COACCH

CO-DESIGNING THE ASSESSMENT OF CLIMATE CHANGE COSTS

The Economic Cost of Climate Change in Europe

Policy Results

Funded by the European Union's Horizon 2020 research and innovation programme

The COACCH project is co-ordinated by Fondazione Centro Euro-Mediterraneo Sui Cambiamenti Climatici (FONDAZIONE CMCC), Italy.

To find out more about the COACCH project, please visit http://www.coacch.eu/
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[Front Page: Sinkhole in Cologne district, Germany, July, 2021]

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Introduction

Climate change will lead to economic costs. These costs, which are often known as the 'costs of inaction', provide key inputs to the policy debate on climate risks, mitigation and adaptation.

The objective of the COACCH project (Codesigning the Assessment of Climate Change costs) is to produce an improved downscaled assessment of the risks and costs of climate change in Europe. The project is proactively involving stakeholders in co-design, co-production and co-dissemination, to produce research that is of direct use to end users from the research, business, investment and policy making communities.

This document summarises the various results from the COACCH project on the economic costs of climate change, presenting the results of the work on policy analysis.

Definitions
The following definitions are used in COACCH

Co-design (cooperative design) is the participatory design of a research project with stakeholders (the users of the research). The aim is to jointly develop and define research questions that meet collective interests and needs.

Co-production is the participatory development and implementation of a research project with stakeholders. This is also sometimes called joint knowledge production.

Co-delivery is the participatory design and implementation for the appropriate use of the research, including the joint delivery of research outputs and exploitation of results.

Practice orientated research aims to help inform decisions and/or decision makers. It uses particpatory approaches and trans-disciplinary research. It is also sometimes known as actionable science or science policy practice.

Policy Analysis

The COACCH project has focused on three policy areas, presented in turn in this policy brief.

The first area focuses on Europe and uses a series of case studies to explore mitigation and adaptation policy options. These case studies are summarised here, and in a separate policy brief for business.

The second looks at the effects of adaptation policy on the public finances in Europe, using a macro-economic analysis to explore the implications from national adaptation action.

The third and final area has been a major update to a number of integrated assessment models. This has taken the new results from the COACCH project, and used these to generate new estimates of the economic costs of climate change in Europe and globally, as well as the costs and benefits of policy action.

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Policy Case Studies

Agricultural and Climate Policy

The European Commission Farm-to-Fork strategy (2021) set out a vision for a fair, healthy and environmentally friendly food system. This included the objective to align the food system to the EU European Green Deal (2019) – to make Europe climate-neutral by 2050 – and the EC Climate Law (2021), which proposes a legally binding target of net zero greenhouse gas emissions by 2050.

However, while these high-level climate ambitions are set out in the Farm to Fork strategy, there is still a need to deliver these. This will involve new policies which could involve trade-offs, between mitigation and adaptation, but also between climate objectives versus agricultural and sustainability objectives (for food production, environment, consumer prices, trade and exports, etc.).

The COACCH project has investigated these policy issues for agriculture, looking at alternative scenarios that meet the EU's climate targets, using a combination of the global land systems model MAgPIE and the global multi-regional impact assessment model REMIND.

The study assessed six different policy paradigms:

- A market-oriented paradigm (S2),
- A behavioural paradigm (S3),
- A technology-oriented paradigm (S4),
- A policy-steered paradigm (S5),
- A mixed paradigm (S1) and
- A current paradigm (S6).

Each of these combines a package of policy measures and a different degree of integration across various economic sectors. These have been used to look at GHG emission reductions (mitigation) within the land-use sector.

This mitigation can be associated with producers, e.g. using more efficient fertilization practices or reduced land expansion. It can also be driven by consumers, e.g. from changed diets and reduced food waste. At the same time, the agricultural sector can also contribute to mitigation through bioenergy

cultivation, including with carbon capture and storage. Finally, emissions from the sector can be transferred to other world regions through imports or exports, noting the global net-effect of such actions depends on the relative emission-intensities of other trading regions.

The different policy packages – while all being in line the Net Zero target – lead to different set of outcomes for producers, consumers and the environment.

The analysis found that agricultural production would change most strongly in the behavioural and mixed paradigm, as these shift towards plant-based diets and lead to a large reduction in animal products. As a result, producers may be less keen on such policies, due to reduced higher value production, even though they have improved societal benefits from reduced inefficiency and food waste.

In terms of consumption and consumers, there are different outcomes depending on whether mitigation is achieved through demand-side or supply side measures.

Demand side measures such as diet shifts and reduced food waste – as captured in the behavioural change scenario – lead to lower food expenditures, although such expenditures remained low in Europe in all scenarios.

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In terms of environmental objectives, the behavioural change scenario was most effective in reducing nitrogen pollution, while these increase in the market and policy-steered scenarios. Land use change (national and international) did not differ substantially between the policy scenarios, even though there was lower pasture area in the behavioural paradigm, due to increasing cropland.

Finally, the relative sector contribution to the Net Zero goal varied between scenarios. The dietary change scenarios led to a higher mitigation contribution directly from agriculture. The market and policy-steered scenarios involved a lower contribution from agriculture, but had the highest increase in bioenergy cultivation, reducing energy sector emission (though this option was only attractive if combined with Carbon Capture and Storage). Interestingly, all the policies had a limited effect on international emission leakage of greenhouse gases, although this may be because it was assumed other world regions also had some mitigation policies in place.

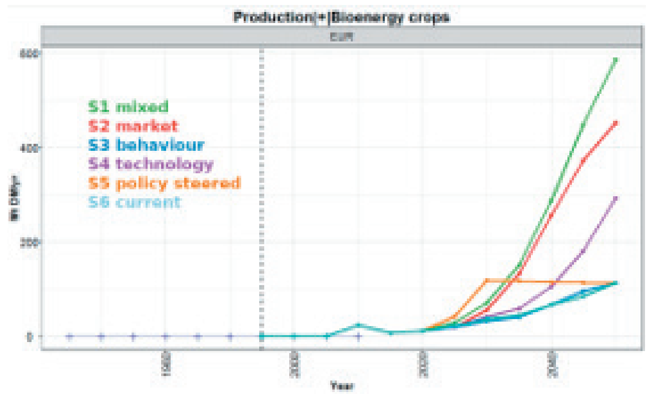
Macroeconomics of Insurance Policy

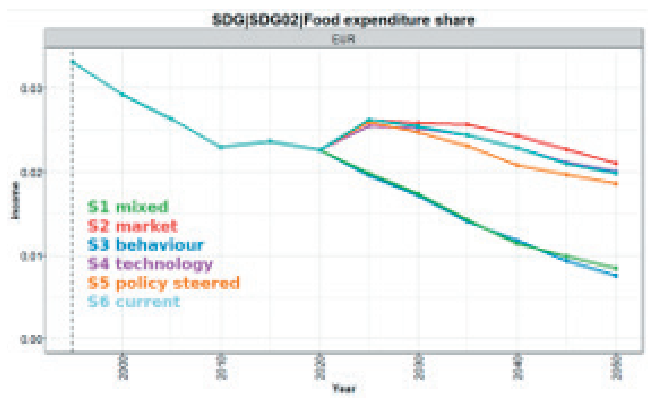
Flood risks are projected to increase in Europe, driven by climate change and rising hazards, but also by socio-economic change and increasing population and assets at risk.

Insurance is a risk spreading mechanism that is used to limit the financial vulnerability of both citizens and governments to flood risk. Insurance has an important role in helping to cope with increasing flood risks, however, climate change will influence the functioning and pricing of insurance products. The COACCH project has undertaken a case study to investigate these issues. An interesting aspect of the case study has been to investigate different types of insurance systems.

Currently, insurance varies significantly across individual European countries. Some countries have voluntary private insurance markets with differing degrees of providing compensation payments through e.g. national disaster funds, while others have public solidarity systems, where coverage is ensured by risk-independent premiums applying for all households.

These alternative systems vary in their ability





to cope with the potential changes arising from climate change. These can be in terms of (un) affordability of premiums, or low insurance uptake or moral hazard. In turn, these have implications for households, insurance providers and insurance markets, and for the public finances (when insurance coverage fails).

