# Policy Brief:

## Review of the Economics of Climate Change and Adaptation in Europe

March 2024

ACCREU
Assessing Climate Change Risk in EUrope

Funded by the European Union

## Summary

The ACCREU project (Assessing Climate Change Risk in EUrope) is an innovative research project that gathers leading experts on climate change economics from 14 European research institutions. ACCREU aims to advance the knowledge on climate change risks and adaptation, working with stakeholders using a co-creation approach.

To help inform the first stakeholder workshop, the project has undertaken a review of the current knowledge on the economic costs of climate change, and the costs and benefits of adaptation. The findings are summarised on the next page.

A similar assessment was undertaken at the start of the previous COACCH project (2018). The new stock-take finds that in recent years, there has been a significant improvement in the information on the costs of climate change impacts, as well as progress on adaptation economics. However, significant gaps remain.

The study has also identified the potential research gaps by sector. These are set out in a table at the end of this policy brief. These priorities were discussed with stakeholders at the first workshop, along with relevant policy questions to consider.

## Knowledge base

| Risk / Sector | Coverage of Economic Analysis | Impacts | Adaptation |
|---|---|---|---|
| **Coastal zones and coastal storms** | Comprehensive coverage (flooding and erosion) of economic impacts at EU, national and local level. Applied adaptation policy studies including decision making under uncertainty (DMUU). | ✓✓✓✓ | ✓✓✓✓ |
| **Floods** | Good coverage at EU, national and local level, especially for river floods (less so surface floods) and estimates of adaptation benefits and costs, as well as adaptation policy studies. | ✓✓✓✓ | ✓✓✓ |
| **Agriculture** | Good coverage of EU and national studies (partial and general equilibrium). Studies of farm and trade adaptation. Emerging policy analysis on agriculture, water, adaptation and economics. | ✓✓✓ | ✓✓ |
| **Forest and fisheries** | Some studies on the economic impacts on forestry (productivity) and forest fires, less on pest and diseases. Limited studies on impacts on marine or freshwater fisheries. Lower coverage of adaptation. | ✓✓ | ✓ |
| **Infrastrucure including Transport** | EU studies on critical infrastructure, including road and rail. Some studies for air and inland waterways. Some adaptation including network and policy analysis. | ✓✓✓ | ✓✓ |
| **Energy** | Studies on costs of energy demand (heating, cooling) and supply (hydro, wind). Coverage of autonomous adaptation and some costs of planned adaptation. | ✓✓✓ | ✓✓ |
| **Water manage-ment** | Some EU wide national and catchment supply-demand studies (and deficit analysis) and analysis of droughts, with some adaptation cost and policy studies. | ✓✓ | ✓✓ |
| **Business, services and industry** | Good coverage of impacts for labour productivity and increasing studies of supply chains. Low evidence base on other areas. Low coverage of adaptation. | ✓✓ | ✓ |
| **Tourism** | EU and national studies on beach tourism (climatic comfort in the Mediterranean) and winter ski tourism (Alps). Low information on other tourism. Less information on adaptation. | ✓✓ | ✓ |
| **Finance** | Most focus on transition risk. Limited mapping of physical climate risk and limited to selected case studies. Little on adaptation other than stress tests. | X | X |
| **Health** | Good coverage of EU and national heat related mortality. Some estimates for food-borne disease. Lower coverage for other impacts. Emerging evidence base on adaptation costs and benefits (for heat). | ✓✓✓ | ✓ |
| **Biodiversity / ecosystem services** | Very low evidence base on economic impacts. Adaptation policy studies limited to restoration costs and extending protected areas. | X | ✓ |
| **Macro-economic analysis** | Several EU studies using CGE models, though coverage varies by sector as above. Limited consideration of adaptation. | ✓✓ | X |
| **Other** | Little coverage of social sectors (education), socially contingent (e.g. migration), and most climate tipping points. Limited analysis of distributional impacts of climate change and adaptation. | X | X |

✓✓✓✓ = Very high coverage ✓✓✓ = High coverage. ✓✓ = Medium coverage. ✓ = Low coverage. x = Evidence gap.

## Introduction

ACCREU (Assessing Climate Change Risk in EUrope) is a project funded by HORIZON Europe and is a Research and Innovation Action. The objective of the project is to address existing knowledge gaps, and to develop a fully integrated framework for climate change impacts, mitigation, adaptation and the prospects for a social and economic sustainable development.

ACCREU will identify challenges, highlight opportunities and deliver practical solutions to policy making and societal actors at the EU, Member State, region and local level to accelerate a just societal transformation towards climate resilience in the short, medium and long term.

## Co-Creation

The ACCREU project is dedicated to producing research that supports evidence-based decisions and policy making. To this end, the project adopts a co-creation approach that actively engages stakeholders in the project's design and research.

ACCREU builds on the outcomes of COACCH (CO-designing the Assessment of Climate CHange costs), a research project on the economics of climate change that developed good practice for climate research co-design and co-production (McGlade et al., 2022). European economic cost studies on climate change had previously limited their outreach to the communication of results. COACCH led a step-change by inviting stakeholders to collaboratively design and produce research on the economics of climate change.

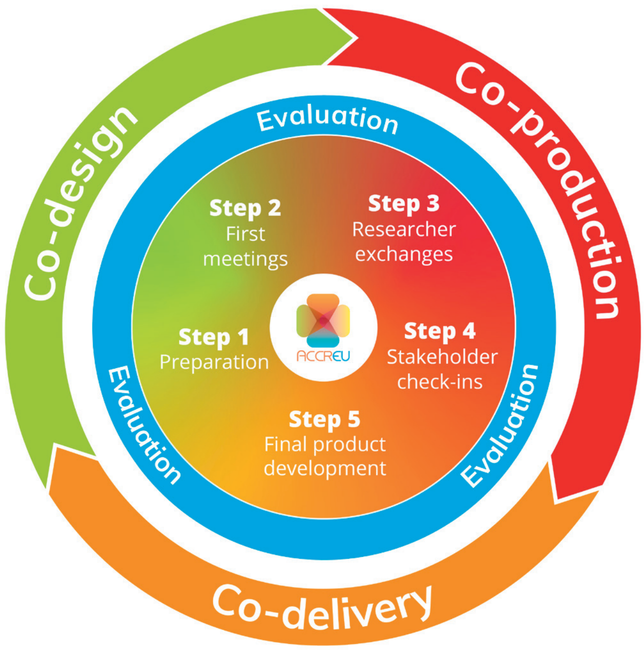
The ACCREU project will build on this approach to co-create research in three phases:

- The first phase is **co-design**, where the project team and stakeholders identify common interests and jointly develop research questions.
- This is followed by **co-production**, an iterative process where the project team work together with stakeholders on chosen case studies to produce cutting-edge research with policy synergies.
- In the final co-delivery stage, the project team and stakeholders develop communication strategies and products to translate project results and support uptake into practice.

The overall project has an inclusive and participatory approach, from defining research questions and policy scenarios to delivering outreach activities and impact.

In line with the co-creation principles, ACCREU is engaging with a diverse group of stakeholders representing a range of European regions, sectors and interests. From this group, some organisations have been identified as key 'deep engagement' end-users and have been offered the opportunity to engage more deeply in specific use-cases.

ACCREU's co-creation practices are mainly focused on producing useable knowledge for decision making. However, ACCREU will also bring together academic and non-academic actors to test open and emergent forms of co-creation. These methodologies will be used to support discussions that can challenge existing thinking and narratives and explore pathways on the economics of transformational adaptation.



## Climate models and scenarios

Analysis of the future impacts and economic costs of climate change uses models and scenarios.

