will be you be able measure the direct costs and benefits qualitatively, quantitatively, or monetised?** **For which co-costs and co-benefits could you provide an order of magnitude?**

#	Path-dependencies	Transfer costs	Timing	Financing of strategies	Distributive effects	Direct costs & benefits	Co-costs & -benefits
1	If early warning and forecasting messages turn out to be wrong -> warning might not be considered in decisions in the future; Hard to determine under which conditions (threshold) diversification should be moved forward; Switching back to former supplier/distributer may be difficult or incur additional costs (question of trust);	Low for no monitoring to monitoring; medium (to high) for diversification conditional on input component;	Lead time is comparatively low for montoring, ongoing learning and improvement of sytem possible; but higher lead time for diversification; this is also potentially irreversible (therefore higher regret)	private	n.a.	Maybe for monitoring system; maybe some substantiation under which conditions costs diversification are medium or high	Mostly intangible values, cannot be monetized
2							
3							
4							
…	…	…					

CS7.3 – Cross-sectoral economic analysis for adaptation

The Cyprus Institute (CyI)

XLRM FRAMEWORK FOR CASE STUDY ASSESSMENT ACCREU

Case study: National adaptation investments, costs and benefits
Representative for Decision Type: *7 (cross-cutting)*
Stakeholders: Ministry of Environment and Ministry of Finance
Where: Cyprus

Policy question (Q)

What is the key policy question that your case study will answer?

Problem statement: what happens without adaptation (and with business-as-usual adaptation)?
No adaptation: Costs of inaction for CY (economic and macro-economic) through to 2050 and beyond (2100 to the extent possible). Business-as-usual adaptation: Costs of adaptation at current levels (public finances) and thus rising residual damage

Policy question of stakeholder
What are the aggregate adaptation investment needs (costs) for Cyprus for time periods 2030/2050? Which of these needs are planned in national budgets or the national adaptation strategy? What might be the effect of adaptation investment on public finances?
This will be used for a considerations by the national Ministries of Finance and Environment about adaptation investment needs. Currently, the Ministries have a vague overview of these needs.

The role of the stakeholder in the decision-making process
Ministry of Finance: Responsible for macro-economic planning, public financial management and medium-term expenditure and budgeting (including spending review) as well as macro-economic and macro-fiscal forecasting.
Ministry of Environment: Revision and implementation of national adaptation action plan

Relation to local, national, and European initiatives/policies
European: Informs the national adaptation strategy that is prepared in line with EU guidance, as well as national macro-economic and fiscal plans in line with the European Semester process.
National: Key initiative to provide costed investment plans for national adaptation programmes and plans

Uncertainties (U)

What are the external factors?

Climate Scenarios
Socioeconomic Scenarios (SSPs)

- CY climate change scenarios
- CY specific socio-economic projections

- Discount rate
- Consideration of distributional effects
- Risk aversion

Models/Methods (M)

What tools/methods/models are used to capture the uncertainties and evaluate the appraisal criteria?

Models

- CyI downscaled climate change models
- CyI energy and economic input-output models
- Other models, e.g. crop models used in earlier studies about adaptation costs for agriculture; etc.

Economic methods
- Multiple, to include at minimum:
- Econometric methods
- Investment cost pathways
- CBA of adaptation investments
- Economic valuation / Benefit transfer methods

Adaptation strategies (S)

Can you cluster the different adaptation options into more overarching strategies in your case study?

Aggregation of costs of adaptation, split by public and private sector, at national level
Assessment of the impact of adaptation on the public finances.

Case study delineation (CS)

Spatial scale	***Temporal scale / time frame***	***Sector / discipline***
National	2030 & 2050	Multi-sectoral aligning to various line ministries and investments

Adaptation options (O)

What adaptation options are considered in the case study?

For each risk, an adaptation portfolio will be developed, which will include different options and potential mixes of grey, green and soft

Grey
- Multiple

Green
- Multiple

Soft
- Multiple

Are the options more incremental or transformative?

Incremental	Transformative

Appraisal criteria (C)

What appraisal criteria are considered? / **How are the criteria measured?**

	Qualitative	Quantitative	Monetised
What costs are considered?			
• Capital investments			✓
• Operating costs			✓
• Potentially other costs (resource cost, opportunity costs)			✓
What direct benefits are considered?			✓
• Reduction in expected annual damages			
What co-benefits?			
Economic			
• Multiple			✓
Social			
• Multiple	✓		
Environmental			
• Multiple	✓	✓	
Are you considering distributional effects? Yes/No	✓		

If yes, how?
We provide evidence from earlier studies about the distributional impact of unmitigated climate change without adaptation.