The COACCH project has investigated these issues using a global hydrological impact model (GLOFRIS) and a partial equilibrium model of the flood insurance sector (DIFI). The study estimated the increase in river floods from climate and socio-economic change up to 2050, the implications for flood

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insurance premiums and household responses, considering different insurance options. These results were then fed into a Computable General Equilibrium (CGE) model (COIN-INT), to consider the differences in terms of public and private burden sharing. The aim was to explore which insurance schemes yielded the lowest overall macroeconomic costs.

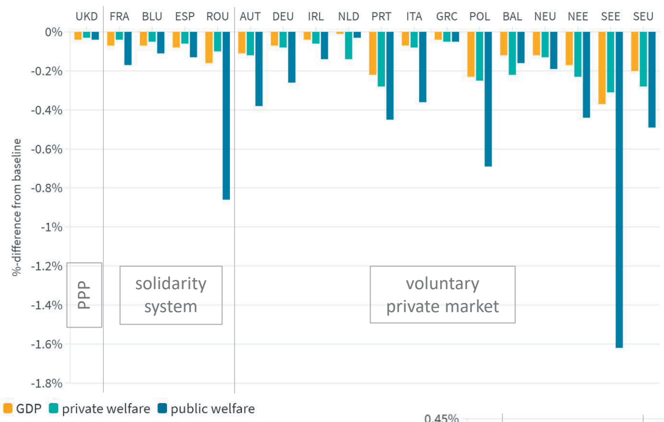
The results of the case study find that climate change and socio-economic change will increase flood damages significantly in Europe. As a result, insurance premiums rise significantly, especially in countries where insurance is risk-based, which leads to declining flood insurance uptake.

The impacts of this affects all macroeconomic indicators negatively, leading to lower GDP, as well as lower private and public welfare. These negative effects occur, in all EU countries (+UK) and regions, but with particularly strong impacts in South-Eastern and Southern EU, as well as Romania and Poland.

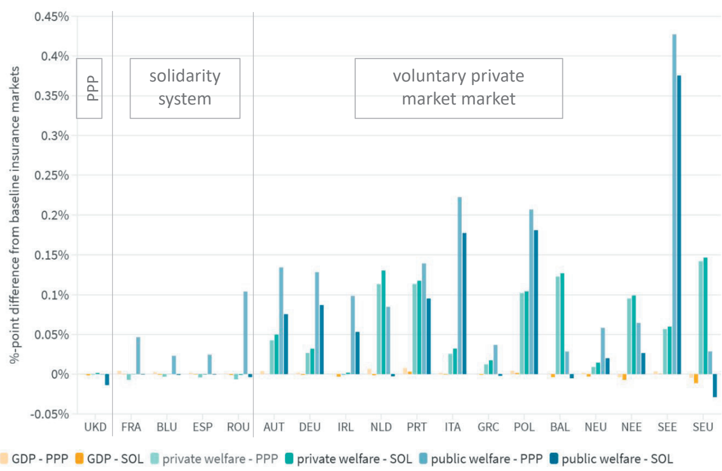
Looking at alternative policy options, the analysis finds that some insurance systems are better able to cope with these rising flood risks and macro-economic effects than others, particularly when considering private and public welfare.

The majority of EU regions currently operate a private insurance system, where uptake of coverage is optional (voluntary) and premiums reflect risk. These systems lead to increased pressure on the public budget, especially when large disasters require unanticipated compensation payments to private households. In contrast, the adverse macroeconomic impact of future flood risk is found to be smaller when flood insurance is public, insurance purchase requirements are maintained and premiums apply in form of a flat tax irrespective the individual risk (solidarity). Macroeconomic costs are lowest, however, when there is a public-private partnership system, where uptake is also mandatory, but risk-based pricing is limited with the public actor covering the most extreme portion of risk.

An important policy insight is that a continued business-as-usual approach will not be enough. Given rising risks from climate change, there will be a need to update national flood insurance mechanisms, and the choice on how this is done can influence the level of macroeconomic costs, as well as impacts on public and private households.



Macroeconomic effects from flood risk with current insurance market systems relative to the baseline scenario in 2050 for EU regions + UK (for a high warming scenario – RCP8.5-SSP5).



Differences in macroeconomic outcomes based on a change from the current system to a Public-Private Partnership (PPP) or a Solidarity market system (SOL) for EU regions + UK expressed as %-points difference from effects with current insurances market systems (for a high warming scenario – RCP8.5-SSP5).

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Coastal Infrastructure Adaptation

Climate change – and sea-level rise – poses major coastal flood risks for Europe. As highlighted in previous COACCH policy briefs, adaptation is a very effective response to these risks, and it can reduce down potential impacts very significantly and cost-effectively.

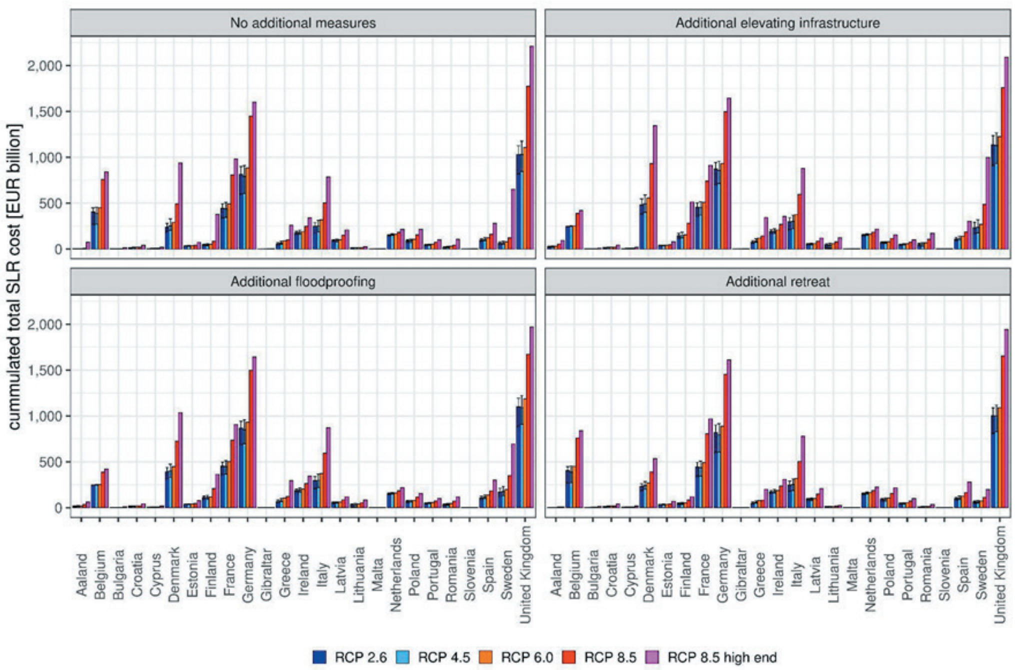
However, flood protection has a cost, and it is unlikely to be adopted in sparsely populated areas. This means there will be residual risks in such areas, notably for infrastructure.

This leads to policy choices on whether to invest in major flood protection infrastructure (such as dikes), or if not, whether to i) do nothing ii) retreat, or whether to invest in local adaptation option such as iii) flood proofing of infrastructure and or iv) elevating infrastructure.

The COACCH project has looked at these policy choices using the DIVA model, looking at these four options for adaptation across the EU when major flood protection infrastructure is not adopted.

This added additional analysis capability to look at dry-flood-proofing techniques for buildings (sometimes called resistance measures), and elevation of capital stock, assessing the benefits (through adjustment of depth-damage functions) as well as additional costs.

The highest total cost of sea-level rise – defined as the residual costs plus the adaptation costs – was found for the case with no additional measures, due to the high damage costs. The lowest total costs, and the most efficient option, was associated with coastal retreat. Infrastructure elevation was found to have a higher cost than infrastructure floodproofing, but the reduction of damages was similar for both measures. These values apply for most European countries, although there will be some national and local differences.



Total cost of sea-level rise during the 21st century for all 22 coastal EU countries + UK with additional adaptation.

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River Flood Adaptation

River flooding has high economic costs in Europe, and these costs are projected to increase significantly with climate change. Existing flood protection measures and river flood adaptation standards are already in place in many areas in Europe, but climate change will mean additional investment is needed.