Climate models are numerical representations of the climate system and are based on physical properties and feedback processes. Global climate models (GCMs) provide a comprehensive analysis of the global climate system. However, these models provide results at an aggregated level, and for higher resolution, downscaling approaches are used, typically with regional climate models (RCMs).

To assess future climate change, a set of common scenarios are used in these models, the **Representative Concentration Pathways (RCPs)**. These provide climate (forcing) pathways that cover futures consistent with the 2°C goal (or even lower) through to highend (4°C) scenarios. To capture the natural interannual variability of the climate, the results from these models are typically presented for a period of 20 years, with a historic reference period compared to future time-slices.

For analysis, the RCPs are combined with a set of **Shared Socio-economic Pathways (SSPs)**. These provide a set of socio-economic data for alternative future pathways, with differing future population, economic development, technology, policies, etc. There are five SSPs, each with a unique set of socio-economic data and assumptions. The SSPs are presented along the dimensions of challenges to mitigation and adaptation.

Combining SSPs and RCPs gives a matrix of possible combinations, as shown below. However, this means there are a very large number of possible RCP—SSP combinations, and it is usual to sample across this matrix.

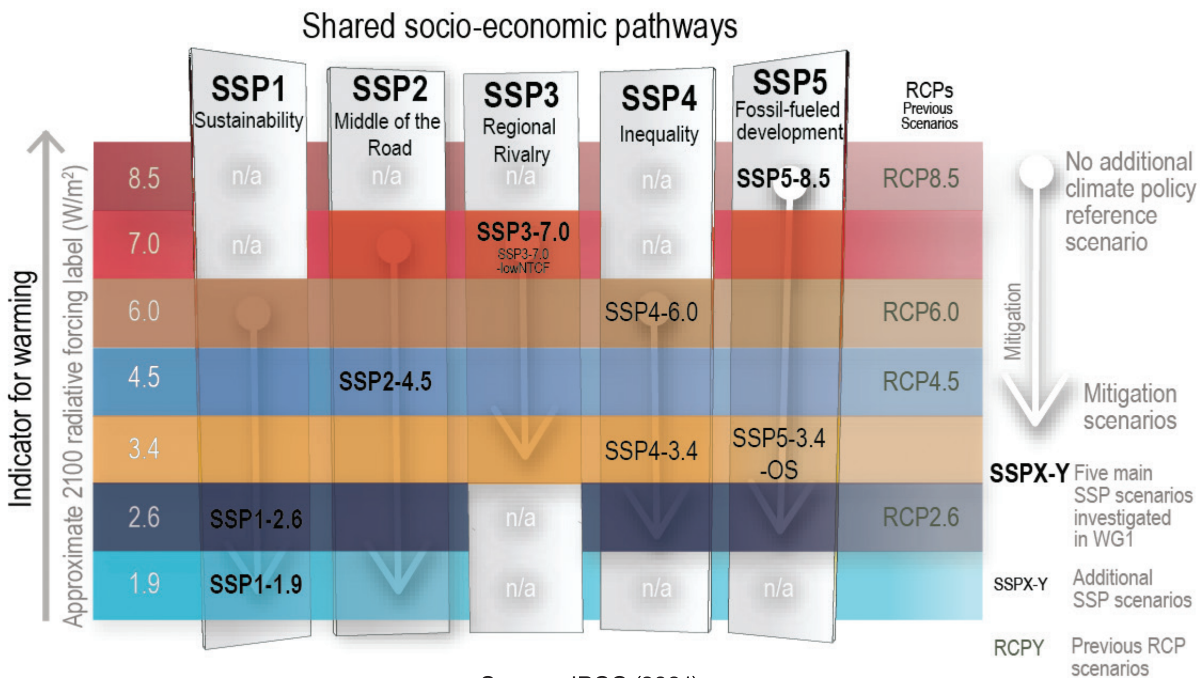
Related to this is the key issue of **uncertainty**, which is critical to the analysis of climate change and especially adaptation.

The first uncertainty issue is around the GHG emission pathway that will emerge and whether the world will warm by 2˚C, 3˚C or 4˚C relative to preindustrial levels. This can be considered by looking at multiple scenarios (RCPs).

However, a further uncertainty factor is the difference in the results from various climate models, both from the GCMs and the RCMs. These often involve very large differences, for example, between hotter or cooler, or wetter and drier models. This can be considered by sampling different climate models across the ensemble.

These RCPs and SSPs are typically used in the analysis of future impacts and economic costs of climate change, However, there is additional uncertainty from differences in impact models and economic models that widens the uncertainty range further.

It is essential to recognise this uncertainty, not to ignore it or use it as a reason for inaction.




Source: IPCC (2021)

## Impacts and Adaptation in ACCREU

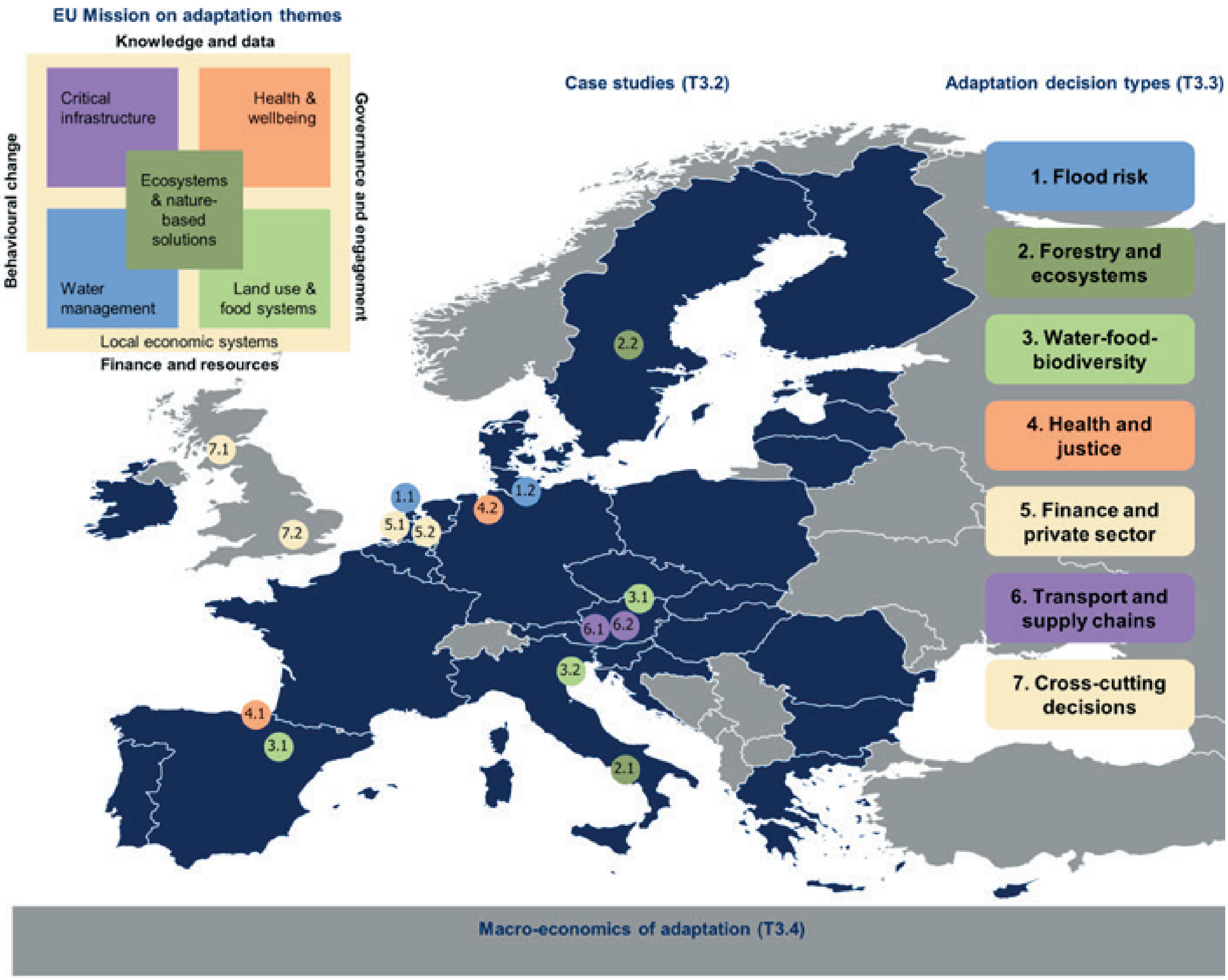
The ACCREU project is using a set of models to assess the economic costs of climate change, and the costs and benefits of adaptation.