The COACCH study has investigated these issues, undertaking a policy case study using the integrated assessment model CLIMRISK-RIVER, as well as a database of existing river flood adaptation standards (FLOPROS). This allows the analysis of future flood impacts under different flood adaptation assumptions.

The analysis was focused on the expected baseline damages in Europe over this century with climate change. The total present value (discounted) was estimated at €67 billion (RCP2.6) to €75 billion (RCP6.0) this century for the 10 most affected countries.

If Member States invest in the optimal level of flood protection, i.e. that would yield the highest net present value (NPV) over this century, these damages can be reduced down to €27 billion.

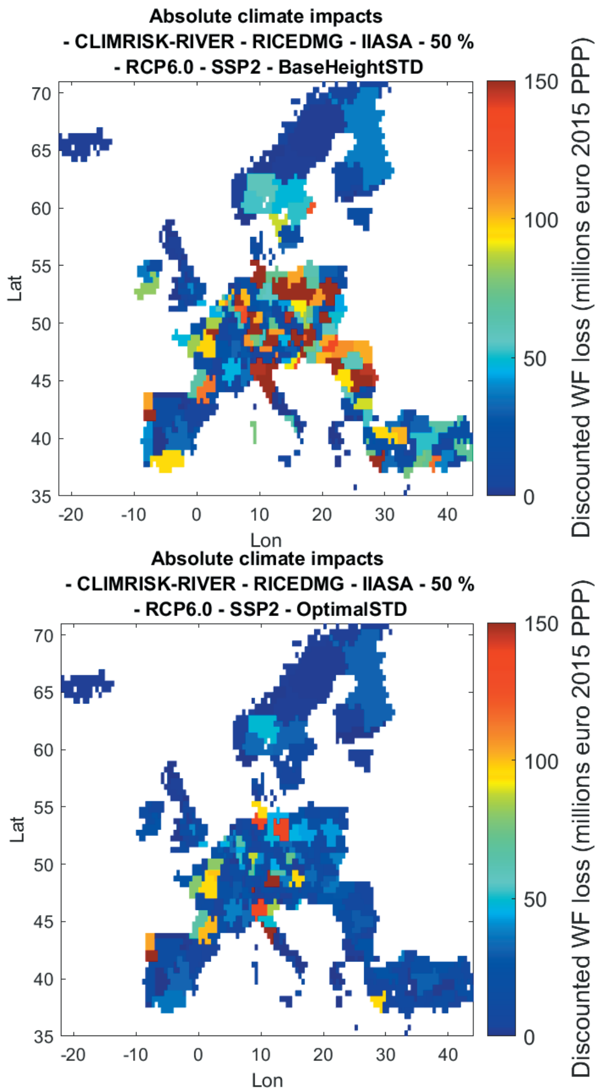
Interestingly, the study finds that flood adaptation is more effective in reducing risks than mitigation. There is also a strong distributional pattern across Europe: some countries, notably Hungary, Moldova, Germany and Italy, are likely to get the largest benefits from national flood adaptation. These differences are due to the levels of flood risk, but also the current standards in place.

The study has also used the model to undertake a deeper dive at the local level. This has identified the top 10 most vulnerable cities in Europe over the 21st century. The analysis finds that the damages in these cities could be significantly reduced if optimal adaptation was introduced, and that this would lead to a near complete reduction in river-flood related risk for many cities in Europe.

The COACCH project has also considered the implications of these findings for the transport sector. The introduction of enhanced flood protection would also reduce down the risks of flood-related road transport disruption in Europe.

The COACCH project has developed a model that allows analysis of the risks to individual road segments and the overall road network at the European scale. Applying this model, the analysis finds that even with the optimal adaptation above, some flood hot-spots will still remain.

There is therefore a strong economic case to focus adaptation on these remaining pinch-points, i.e. vulnerable segments or nodes that are critical for the performance of the network. These represent priority areas for investment, as a relatively small amount of localised adaptation can generate large economic benefits, by reducing large-scale, cascading effects.



Benefits of of optimal adaptation for the RCP6.0 Scenario (NUTS-2 Level).

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Non-Market Sectors: Health, Biodiversity and Ecosystem Services

The impacts of climate change on non-market sectors are anticipated to be very large in Europe, however, these impacts have been less well modelled than for other sectors.

To date, the focus of economic assessment has been on heat-related mortality, but there are a number of other health impacts. There are also risks to the natural environment, including on biodiversity and ecosystem services (provisioning, regulating, cultural and supporting services), but other than for provisioning services, these have proved difficult for valuation.

The COACCH project has investigated these non-market sector gaps, working with policy makers in a co-designed case study. This aimed to value non-market risks at the national scale in the UK, to provide inputs to the UK's 3rd Climate Change Risk Assessment (CCRA3).

The analysis assessed the indicative economic costs for 25 non-market risks – and also potential opportunities – considering how these might change in low versus high warming pathways.

While there were some cases where valuation proved challenging, values were possible for most risks. The results (see Table) found that climate change could lead to very high economic costs in these non-market sectors, estimated at £billions/year in the UK, even by mid-century.

The analysis also found a clear step change in costs under a 4°C versus a 2°C future. Global mitigation will therefore have very large economic benefits in reducing the impacts to non-market sectors in the UK.

Natural Environment	Current	2050s	2080s, 2°C	2080s, 4°C
Risks to terrestrial species and habitats	Unknown	Unknown	Unknown	Unknown
Risks of pests, pathogens and invasives	Unknown	Unknown	Unknown	Unknown
Opportunities from new species	Unknown	Unknown	Unknown	Unknown
Risk to soils	H	H	H	H
Risks to natural carbon stores	VH	VH	VH	VH
Risks to and opportunities to agriculture	L - H	H +H	VH +VH	VH +VH
Risks of ag. pests, pathogens and invasives	M	M	H	H
Risks to and opportunities to forestry		L - H	L - H	L - H
Risks of forestry pests, pathogens and invasives	M	M	M	H
Opportunities for productivity	+M	+H	+H	+VH
Risks to aquifers and agricultural land from SLR	L	Unknown	Unknown	Unknown
Risks to freshwater species and habitats	H	H	H	H - VH
Risks of water pests, pathogens and invasives	L	L	L	M
Opportunities to freshwater species and habitats	+L	+L	+L	+M
Risks to marine species, habitats and fisheries	L - M	M	M	H
Opportunities marine species, habitats, fisheries	+L	+M	+M	+H
Risks of marine pests, pathogens and invasives	L	M	M	M
Risks to coastal species and habitats	L	M	M	M
Risks to landscape character	Unknown	Unknown	Unknown	Unknown
Health and social				
Risks to health / wellbeing from high temperatures	VH	VH	VH	VH
Opportunities from higher temperatures	+M	+ VH	+ VH	+ VH
Risks to health from changes in air pollution	L	L	L	L
Risks to health from changes in aeroallergens	Unknown	Unknown	Unknown	Unknown
Risks to health from vector-borne disease	L-M	L-M	M	M
Risks to food safety and food security	L	L-M	L-M	L-M
Risks to cultural heritage	Unknown	Unknown	Unknown	Unknown
Risks to health and social care delivery	Unknown	Unknown	Unknown	Unknown

Risks		Opportunities		
VH		+VH		£billions/year
H		+H		£hundreds of millions/year
M		+M		£tens of millions/year
L		+L		£<10 million/year

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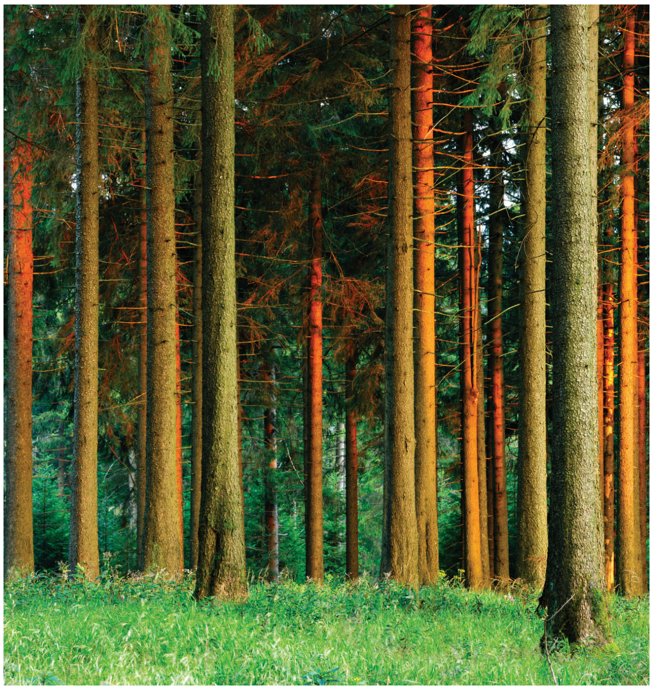
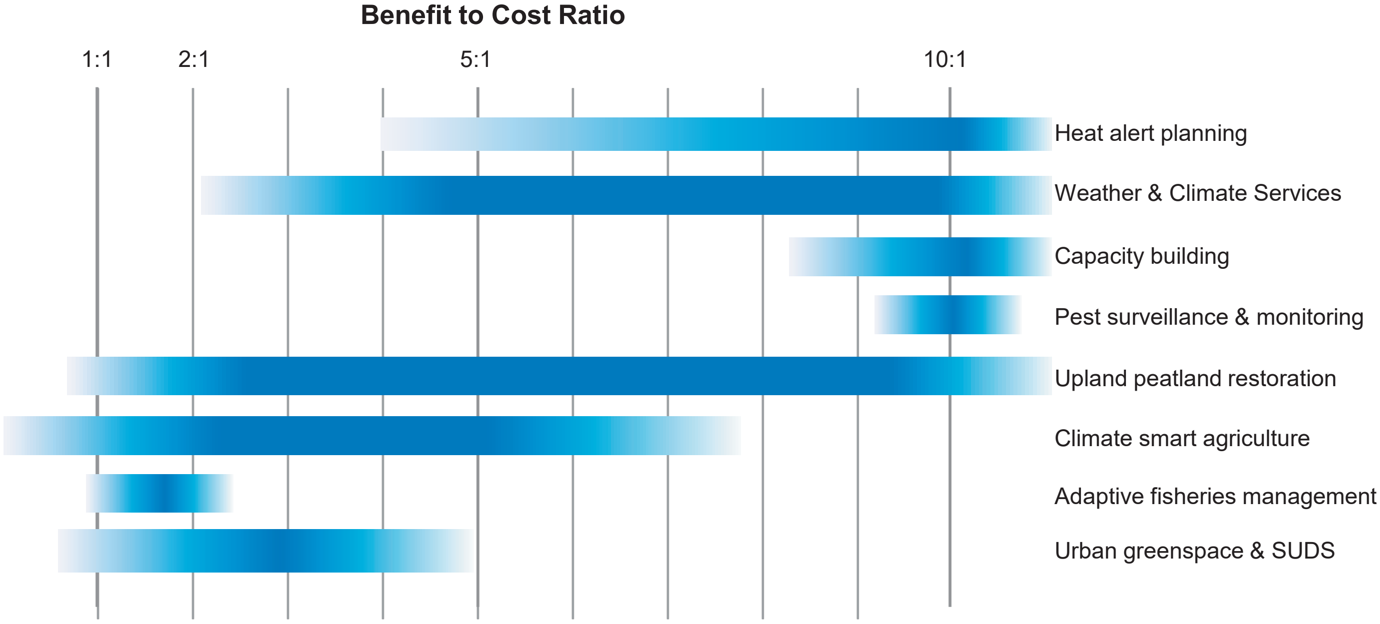
The analysis then undertook a review of adaptation to address these non-market risks, including the potential costs and benefits.

This review concluded that for most non-market risks, there were high economic benefits from further action, and that many early adaptation options delivered highly positive benefit to cost ratios.

The case study also provided some additional policy insights. First, it identified a large number of non-market risks are potentially costly, and there is need to investigate these in studies such as COACCH. This highlights the need to expand current modelling analysis. Second, it identified that in many cases, existing adaptation options are already in place, and so the policy focus is on identifying the current gap (with policy), and the benefits and costs of further action.





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Adaptation and the Public Finances

The physical impacts of climate change are now recognised as a major financial and macro-economic risk, with implications for the public finances. Many of these risks can be reduced with adaptation, but this involves additional costs, which may also affect public budgets.

These effects involve complex pathways and transmission mechanisms, e.g. the implications of climate change for government revenues and expenditures, the level of contingent liabilities, debt levels, etc. and feedbacks across the economy. In order to look at these effects, therefore, there is a need to use economic models, which can consider the macro-economic implications of impacts and adaptation in an integrated framework.

The COACCH project has undertaken such an analysis, using a multi-sectoral, multi-regional comparative static computable general equilibrium (CGE) model.

The case study has looked at the macro-economic effects of climate change and adaptation in three different countries in Europe – in Austria, Spain, and the Netherlands – with a deeper dive analysis in two risk areas, for flood risk management and adaptation in the agricultural & forestry sectors.

To do this, the analysis considered the current public adaptation expenditures in these countries – and how these might evolve in the future to 2050. This was based on a review of existing literature, budget and project reports and consultation with national experts and stakeholders.

The economy-wide repercussions and budgetary consequences of these policies were then assessed in the macro-economic model. First, an impact scenario was developed including a range of climate impacts for each country (riverine & coastal flooding, impacts in forestry & agriculture) based on previous results from the COACCH project. Second, adaptation measures and their effectiveness in reducing climate risks were included in the model (adaptation scenario). This allows an evaluation of the consequences of impacts and adaptation expenditure for government budgets, looking at both direct (expenditures) and indirect effects (e.g. changes to the tax base from changes in economic output, labour and capital income).

These results provide some key policy insights on adaptation, that are of high relevance for Member States, e.g whether adaptation is cost-effective from a macro-economic perspective, as well as which sectoral effects are to be expected and how public adaptation affects public budgets.

The first key finding is that for the adaptation strategies considered, national adaptation is effective in reducing the negative sectoral and economy-wide effects of a range of climate impacts, and leads to positive outcomes for public budgets.

This held true for moderate (e.g. RCP4.5 – SSP2) and extreme (e.g. RCP8.5 – SSP5) warming scenarios and across a range of assumptions on the effectiveness of adaptation. An example is shown below for Austria and Spain for the latter scenario, finding that adaptation reduces macro-economic impacts (in terms of relative changes in GDP) by more than 50%, although residual impacts still remain.

The adaptation actions considered in this analysis largely avoid direct capital damages from river flooding, and they reduce climate change induced losses in sectoral productivity levels in agriculture and forestry sector, and thus generate a higher level of economic activity. Thereby they reduce climate-change induced disruptions to the tax base, alleviating the negative effects of climate impacts on the revenue side of public budgets, as compared to a scenario without adaptation. This finding occurs even though many adaptation actions are financed out of the public budget, and this diverts financial resources away from other government expenditures.

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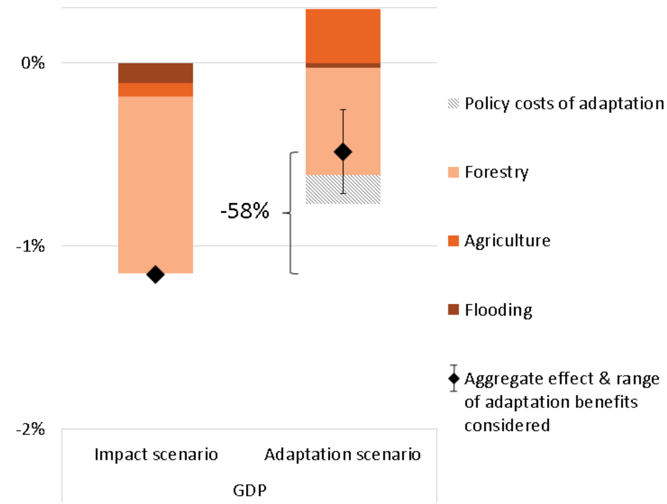
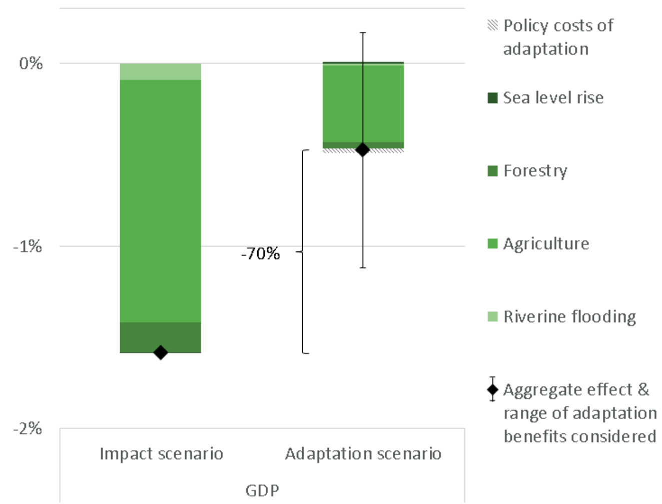