**Global level.** The project will use Integrated Assessment Models for global analysis of the impacts of climate change over time, including with mitigation policy, and will extend these to include adaptation.

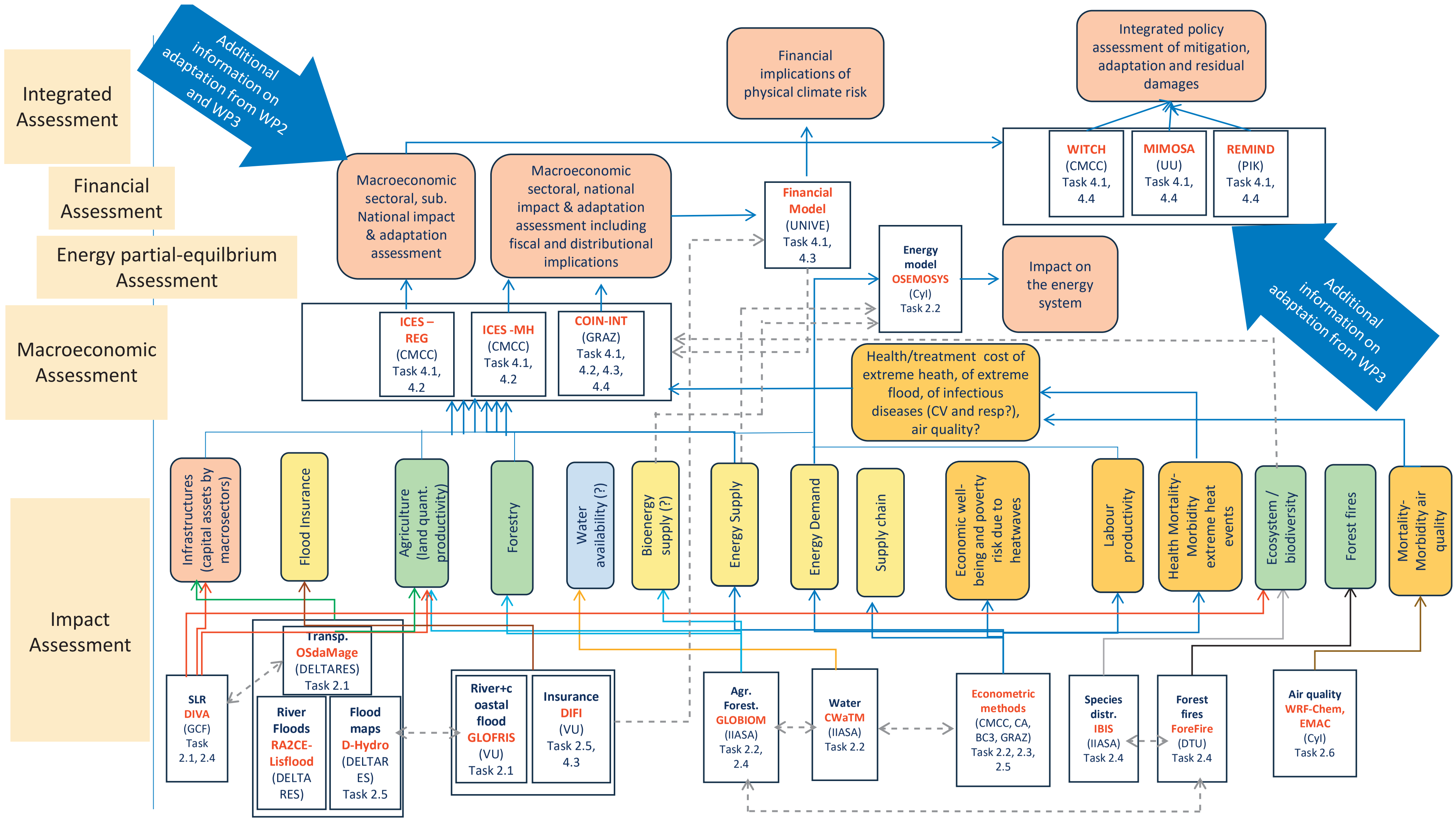
**European level.** The project will further develop the modelling framework used in the previous COACCH project with a more comprehensive framework, shown over the page.

This includes a large number of sector models, which are run for consistent scenarios, with the results fed into a cross-economy Computable General Equilibrium model (CGE). A key focus of the project is to extend these sector assessments to include adaptation.

**National to local adaptation case studies.** Complementing the analysis above, the ACCREU project will undertake a series of case studies, shown below, that are focused on adaptation. These will include national level analysis of adaptation, but also key case studies that align to the key themes of the Adaptation Mission.