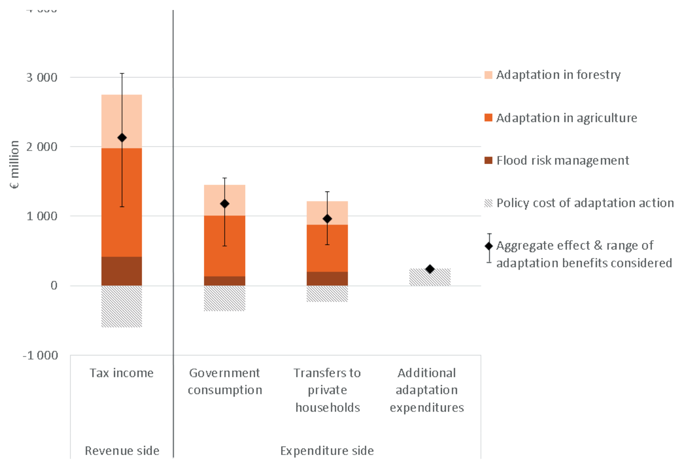


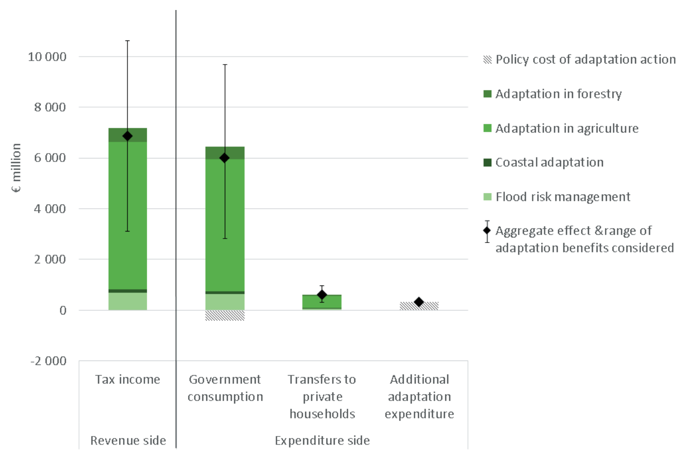
This means that the benefits of adaptation on the government revenues, generated through taxes on consumption, factor income, output and trade, more than offset the direct costs of adaptation. In turn, this allows higher levels of government consumption and public transfers to private households in a scenario with adaptation.

This shows that additional public expenditure targeted towards effective adaptation actions leads to overall economy-wide benefits including the effects on the public budget.

This is shown below as the absolute difference in the revenue and expenditure side of the public budget between the impact and adaptation scenario.

There were, however, some differences between the countries and sectors. National adaptation across Europe does not follow a one-size-fits-all approach, and this has implications for public finances.





Absolute difference between the impact and adaptation scenario on the revenue and expenditure side of the Austrian (left) and Spanish (right) public budget in 2050.

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In particular, there were slightly different findings from the deep dive on the Dutch Delta programme, when compared to the Austrian and Spanish cases. The Dutch programme has the aim of establishing extremely high protection levels, and it involves very large-scale public projects with very high annual expenditures foreseen.

For average annual expected damages from floods, the analysis found that while adaptation is likely to be successful in reducing the economy-wide and budgetary impacts caused by capital destruction, the very large additional adaptation expenditures have strong budgetary consequences. By crowding out other government consumption, benefits of avoided damages do not compensate for the direct and indirect costs of implementation.

However, when the occurrence of a 100-year flood event is considered, this finding changes. A low-probability, high-impact event of such magnitude causes severe macroeconomic and budgetary disruptions, with a significant share of private and public capital destroyed. High protection levels established under the Delta programme are successful in avoiding these losses largely, preventing economy-wide disruptions and a reduction of the tax base. Thereby, higher government revenues in the adaptation scenario offset government expenditures on flood risk management many times over. This leads to clearly positive economy-wide and budgetary net-benefits from adaptation.

Taken overall, the case study finds that adaptation is effective in reducing the macroeconomic disruptions of climate impacts and the resulting strain on public finances.

While the implementation of adaptation requires public expenditures, which at least partly divert expenditure away from other expenditures, it reduces impacts on revenues by alleviating the effect on the tax base. Results show that adaptation ameliorates the impact on sectors that are negatively hit by climate change impacts and even leads to benefits is some sectors such as construction, due to the positive effects from the higher public expenditures. This highlights the central role for government action on adaptation, while noting the importance of household and private sector action.

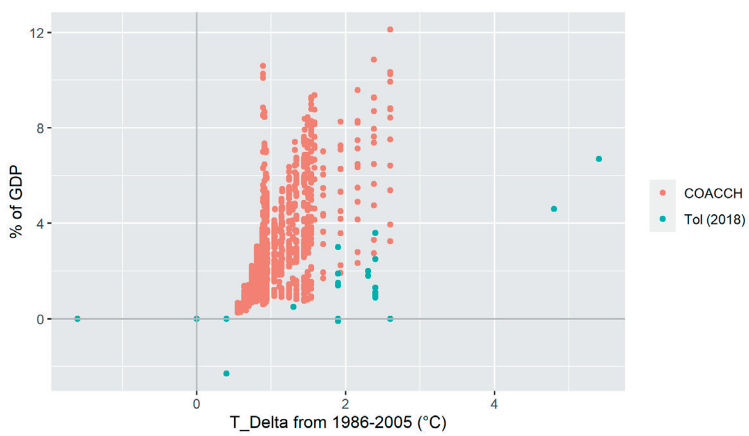
Integrated Assessment and Macroeconomic Policy Modelling

The COACCH project has developed new estimates of the economic costs of climate change in Europe and globally, as well as the costs and benefits of policy options.

These economic costs are estimated using global integrated assessment models. These use a consistent framework that allows modelling of baseline and climate futures, economic impacts, and the subsequent exploration of mitigation and adaptation policy choices.

Given the complexity of global analysis, these models use simplified or reduced-form damage functions, which provide relationships between climate (e.g. temperature) and economic losses.

The COACCH project has produced a new set of such damage functions, based on the new information generated from the sector modelling results across the project. These provide a significant improvement from the current



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literature in terms of transparency, regional granularity and the representation of uncertainty.

The new COACCH damage functions generate higher central estimates (for the economic costs of climate change) than many previous functions. This reflects the more negative results in more recent literature (e.g. in terms of extreme events, increased sea-level rise). For 2.5°C warming, the COACCH estimates indicate a loss of between 2.7 and 12.4% of world GDP.

The COACCH analysis analysed project results and has used this information and statistical methods to produce disaggregated damage functions.

It has produced harmonised damage functions for 14 macro-regions across the world, and at the NUTS2-level (sub-national) for Europe, for both global mean temperature increases and for sea-level rise. For the latter, separate functions were included without and with adaptation (in line with the analysis in the DIVA model and work in COACCH). These functions include uncertainty

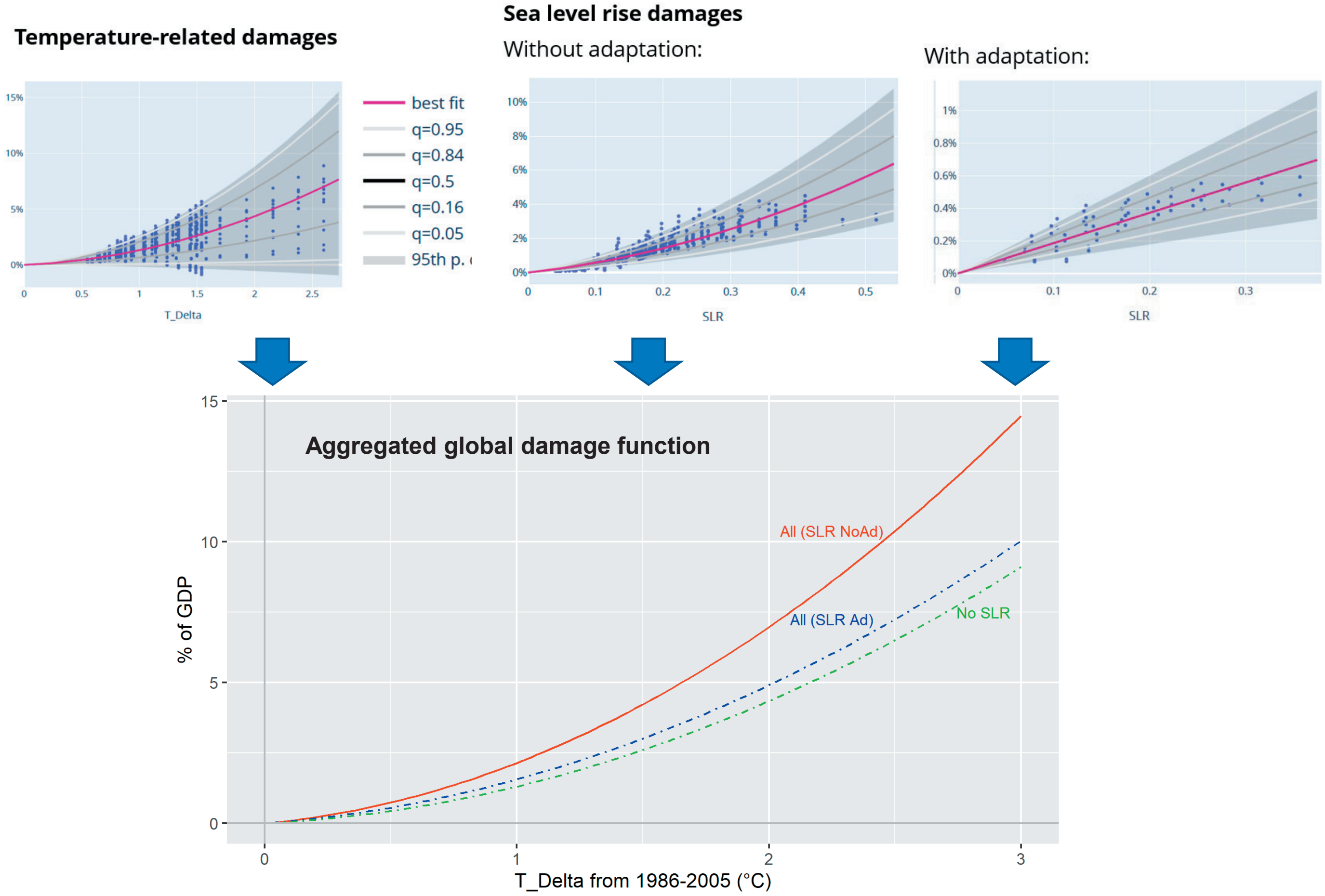
These new COACCH damage function were then integrated into three Integrated Assessment Models (IAMs): MIMOSA, WITCH and REMIND. These have different functional forms and levels of complexity. The use of alternative models allows an inter-comparison of the results.

- MIMOSA6 is a recent IAM based on FAIR7 with 26 regions covering the world. It is a relatively simple Cost-Benefit IAM.

- WITCH8 is a dynamic optimisation IAM of intermediate complexity, with 17 world regions.

- REMIND9 is a Computable General Equilibrium (CGE) model and has the highest level of detail in the representation of the economy. However, it does not model sea-level rise explicitly, and therefore uses a combined damage function that depends only on temperature.

The models were run with harmonised socio-economic scenarios (SSP2) and assumptions on baseline GDP and population growth.



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The models were run to explore two key issues. The first was to use the models to estimate global and regional GDP losses from climate change. The second was to run some policy experiments to look at mitigation costs and benefits.

Economic costs of Climate Change

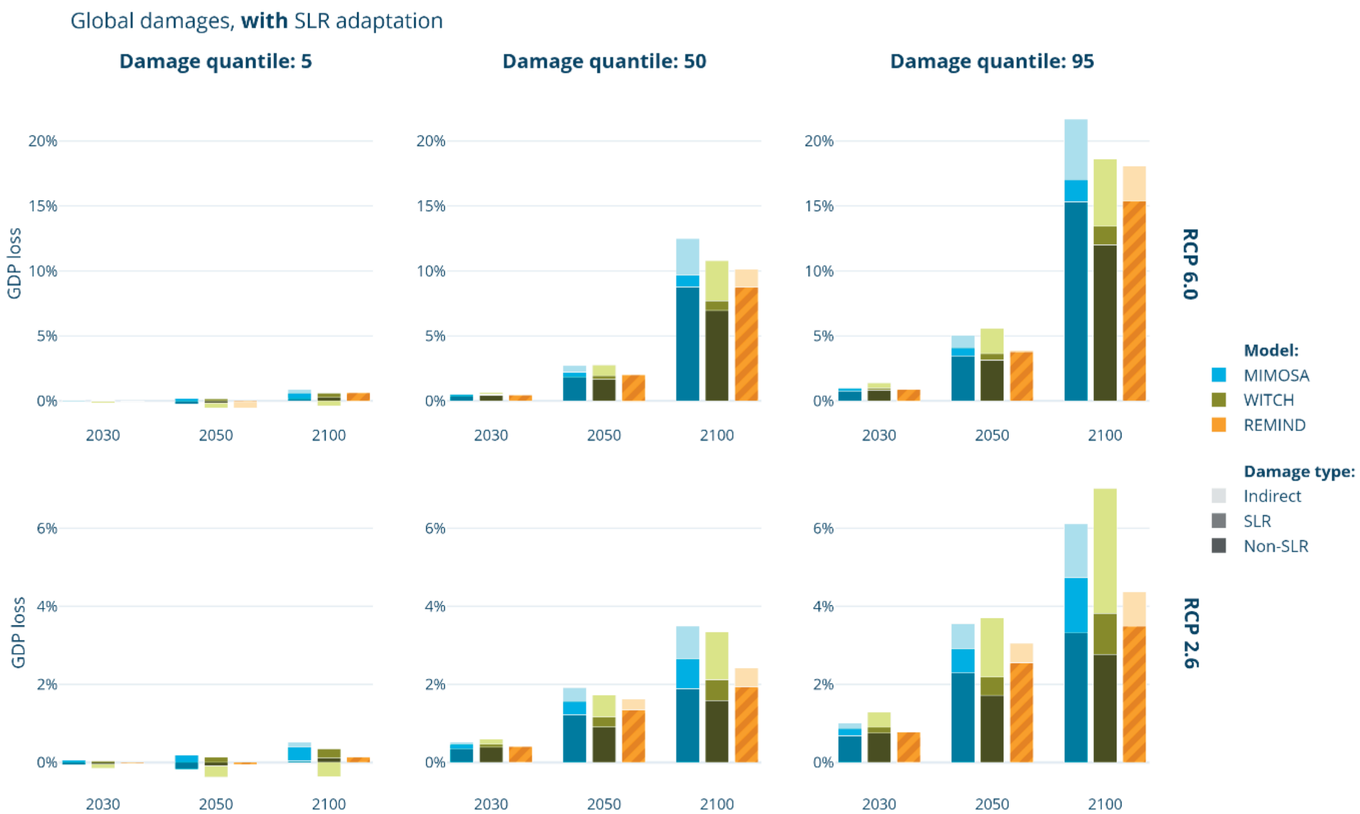
The first analysis was to run the models to look at the economic costs of climate change for low and high warming scenarios. This compared RCP2.6, which is a mitigation trajectory broadly in line with the Paris Agreement (to limit temperature to well below 2°C above pre-industrial levels and pursue efforts to limit to 1.5°C), against RCP 6.0, which is a baseline emission trajectory. The results are shown for the scenario that assumes SLR adaptation – they are higher for the no SLR adaptation analysis (see deliverable).