ACCREU Adaptation Case Studies

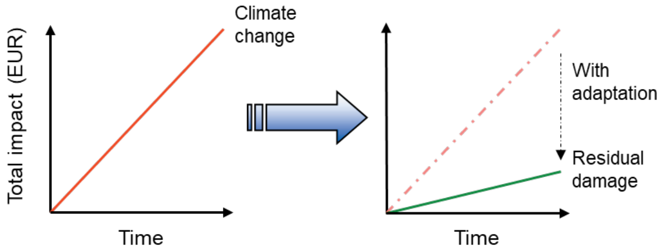



The Project Modelling Framework

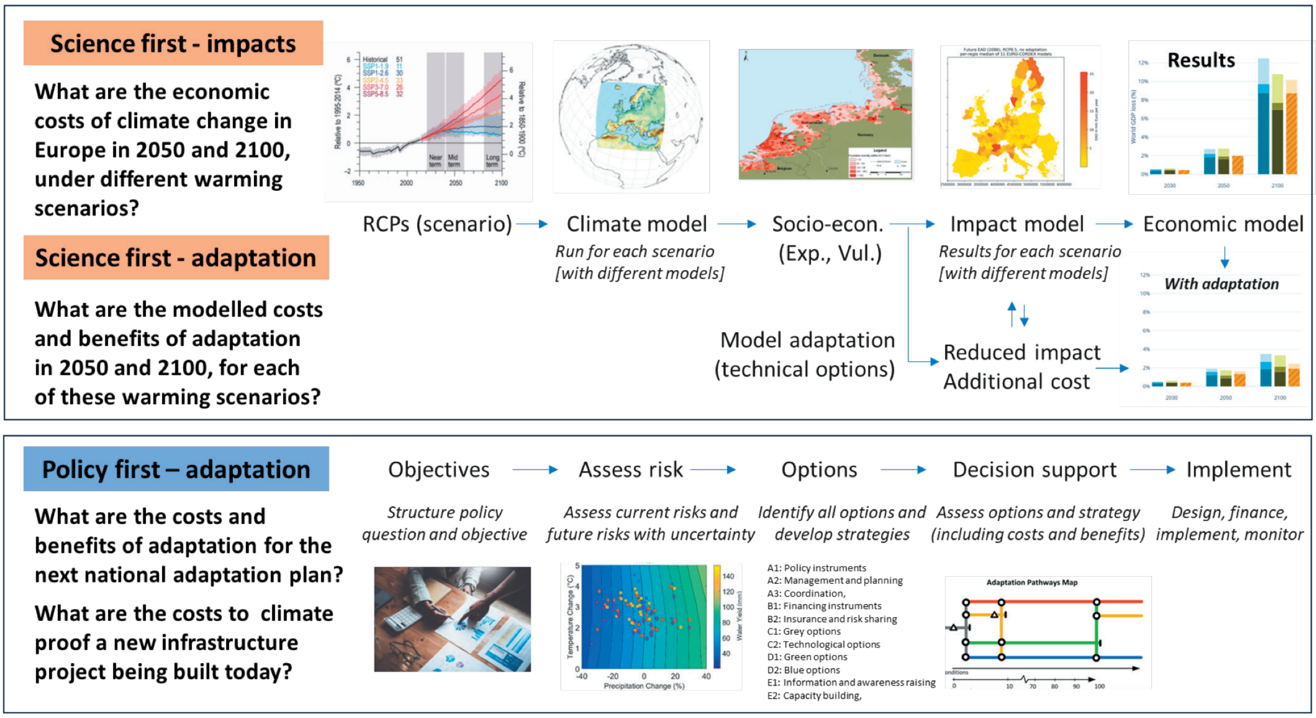
## The framing of impacts and adaptation

The economic costs of climate change can be assessed using the scenarios and models described previously. This is often called a **'science-first approach'** because it starts with the climate models, and then undertakes a step-by-step analysis, where the output of one step is used as the input for the next. The climate model outputs are used to run impact assessments to assess physical impacts, for example agriculture yield loss or flood damages. The outputs of these models can then be quantified in monetary terms and put into a macro-economic model. This approach is typically used for medium and long-term assessment of the costs of climate change.

This framework can be extended to model adaptation (see schematic, top right). In this case, the impact analysis can assess the costs of adaptation (e.g., irrigation or dyke costs) and assess the benefits these have in reducing future climate change. However, even with adaptation, it is often not possible (or very costly) to reduce impacts to zero, so there is a residual cost after adaptation. This means there are different objectives for adaptation, with a trade-off over how much adaptation to undertake, and the balance of costs, benefits and residual damage.




However, while the science first approach provides key results, it often does not provide the information needed for real-world adaptation decisions that have to be taken now (and not in 2050). This is because of two key reasons. First, the impacts of climate change, and thus the benefits of adaptation, primarily arise in the future, and this makes it difficult to justify up-front costs (today) in economic terms. Second, there is high uncertainty about future climate change, which makes it difficult to make decisions now, because of the risk of under or overinvesting in adaptation. To address this, an alternative approach is often used for adaptation, the **'policy-first approach'**. This frames the analysis from the policy question and supports early decisions that are made under uncertainty. This is more relevant for the adaptation case studies in the project. The two frameworks are shown below.



## ACCREU Review

To help inform the first stakeholder workshop, the ACCREU project undertook a review of the current knowledge on the economics of climate change and adaptation. The findings are summarised by sector in the sections below.

## Coastal

Coastal zones contain high populations and significant economic activity, as well as providing important ecosystem services. Sea level rise and changes in storm surges will increase risks to coastal areas, which can lead to increased flooding, loss of land, coastal erosion, salt-water intrusion and ecosystem impacts.

Adaptation to these coastal risks includes strategies to protect, accommodate, retreat, or advance, and with the potential to use ecosystem-based adaptation, as well as engineered options.

### Economic analysis

Methods and models for assessing the economic costs of sea level rise, and the costs and benefits of coastal adaptation, are well developed and have been applied at multiple scales. Indeed, the economic costs of coastal impacts, and adaptation costs and benefits, are the most comprehensively covered area. Most adaptation cost studies have focused on protection to address flood risks and measures to reduce erosion. However, even with coastal protection, a residual risk will remain.

### Estimates

There are numerous estimates for Europe, as well as national and local assessments. These results vary strongly with the sea level rise scenario considered, the digital elevation input data and population sets used, the consideration of existing protection, and with the models used.

At the European scale, several studies have assessed the economic costs of sea-level rise, and the costs and benefits of adaptation. While current damage costs are modest, reported at €1 to 2 billion/year, these are projected to rise rapidly.

The COACCH project (Lincke et al., 2021) estimated expected damage costs in Europe (EU28) at €135-145 billion/year for the 2050s (mid estimates for RCP2.6 and RCP4.5 respectively), rising to €450 billion/year to €650 billion/year by the 2080s for the same scenarios. The study also found that adaptation could reduce these costs down to €28-30 billion/year for the 2050s, which would cost €14-17 billion/year. The analysis found much higher costs for high sea-level rise scenarios (RCP8.5). The PESETA IV project (Vousdoukas et al, 2020) estimated lower though still significant impacts of coastal flood damages, at €111-239 billion/year by 2100 for RCP4.5 and 8.5, respectively. Again, adaptation could reduce these down to €12-23 billion/year, at a cost of €1.3 billion/year.

There are also many national studies, that apply similar modelling frameworks to look at damages and adaptation. Coastal adaptation has also been extensively captured in policy studies including decision making under uncertainty, and adaptation pathways, partly because it is easier to apply these techniques to sea-level rise than for other sectors.

Nonetheless, key gaps remain in knowledge. These are summarised along with other sectors later in the document.

## Flooding

Floods are one of the most important weather-related loss events and have significant economic impacts. In addition to affecting hydrological cycles, climate change has the potential to increase the magnitude and/or frequency of intense precipitation events and flood events, although there will be differences in how these changes take place between regions. There are wide range of adaptation options for addressing these flood risks, though the modelling literature mainly focuses on flood protection structures.

### Economic analysis

Modelling of the costs of (river) floods and of the costs and benefits of flood protection are well established in the literature. Most studies use hydrological models that link flood hazard (flood events) and exposure, then use probability-loss (depth) damage functions to capture the impacts of events of different return periods. These are then integrated into a probabilistic expected annual damage (EAD).

These models can also consider adaptation protection levels, and thus estimate the benefits of adaptation (in reducing risks) and for some models, extend this to look at costs of protection. Most of the focus has been on flooding of property (residential and non-residential) though with some consideration of other receptors.

### Estimates

There are estimates at the Europe, Member State and local level.

River floods are responsible for around a quarter of climate induced losses in Europe and are currently estimated to cause annual damage of €7.6 (5.6–11.2) billion/ year (Dottori et al., 2023) in the EU27+UK. However, there is large inter-annual variability and extreme events in individual years can have much larger impacts, notably the floods in Germany and Belgium in 2021 which led to estimated losses of €40 billion (Prognos, 2023).

There are several estimates of future climate impacts. Dottori et al. (2020, 2023) estimate that future climate change could increase the annual costs of river flooding in the EU27 + UK to €44 billion per year (for a 3C scenario for 2100) (range (30–61 billion/year) but that these could be reduced significantly with adaptation (depending on strategy). The study also estimates that a protection (dykes) strategy of annual investment of €3.1 (2.1–4.5) billion per year (undiscounted) over 2020–2100) would lower annual flood damages by 70% (a reduction of €30 billion/year by the end of the century) while a strategy with natural detention areas would cost €2.6 (1.9–3.8) billion/year and reduce damage by 83%. These investments have positive benefit to cost ratios.