For RCP6.0, the three models all show similar results, although MIMOSA give slightly higher damages and REMIND slightly lower. The models indicate global damage costs of approximately 2 to 3% by 2050 (central estimate) rising to 10% to 12% by 2100 (central estimate).

The benefits of mitigation in reducing damages can be seen by looking at the RCP2.6 scenario, which reduces global damage costs to under 2% by 2050 (central estimate) and to 2% to 4% by 2100 (central estimate).

The results show that mitigation is extremely beneficial in reducing the more severe impacts of climate change. This reinforces the need for ambitious mitigation scenarios. However, there are still high residual damages in the RCP2.6 scenario, and furthermore, the benefits of ambitious mitigation mostly occur after 2050. This means some economic costs from climate change are already locked-in and this highlights the need for complementary action on adaptation.

The results have been disaggregated to show i) direct effects (without SLR) ii) direct effects of SLR and iii) indirect effects, which are the accumulated GDP effects from the impacts on growth. The proportion of these differs between the models (though REMIND does not model sea level rise explicitly). Direct effects (i) dominate the values. The accumulated effects are approximately 10-20% of the total values.



Global GDP losses (%) over time for RCP2.6 and 6.0 – note that scales are different. The damages shown include sea-level rise adaptation. Values would be higher for the no SLR-adaptation scenario.

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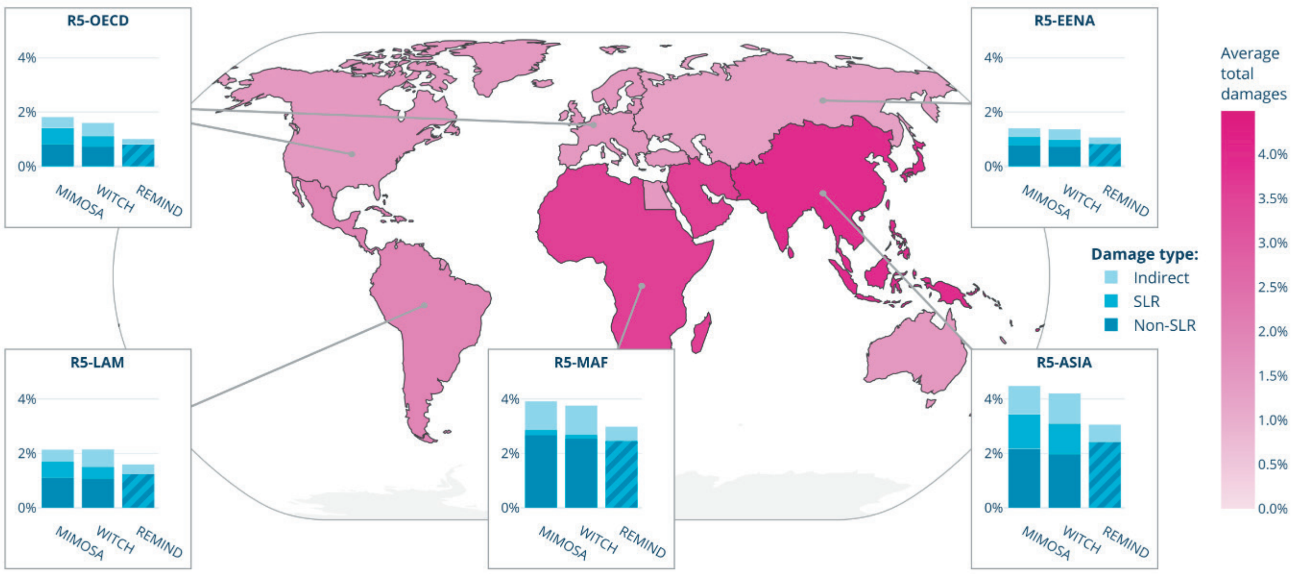
These values do not include major earth-system discontinuities, i.e. tipping points. However, they do consider uncertainty ranges which provide insights on worst-case scenarios. These show much higher damages, e.g. for RCP6.0, global damages rise to 18-22% (95th damage quantile) by 2100, almost double the central values.

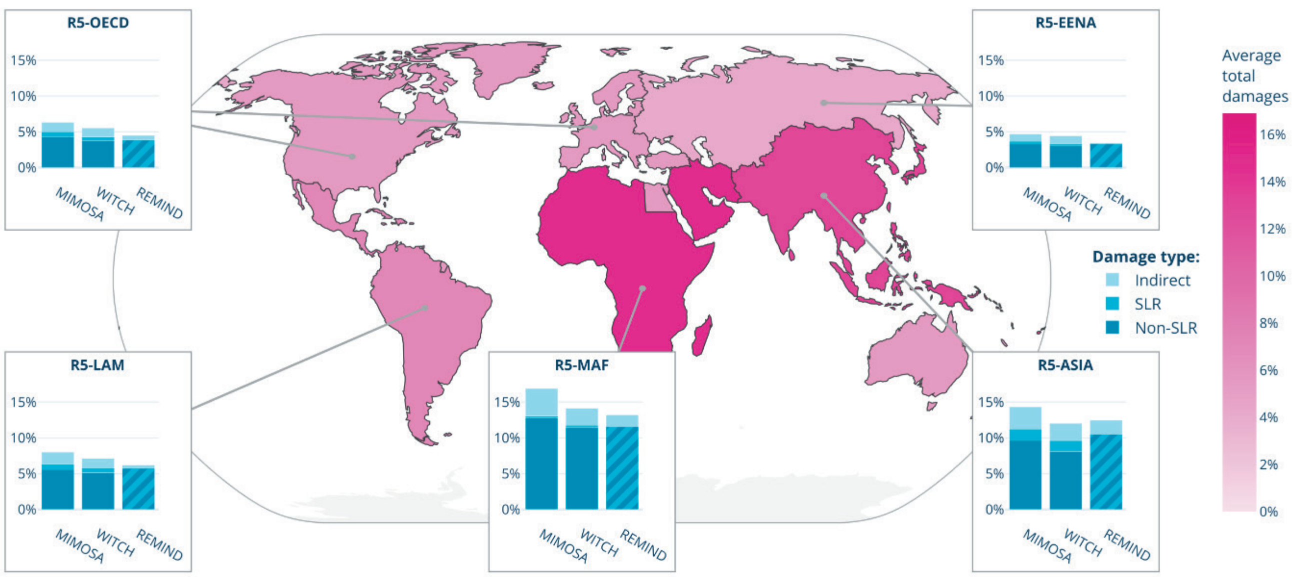
The global pattern of results is summarised in the figures below for 2100. Results are aggregated into five world regions: Asia; Eastern Europe and North Asia (including Russia); Latin America; the Middle East and Africa; and OECD (including the EU). Note that these values do assume SLR Adaptation. If this is not included, values would rise in all regions, though especially in the OECD and Asia.

As shown in the RCP 6.0 scenario, the damages are highest in the Middle East and Africa region, at 13% to 17% of GDP, followed by Asia at 12% to 14%. These are significantly higher than world average values. Again, these damages are significantly reduced in the RCP 2.6 scenario, and total damages are reduced to a regional maximum of 4.5%, as compared to the 15% for RCP 6.0.

b. Damages in 2100 (**RCP 2.6,** with SLR adaptation)



a. Damages in 2100 (**RCP 6.0,** with SLR adaptation)



Regional breakdown of damages as GDP losses (%) in 2100 split in world regions. Values are presented for the with SLR adaptation: values would be higher for the no SLR-adaptation scenario.

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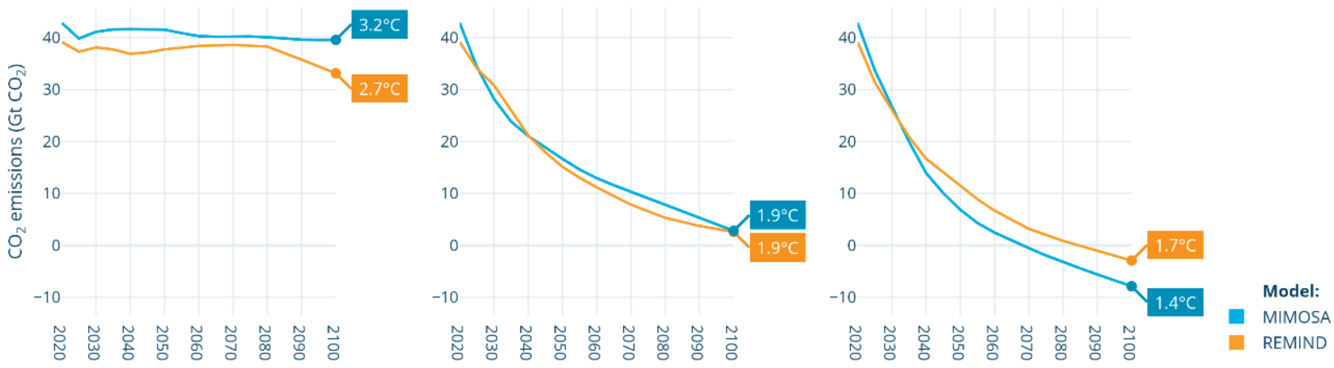


Cost-optimal emission trajectory and corresponding end-of-century temperature from the cost-benefit runs for two models for the low, medium and high end of the damage function.

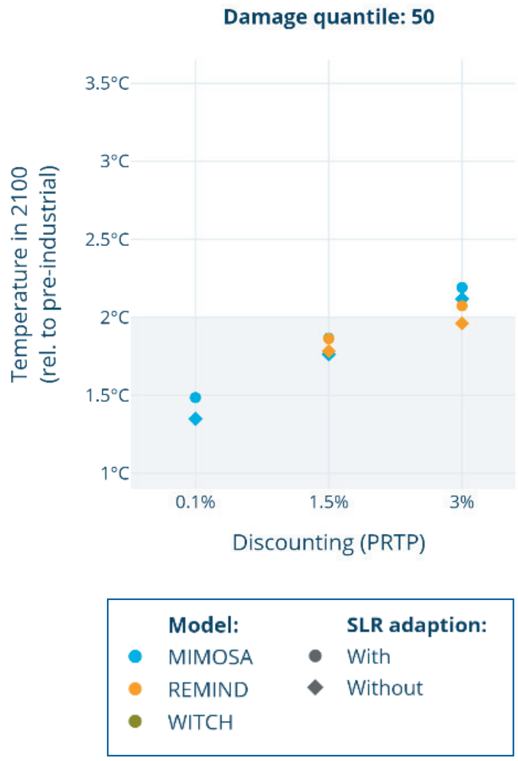
Policy Experiments on Mitigation

The second area assessed the implications of the new functions for mitigation policy, undertaking a cost-benefit analysis with the models. It is stressed that IAMs do not capture all the economic costs of climate change, and there are important ethical as well as economic consideration in setting mitigation policy. The results below, therefore, should only be seen as experiments to provide policy insights.

The COACCH project used the models to investigate the possible 'optimal' level of mitigation, based on the central projections of warming, the damage costs from the new functions over the century, and the mitigation cost estimates built into each model. For this economic analysis, the discount rate was harmonised using a Pure Rate of Time Preference (PRTP) of 1.5% and an elasticity of marginal utility of 1, in line with recent expert elicitation.

The results found that the modelled 'optimal' end-of-century temperature was approximately 1.9°C above pre-industrial (central projections). This is in line with the Paris Agreement to limit warming to below 2°C. When the full model uncertainty range was considered, the optimal temperature fell to 1.4-1.7°C, which is in line with the higher Paris Agreement ambition to limit warming towards 1.5°C.

The analysis also explored the influence of discount rate on the results. This varied the PRTP value from 0.1% (as used in the Stern review) to 3% (used in higher estimates in the literature). It is highlighted that the PRTP is combined with the growth rate to generate the overall discount rate (the Social Rate of Time Preference) and thus the actual discount rates used are accordingly higher. Interestingly, the uncertainty in the damage function was more important than the choice of discount rate.



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Local Economic Analysis

Finally, the COACCH project has also used the new damage functions and integrated these in the CLIMRISK Model, to allow new downscaled analysis of the economic costs of climate change in Europe.

The analysis has integrated the new damage functions at the NUT-2 level in Europe, i.e. at the sub-national level, with separate functions for 138 sub-national regions. Alongside this, the model includes more detailed local scale temperature change, which provides a higher resolution on warming levels as well as damage functions.

The results of the analysis provide interesting results.

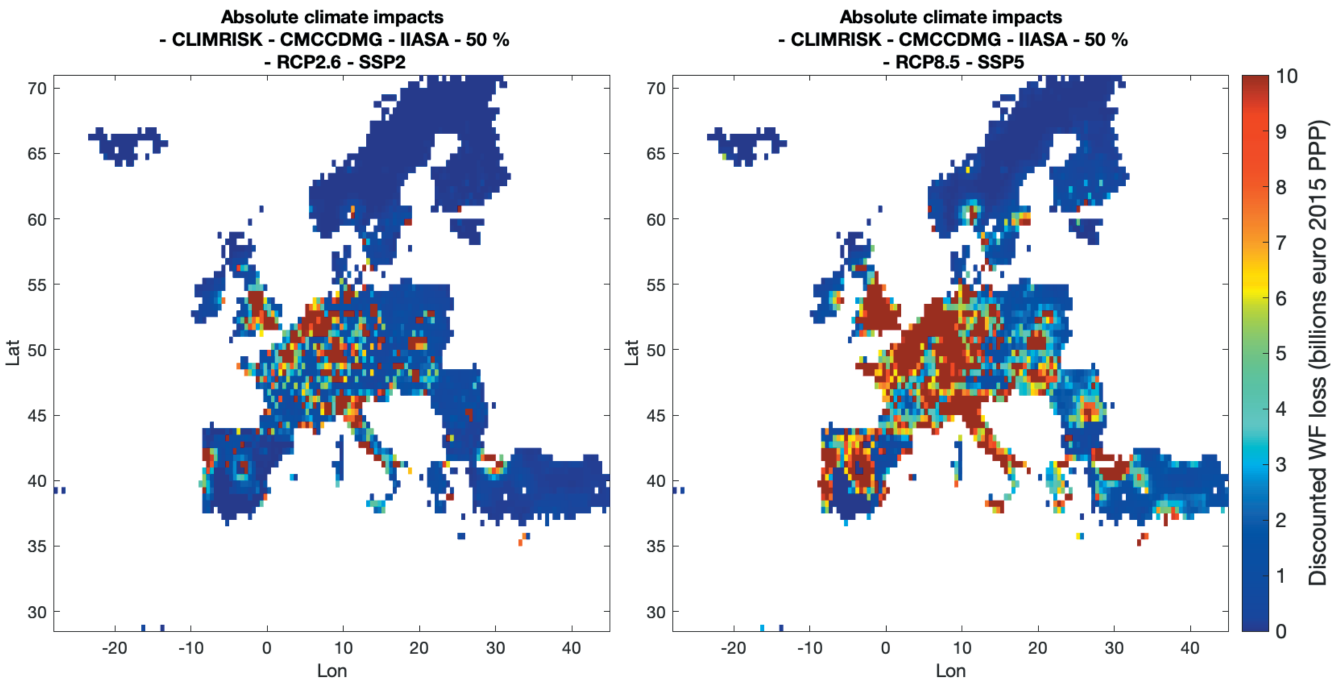
First, the use of more downscaled information reveals a pattern of winners and losers across Europe, as compared to more aggregated IAM analysis.

Second, the combination of local temperature and functions shows higher damages in urban areas.

These effects can be seen below in the total discounted estimates of the economic costs of climate change in Europe over this century.

Major differences start to emerge in the second half of the 21st century. The cumulative climate impacts in Europe reach €1 trillion by 2055 alone under the RCP8.5 scenario, but this would be reduced to below €250 billion under the high mitigation scenario of RCP2.6. These differences expand later in the century, to €2.5 trillion versus €350 billion respectively in 2080, and by 2100 the difference is a factor of 10 between the scenarios.

The model has also been run with the additional of the urban heat island (UHI) effect. This significantly increases damages in urban areas, more than doubling the damages in major populated cities such as Paris. This is due to the greater hazard but also the greater stock at risk. Mitigation policy (RCP2.6) significantly reduces these city level damages, highlighting an additional benefit of such action.



Total discounted damages in Europe over this century for RCP2.6-SSP2 and RCP8.5-SSP5.

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