The COACCH project (Lincke et al., 2018), using the GLOFRIS model, estimated annual expected damage costs in Europe (EU28) from climate change at €12 billion/year by the 2050s (for the mid estimates for both RCP2.6 and RCP4.5), rising to approximately €20 billion/year by the 2080s. These damages were reduced significantly with adaptation, with economic benefits of €6.4 to 6.9 billion/year (RCP2.6 and 4.5 respectively) in the 2050s. However, adaptation still involves significant investment over the century.

There are also many national studies that have similar modelling frameworks, studies that include more policy focused assessments.

## Agriculture

Climate change has the potential to affect the agriculture sector, both negatively (from changes in temperature, rainfall and extremes) but also positively (for example from extended seasons). These may directly change crop productivity and suitability in existing areas, but can also act indirectly, for example from changes in the range and prevalence of pests and diseases. These changes can affect yields, production, consumption, prices, trade and land-use decisions. There are a wide range of potential adaptation options for addressing these risks, including farm-level management, water management and climate-smart agriculture, as well as trade.

### Economic analysis

Most studies take outputs from climate models and use these in crop growth models or statistical models to assess changes in yields. These can then be fed into bio-economic models, partial equilibrium (PE) or computable general equilibrium (CGE) models. These models can also be used to assess adaptation options, from farm level options through to trade.

### Estimates

There is a large body of literature on the slow onset impacts of climate change on production, but less research into variance and extremes. Results also vary significantly depending on the modelling framework used, and whether international effects, comparative advantage and trade are considered. Results are also very sensitive to whether CO2 fertilization is included or not.

Most studies project differentiated impacts across Europe, with greater impacts in the South, and potentialy gains in Northern and Central-Eastern countries (Bednar-Friedl et al., 2022), which could in turn lead to a reallocation of agricultural activities.

These can lead to projected impacts, for example, in COACCH, the GLOBIOM model estimated (Boere et al., 2019) the economic costs on agriculture for producers at 1.7 billion Euros (RCP4.5 in 2050). However, it also found that many of the changes in Europe are driven by changes in other competing production sites in other world regions. The analysis of the sector results in the CGE models (Bosello et al., 2020) found noticeable GDP changes by mid-century, though with losses and gains varying by countries, with a higher vulnerability for southern regions such as Spain and Italy indicating losses ranging from 2.5 to 5% of GDP.

These assessments do not fully include variability and extremes, or indirect effects, such as changes in pests and diseases, and the inclusion or omission of CO2 fertilization significantly affects results.

Modelling studies show many of these impacts could be addressed with irrigation, but this depends on assumptions about water availability (also affected by the changing climate). There are also a range of other adaptation options that can be modelled in crop models, and then assessed through these frameworks.

The use of crop models is also widespread at the national and sub-national level and can be used to look at more detailed adaptation strategies.

## Forestry and fisheries

Forestry is a sector with long life-times, and so potentially at high risk from climate change. As with agriculture, the effects of climate change on forests can involve some positive effects but also impacts, the latter including from changes in water availability, extremes (droughts, windstorms) and pests and diseases (such as bark beetle), and there also indirect effects that can affect forest ecosystem health. Additional impacts can arise from climate change affecting the potential risks and spread of wildfire, for both managed and natural forests.

Climate change will also impact the fisheries and aquaculture sector, from changes in the abiotic (temperature, oxygen levels, salinity and acidity) and biotic (primary production and food webs) conditions of the sea and inland waters, affecting reproductive success, growth, size and disease resistance, as well as the distributional patterns and composition, of species. While human fishing activities are the dominant factor for commercial fisheries, climate change will add additional pressure.

### Economic analysis

As with agriculture, there are forest models that can assess climate change, with results then put into partial or general equilibrium models to assess market impacts (timber), though such analysis is challenging due to the variety of locations, landscapes and tree species. However, other impacts (windstorm, pests and diseases, other ecosystem services) are often omitted. There are also wildfire models which can project changes in wildfire risks. For fisheries, a number of physical models can be used (ecological trophic modelling, statistical analysis, or coupled modelling approaches) that can assess potential shifts in fish species and catch potential, which can then be assessed in economic models. There has been less focus on the impacts of climate change on acidification, and less attention on aquaculture.

### Estimates

There are fewer studies on forestry and fisheries than for agriculture.

Forest studies often show differentiated growth patterns across Europe, affecting timber production, though potentially large additional impacts are projected to arise from wildfires, windstorms and insect outbreaks (Forziere et al., 2020). Economic modelling in the COACCH project (Bosello et al., 2020) did find high economic costs (impacts on GDP) for some countries. There has been some modelling of potential adaptation costs, both aggregate analysis, but also more specific assessments on forest management, including for wind and pests.

Wildfires are an increasing problem in Europe and recent years have seen unprecedented events and economic damages, especially in the Mediterranean. While many studies project increases in risk with climate change, there is not as much on the economic damage, though Meier et al (2023) estimate current economic costs of wildfires at €13–21 billion/year for Southern Europe. While there are a range of adaptation options, including suppression and prevention, the latter including species choice, forest management, firebreaks/belts, and some studies of these options, with some aggregate modelling and more case study assessments.

Globally, most studies report marine fisheries productivity will increase in high latitudes and decrease in mid- to low latitudes, due to species shifts, though there are still impacts for Europe. The COACCH study projected a decrease in EU marine fisheries by mid-century and potentially producer losses of1.3 billion Euros/year (Boere et al 2019). Adaptation options include institutional (policy), livelihood diversification (within or outside the sector) and risk reduction. There are some adaptation cost and economic estimates (FAO, 2019) though estimates are partial.

## Infrastructure and transport

Infrastructure plays a key role in social and economic development. There is continuous demand for new infrastructure in Europe, including renewal, in the subsectors of transport, power, telecommunications and digital. However, this infrastructure is potentially vulnerable to climate change, especially given its long lifetime.

### Economic analysis

A number of impact models (especially flood models) extend to cover infrastructure, and there are also other hazard-based models such as for windstorms. These can be used to look at the direct loss or damage of assets (EAD, expected annual damage) as well as wider economic costs (such as lost travel time). More detailed physical impact modelling can be taken for individual investments or even networks. These can be extended to look at adaptation costs and benefits, though a simpler approach is often used at an aggregated level, with a 'mark-up' (% increase) applied to approximate the costs of climate proofing different infrastructure types.

### Estimates

Forzieri et al. (2018) estimated the current EAD to critical infrastructure in the EU at €3.4 billion per year, and projected that this could increase to €9.3 billion (€5.2–14.2), €19.6 billion (€12.5–34.0 billion) and €37.0 billion (€21.3–53.2 billion) per year by the 2020s, 2050s, and 2080s, with climate change. 44% of current damage was related to river floods and 27% to windstorms, however, by the end of the century, drought and heat waves were projected to account for ~90%. The largest increase over time was projected for the energy sector, and south and south-eastern Europe were the most affected regions. The study also looked at the benefits of adaptation in reducing these impacts and found these were high.

There are specific studies for individual sectors. For example, in COACCH, there was a detailed model developed for river flooding for road infrastructure (Lincke et al. 2018). EAD was estimated at direct costs of ~€200 million per year, though this did not include travel time losses. These damages were significantly reduced with adaptation.

There are detailed adaptation studies of individual infrastructure investments, including the use of decision making under uncertainty. The analysis of infrastructure networks also allows additional analysis of adaptation, as this can identify critical nodes or pinch points on the network where adaptation can be focused, as well as the potential for adding redundancy to enhance resilience.

## Energy

Climate change will affect future energy demand, increasing summer cooling but reducing winter heating. These responses are often autonomous and can be considered as an impact or an adaptation. Adaptation can help maintain desirable levels of temperatures in homes and businesses through the adoption of technologies such as mechanical (air conditioning) or passive cooling, as well as green infrastructure or urban planning. These options have strong interactions with mitigation policy and linkages with health.

Climate change will also have effects on energy supply, notably on hydro-electric generation, as well as on wind, solar, biomass and thermal power (nuclear and fossil). It also has the potential to have impacts on electricity transmission infrastructure (assets and efficiency).

### Estimates

There are several approaches for assessing the impact of climate change on energy demand, including technology models, econometric analysis and integrated assessment models. These show strong distributional patterns across Europe, with rising cooling demand in Southern Europe, which could experience an increase in electricity consumption of 20-30% by 2050. However, at the same time, overall total energy demand in Europe (all fuels and sectors) could decline by 3.6 EJ/year by 2050 (central warming scenario), due to the strong reduction in heating demand (Colelli and Sue Wing (In. prep.). Air conditioning has a role in reducing heat-related mortality (Sera et al. 2020), but increases household electricity use significantly (Randazzo et al. 2020).

Physical assessments (Després et al. 2020) and econometric analyses (Schleypen et al. (2019) have assessed the impacts of climate change on energy supply. These studies report differences across Europe (between north and south), though there are often different results between studies, especially for renewable energy (Russo et al. 2022). There are also projected reductions in cooling system efficiency due to higher water/air temperature for thermal and nuclear power plants. Power system grids (critical infrastructure) are also vulnerable to extremes.

There are more technical studies that look at housing stock, technology choice, and the linkages with mitigation policy (energy efficiency, fuel switching, etc.) and consider the costs and benefits of adaptation options for cooling, and comparing AC with passive cooling. Many of these report high adaptation costs to improve the stock of existing buildings in countries that have currently lower levels of AC (Arup, 2022). Other studies look at end-use efficiency, for example, Colelli et al. (2023) report that improving European AC units seasonal energy efficiency ratios (SEERs) to best available levels could reduce annual electricity consumption increases by 50% (17 TWh).

### Economic analysis

The macro-economic assessment of climate change impacts on energy (Bosello et al. 2020) indicates a moderate reduction in GDP over EU regions. Further economic analysis is needed to consider additional investments, implications on wholesale electricity prices, and balancing costs from transmission operators.

## Water

As well as risks to water resources (and possible supply deficits) from climate change, there are risks to water infrastructure and water quality, as well as likely increases in water demand, from higher temperatures. These changes will vary across Europe and arise from shifts in the average and seasonal patterns, as well changes in variability and extremes. These effects can lead to potential economic costs, which arise from changes to the supply-demand balance as well as from extreme droughts. In response there are a number of adaptation responses to these potential changes, which include supply side measures (water storage), transfers of water, and demand side measures (water efficiency, prices).

### Economic analysis

Economic assessments in the water sector are based on regional hydrological models, usually combined with integrated (dynamic) hydrological-economic models. Many studies use integrated assessment analysis, with hydrological and water management models at river basin level to consider cross-sectoral demand as well as supply. It is also possible to feed such studies into macroeconomic modelling, with partial or general equilibrium modelling to assess the total economic costs. These same frameworks can also look at adaptation options.

### Estimates

Droughts can involve below average rainfall (meteorological droughts) as well as changes in evapotranspiration and river flows (agricultural and hydrological droughts). While these events are common in Europe, recent extremes in 2022 have been unprecedented. Large events can lead to cascading impacts across sectors, as well as compounding effects with extreme heat.

The PESETA IV project (Cammalleri et al., 2020) assessed annual economic losses currently at 9.4 €billion/year for EU+UK, with the most affected regions being Spain, Italy, and France.

The study also projected drought losses for 2050 for a 1.5 and 2°C warming scenario at 12.4 and 15.5€ billion/year respectively, but that economic losses from drought in Europe would grow up to 45 €billion/year with 3°C global warming in 2100. These impacts were projected primarily in Mediterranean and Atlantic regions of Europe, and the largest losses relate to agriculture and energy sectors.

While this study did not extend to adaptation, there are national studies that do undertake such assessments, and look at the costs of alternative strategies to meet demand deficits and have additional contingencies for extremes (droughts).

## Business and industry

Climate change will impact business and industry. These risks will vary with subsector and location, and sites and operations will be affected differently. These risks also extend along supply chains, potentially affecting the production and transport of raw materials and intermediate goods and will also lead to shifts in demand for goods, services and trade. All of these may affect business costs, profitability, competitiveness, employment and sector economic performance.

There are several approaches in the literature to assess these impacts and these include supply chain risk assessments, input-output analysis and macro-economic assessments. There is also an analytical modelling base for disasters and the insurance sector. Insurance and catastrophe models are also used to assess the impact of climate-related extremes.

The COACCH project (Kuik et al., 2021) investigated such risks with econometric analysis, assessing historical data on extreme weather shocks by country, the transmission of these shocks along international supply chains using input-output data for countries and sectors, and the impacts on exports. This found that shocks in one country can propagate along the supply chain, leading indirectly to an adverse economic impact in another. The potential strength of impact transmission has grown over the last twenty years due to increased globalization.

There is information emerging on adaptation in these areas. These options can include different types of response, such as information, risk management, actions in different places (in the country of origin, along the trade pathway, or in the destination country) and different actors (public and private (Bednar-Friedl et al, 2022).

The COACCH study investigated and found that a diversified supply chain contributes to resilience against non-local extreme weather shocks, but may involve trade-offs with supply chain efficiency in normal times.

### Labour productivity

Higher temperatures and extreme heat have impacts on the labour force, and on productivity. This has emerged as a major impact over recent years and relates to the reduced working time and output at higher temperatures (though there are also some potential benefits for some colder regions or countries).

These studies consider both outdoor and indoor work, though the latter is also influenced by air conditioning.

There are numerous studies of the economic costs of climate change on labour productivity for example, (Dasgupta et al. 2021) that use either impact assessment methods with functional relationships or econometric analysis.

Bosello et al. (2020) identified southern and central-eastern European regions are hit more adversely with potential GDP contractions in the order of 1.5-2%, while cooler areas of northern-Europe, might gain a 1% improvement in economic performance.

Szewczyk et al., (2021) assessed annual economic losses in Europe could reach 1.2% of EU GDP by the 2080s in the worst-case scenario, with higher impacts in the Mediterranean.

The focus to date has been on the economic costs of labour productivity but there are also a set of potential adaptation options, which include a range of regulatory, behavioural, technical and other options. These can include heat alerts, work practice change, and moving labour activities to different times of the day, as well as air conditioning and other options for the indoor environment.

## Tourism

While the overall demand for tourism will continue to increase over the next few decades, the distribution, timing, and type is expected to shift as a result of climate change. Currently, summer tourism (beach tourism) in Europe is focused on the Mediterranean where it is an important contributor to GDP. Increasing temperatures, heat waves and availability of water may have negative effects for tourism in these regions, leading to a shift to more northerly locations (redistribution).

For winter tourism, changes in snow availability and other factors will impact the length and quality of the European season. Resorts at lower altitudes will have their economic viability potentially threatened in the long term, although impacts could be partially offset by summer tourism.

Economic analysis

Quantitative evaluation of climate change effects on tourism include physical changes, often with the use of climate indexes, as well as tourism demand modelling based on revealed preferences. The majority of studies assess beach tourism using the Tourism Climate Index (TCI) and cost changes in tourism expenditure. Other approaches include the use of econometric analysis, partial adjustment models, hedonic price models and integrated CGE models.

Several studies projects large potential decreases in summer tourism in Southern Europe during summer (for example Schleypen et al., 2019), and several studies project potentially severe impacts on winter tourism for resorts at lower altitudes (Tröltzsch et al., 2018).

## Finance

Climate change is now recognised as a major financial risk, which will potentially affect the public finances of European countries (see macro-economic section), as well as the financial system and thus potentially financial stability.

Climate change can affect the financial markets, including banking, insurance, stock markets, bond markets, and international financial flows, although these involve complex transmission pathways (Zhou, Endendijk and Botzen 2023).

These effects may arise from impacts and shocks within Europe but also from similar events internationally, with these risks propagating through EU financial markets through corporate value chains, trade and foreign portfolio investments, non-EU sovereign bonds, etc. There is also the potential for the market to amplify climate-related financial risks, and through market anticipation, to potential bring forward impacts.

These issues are becoming more important in light of the Task Force on Climate-related Financial Disclosures and the focus on physical risk disclosure. However, financial and economic modelling is at an early stage, and primarily focused on individual case studies.

Adaptation is currently focused on risk analysis and disclosure and stress tests of the financial system. (e.g. ECB, 2021)

## Health

Climate change is increasing health burdens, including those caused by direct impacts, such as heat-related mortality, but also indirect impacts such as from changes in the range, seasonality and intensity of vector-borne, food-borne and waterborne disease transmission. There are also risks caused by climate change to the delivery and demand for health systems and services, including health infrastructure or supply chains, as well as disruption to access. Many impacts projected in the short term can be reduced through effective and timely adaptation. There is increasing information on health adaptation options (Berrang-Ford et al. 2021) but much less evidence on the costs and benefits of this. (Berrang-Ford et al. 2021).

### Economic analysis

Most studies use some form of impact assessment, to assess the physical impacts of climate change on health, then subsequently value the effect on welfare in terms of the resource (treatment costs) and health expenditure, opportunity costs (lost productivity) and dis-utility (from willingness to pay studies). For heat-related mortality most studies use epidemiological functions though there are also econometric studies. For vector-borne disease bioclimatic models are often used.

### Estimates

The 2022 heatwaves across Europe are estimated to have led to between 15000 and 61000 additional fatalities (Ballester et al., 2023). Climate change and warmer temperatures are projected to lead to increased temperature related mortality.

There are numerous studies of the potential impacts of climate change on fatalities in Europe and in Member States, though the exact numbers vary with the study, including whether acclimatization is included. These additional fatalities can be valued, but there are very different results depending on whether the full value of a statistical life (VSL) is used or the value of a life year lost (VOLY).

Kendrovski et al. 2017 estimated an additional 23 thousand attributable deaths at 2°C of warming (mid century) in Europe, with estimated economic costs of €41 billion/year (VSL). PESETA IV (Naumann et al., 2020) estimated 29,000, 49,000 and 89,000 deaths for 1.5°C, 2°C and 3°C by the end of century respectively, and higher numbers were estimated in the COACCH project (Ščasný et al. (2020). These higher estimates of mortality lead to higher economic damages (when the VSL is used) and are one of the highest € impact categories reported in PESETA IV. There are many similar studies at national level.

There are studies of adaptation to address these heat risks, which focus on the costs and benefits of heat-alert schemes and supporting health sector responses. These are low cost, though there are questions about their effectiveness. However, there are additional costs associated with reducing heat risks in hospitals and care homes for the elderly, which could be much higher. There are also some estimates of the impacts of the economic costs of food borne disease, and some studies on vector borne (e.g. malaria, dengue) and tick-borne disease are emerging, which could be important for Europe. The immediate adaptation costs are associated with increased monitoring and surveillance, and in some cases, vaccination.

Finally, the analysis of climate and health risks and adaptation is moving away from a focus on individual outcomes towards consideration of risks to health systems and health services. This includes the integration of climate change adaptation into health programmes and delivery, emergency preparedness and health information systems, as well as supply chains and health infrastructure (hospitals and health facilities), though as yet there is less information on the costs and benefits involved.

## Biodiversity and ecosystem services

Climate change is already leading to rapid, broad-scale ecosystem changes, with significant consequences for biodiversity (and the ecosystem services and economic value these provide, Dasgupta, 2021) and these impacts will increase with future climate change. Climate change will shift geographic ranges, seasonal activities, migration patterns, reproduction, growth, abundance and species interactions and will increase the rate of species extinction.

As well as terrestrial ecosystems, there are potentially large impacts on marine ecosystems, including from ocean acidification, ocean warming and sea level rise as well as impacts on freshwater ecosystems (rivers and lakes).

Adaptation can address some of these impacts, though not all. Early adaptation actions are to increase conservation activities and expand protected areas, while longer-term options include connectively, corridors and even translocation.

### Economic analysis

The quantification of the impacts of climate change on biodiversity and ecosystems services in physical terms, let alone in monetary terms, makes the analysis of economic impacts and adaptation costs extremely challenging. As a consequence, these damages are often omitted, despite the high vulnerability. There are some bioclimatic models that estimate projected changes in habitats and species, including species abundance, but this still means valuation is a challenge.

### Estimates

Beyond the provisioning services and carbon sequestration values, there are very few aggregate impact studies. Much of the focus has been on the costs of adaptation as a proxy for impacts, by assessing the costs of expanding protected areas (Waldron et al., 2020) or using the costs of restoration to address potential habitat or species loss (Hunt et al., 2020).

## Macro-economic studies

It is also possible to assess the wider economic costs of climate change in individual countries, Europe and globally. This investigates the relationship between climate change and the economic performance of countries, most commonly represented by indicators of competitiveness, GDP and, in broader terms, growth. This is a step beyond the aggregation of costs at the sectoral level, as it captures interactions across impacts and sectors, and the economic transmission channels (including market-driven adaptation). It also can assess how these interactions affect the overall capacity of country economies to produce goods, services and ultimately “welfare”.

Climate change can also impact on the public finances of countries, potentially reducing tax revenues, increasing government expenditure and public spending, increasing contingent liabilities, and generally increasing risks of financial uncertainty from various impacts on the economy.

### Economic analysis

The macro-economic effects of climate change can be assessed by feeding sector impacts results into economy-wide simulation models, such as computable general equilibrium (CGE) models. These have the advantage of capturing the whole economy (sectors, domestic and international interlinkages) and can analyze impacts on national production, welfare and GDP, though it is often challenging to represent impacts and these models omit non-market effects. It is also possible to use econometric analysis, establishing past relationships between climate and the economy, applying these to future climate change.

At a more aggregated scale, it is possible to undertake economic analysis at the global scale using integrated assessment models (IAMs). These provide a self-consistent integrated analysis of emissions, climate change, impacts and economic effects, including market and non-market impacts.

These IAMs report aggregate economic effects as a % of GDP or consumption, and capture investment dynamics but typically lack sectorally detailed impact channels.

### Estimates

At the global level, more estimates have emerged on the aggregate economic costs of climate change (and the social cost of carbon, the marginal cost of carbon emissions) over the past five years. This has significantly widened the evidence base, but the range of results is now so large that this prevents identification of a robust estimate with confidence (O’Neill et al. 2022). What is clear, however, is that this new literature includes many higher estimates than earlier studies.

At the European level, the PESETA IV study (Szewczyk et al., 20202) estimated that future climate change – if acting on the present EU27+UK economy – would result in an annual welfare loss of at least 83 €billion/year (0.65% of GDP) under a 2°C scenario and at least 175 €billion (1.4% of GDP) under a 3°C scenario. The impacts for Central Southern Europe and especially Southern Europe were much higher (the latter with annual welfare loss of over 2.5% of GDP under 3°C).

The COACCH study (Bosello et al. 2020) analyzed future climate change impacts in the EU+UK, reporting a median GDP loss of 2.2% between 2020 and 2070, and estimated that one quarter of EU regions could experience GDP losses larger than 5% within the same period.

To date there has been less consideration of adaptation in these models, or it is undertaken with highly stylized analysis. However, there are some CGE studies that look at adaptation (Wei and Aaheim 2023), focusing on autonomous adaptation at the aggregated level, and planned adaptation studies at the sectoral or regional level.

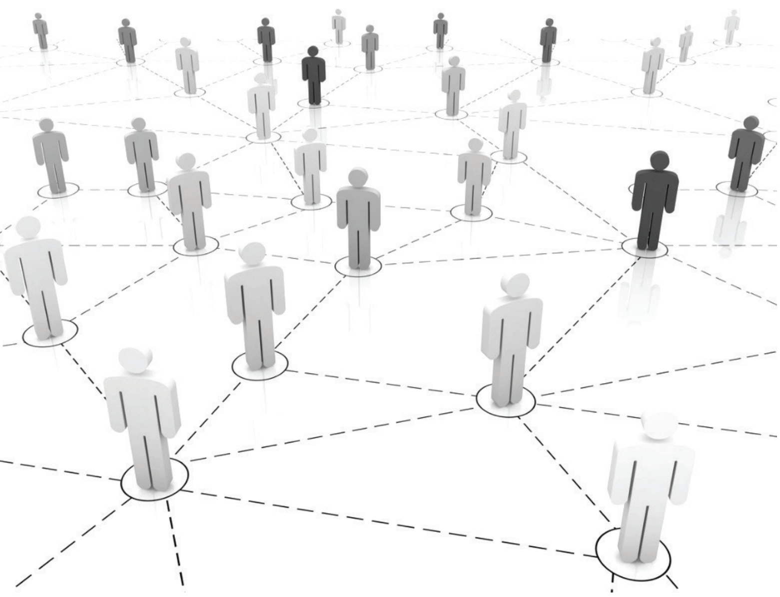
## Other areas

There are a number of other areas that have received less attention to date but are important for economics of climate change and adaptation.

## Distributional effects and justice

Climate change will affect countries across Europe differently, with potential losses and gains for different regions and Member States. Climate change is also projected to affect people within countries differently, with the poorest and most vulnerable people being potentially affected the most in relative terms. There has been some work on the exposure and vulnerability of different groups to climate change, but much less consideration of the distributional effects. At the same time, adaptation strategies and options can be designed with the same distributional issues in mind.

A 'justice' lens, as identified in the IPCC AR6 report involves principles of distributional and procedural justice, as well as recognition (IPCC, 2022). A justice-informed approach can address the unequal effects of climate change and differential access to adaptation.



## Social sectors

There are some sectors that have not been well covered to date, including social sectors. Climate change can affect education, with the risk of overheating on educational attainment, and the effects of climate extremes on the functioning of and access to infrastructure. At the same time, education can have an important role in providing the knowledge and skills to support adaptation.

## Socially contingent impacts

There is also growing literature around the potential socially contingent impacts and the role of climate change, directly or as a risk multiplier, for migration and for conflict. Migration is also a potential adaptation strategy and can arise in response to incremental risks, though the greater concern is when it is forced, or required because limits to adaptation are reached.

There is little information on the potential costs of migration in the literature, and such costs are highly variable and context specific.

## Adaptive capacity

Adaptive capacity is a key component of climate change risks, and it also affects the effectiveness of adaptation. There is also increasing awareness of the role of governance in delivering adaptation (Andrijevic et al. 2020) and the need to consider these issues in assessment. This includes the costs and benefits of capacity building, institutional strengthening and governance.

There is also a further issue on the additional costs of costs of delivering and implementing adaptation. This involves significant additional costs of design (including safeguards) and implementation (project management, reporting, monitoring and evaluation, and oversight). These costs are often omitted, or only partially captured, in the sectoral modelling estimates above and so further consideration of these is important.

## Potential gaps

| Risk / Sector | Potential gaps impacts | Potential gaps adaptation |
|---|---|---|
| **Coastal zones and coastal storms** | Ongoing improvements.<br>Multi-hazard assessment. | Ongoing improvements, local dimensions, adaptation in multi-hazard assessment.<br>Adaptation pathway economics.<br>Nature based solutions. |
| **Floods** | Ongoing improvements for river flood.<br>Addition of surface water floods + drainage.<br>Cascading and compounding risks.<br>Interactions hydrologic-human-economic. | Improvement in adaptation costs (river)<br>Surface water costs and benefits.<br>Nature based solutions.<br>Adaptation to cascading effects. |
| **Agriculture** | Ongoing improvements.<br>Food security and supply chains.<br>international and extremes, shifts in diets.<br>Pests and diseases. | Adaptation costs and benefits including climate smart agriculture and integrated land management.<br>Household dimensions. |
| **Forest and fisheries** | Ecosystem services (non-market).<br>Wildfire economic costs (beyond hazard).<br>Cascade effects in marine ecosystems.<br>Aquaculture. Ocean acidification. | Cost and benefits of adaptation strategies, including pests and diseases, and wildfires.<br>Costs and benefits of adaptation strategies including marine fisheries and aquaculture. |
| **Infrastrucure & Transport** | Cascading and compounding risks.<br>Digital infrastructure. | Adaptation for networks, multi-hazard, cascading and compounding effects. |
| **Energy** | Compound effect of extreme events on power systems (demand & supply shocks).<br>Integration with net zero analysis | Adaptation costs of retrofitting buildings.<br>Green solutions. Iinteraction between public and autonomous adaptation |
| **Water management** | Droughts & cascading effects.<br>Cross-sectoral, cross-national impacts. | Adaptation costs and benefits, including linkages to EU strategies. |
| **Business, services and industry** | Higher granularity for impacts of specific business sectors. Other impacts beyond labour productivity and floods. | Adaptation for labour productivity impacts and food supply chains. |
| **Tourism** | Heat-related and wildfire impact, especially for summer tourism.<br>Demand assessment beyond temperature. | Future tourist preferences to develop adaptation strategies. |
| **Finance** | Impacts of physical risks on financial markets and financial stability.<br>Interactions with transition risk.<br>Cascading and international risks. | Insurance for businesses (flood risks).<br>Welfare benefits of adaptation.<br>Costs and benefits of adaptation (stress tests and beyond). |
| **Health** | Heat related morbidity.<br>Vector borne diseases.<br>Health systems and services. | Options for heat beyond heat alert systems.<br>Access to air conditioning.<br>Costs and benefits for other endpoints, and health services and systems. |
| **Biodiversity / ecosystem services** | Quantification and valuation of ecosystem services.<br>Droughts and wildfires. | Adaptation pathways. Cost & benefit of species conservation under different climate scenarios. Costs and benefits of refugia, connectivity, corridors |
| **Macro-economic analysis** | Coverage of omitted risks into existing frameworks and models.<br>Impacts on the public finances. | Integration of adaptation into macro-economic analysis.<br>Analysis of costs and benefits of adaptation for public finances (EU, MS and regions). |
| **Other** | Education (assets and learning).<br>Socially contingent (migration, conflict).<br>Adaptive capacity.<br>Tipping point (climate and socio-economic).<br>Distributional effects of climate change. | Potential costs and benefits for other areas.<br>Limits to adaptation (soft and hard) and cost implications.<br>Distributional effects of adaptation measures. |

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ACCREU
Assessing Climate Change Risk in EUrope

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