Grant agreement no. 776479

COACCH

CO-designing the Assessment of Climate CHange costs

H2020-SC5-2016-2017/H2020-SC5-2017-OneStageB

D5.7 Climate Change Impacts & Policy Synthesis

Work Package:	5
Due date of deliverable:	M 42 (Revised M 46)
Actual submission date:	14/NOV/2021
Start date of project:	01/DEC/2017
Duration:	48 months
Lead beneficiary for this deliverable:	Paul Watkiss (PWA)
Contributors:	Paul Watkiss, Michelle Watkiss (PWA)

Disclaimer

Dissemination Level		
PU	Public	X
CO	Confidential, only for members of the consortium (including the Commission Services)	
CI	Classified, as referred to in Commission Decision 2001/844/EC	

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No **776479.***

Version log

Version	Date	Released by	Nature of Change
1.1	14/November/ 2021	PWA	First Draft

Summary

The COACCH Project has produced a series of policy briefs that summarize the project results, as the project has progressed. These have been used to provide targeted results for key stakeholders, as well as for wider communication and dissemination of the project.

These briefs and the overall results from the project are brought together in the final policy synthesis, D5.7. This summarizes the relevant results in three areas: the results for Europe; the global results; and results of potential interest to business, which are compiled together in this deliverable. These were produced as very concise synthesis documents, to collate headline results from the study. These are complementary to the four longer and slightly more technical policy briefs (5.3 – 5.6)

The synthesis was used to communicate results to COACCH stakeholders, including for policy, research, business and investment stakeholders, in advance of the COACCH final meeting. It was also used to disseminate the COACCH results to other potential stakeholders.

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COACCH

CO-DESIGNING THE ASSESSMENT OF CLIMATE CHANGE COSTS

The Economic Cost of Climate Change in Europe

Policy Summary Europe

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

Key Messages - Europe

- The COACCH project has developed new sectoral analysis of the impacts of climate change in Europe. This work has been delivered using a co-design process, which has jointly developed and delivered research outputs that meet user interests.
- The project has run a series of sectoral assessments. These identify very large damage costs from climate change for Europe, for direct damages such as from coastal and river flooding, but also for non-market sectors, notably health.
- These sector results have been fed into macro-economic models to estimate the overall economic costs. This finds high economic costs of climate change in Europe, even for central scenarios at mid-century. These findings contrast with some of the earlier literature, which estimated more modest impacts for the continent.
- The analysis also finds a very strong distributional pattern of economic costs across Europe, with higher costs projected for south and south-eastern Europe. These economic costs rise significantly, especially for higher warming scenarios later in the century.
- Ambitious global mitigation policy has a major benefit in reducing these economic costs in Europe, however, these benefits mostly arise after mid-century.
- The project has found the use of economic models provides additional insight, for examples, economic impacts in Europe are influenced by what happens globally.
- The COACCH project has also looked at climate and socio-economic tipping points. It finds these large-scale events would have major economic consequences for Europe, and add weight to the need for ambitious mitigation.
- Even if the Paris Goals are achieved, there will still be high economic costs of climate change in Europe. The lags in the climate system means that the impacts in the next two decades are locked-in, and can only be reduced with adaptation.
- The COACCH project has also looked at the economics of adaptation. Adaptation can dramatically reduce the economic costs of climate change, reducing down impacts over the next twenty years, as well as later. However, adaptation, although very effective, does not negate the need for ambitious mitigation
- Many early adaptation investments deliver high benefit to cost ratios, i.e. they are no or low-regret in nature, and a priority for early plans.
- Finally, national level macro-economic analysis finds that adaptation reduces the negative impacts of climate change, and leads to net positive outcomes for public budgets, due to the benefits of adaptation on government revenues.

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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. This brief summarises the various results from the COACCH project on the economic costs of climate change in Europe.

Co-Design

The COACCH project adopted a co-creation process as a core part of the research. This adopted a different way of working to a traditional research project, and involved stakeholders (from the policy, business and research domains) in a co-operative process of design, production and dissemination (see box).

There are different approaches to co-design and COACCH has focused on generating usable information for policy makers, and has used knowledge brokers, as shown in the figure.

To help the co-design process, COACCH undertook a detailed literature review on previous studies, to identify what makes a successful co-design process. Based on this, the project co-design was designed to be:

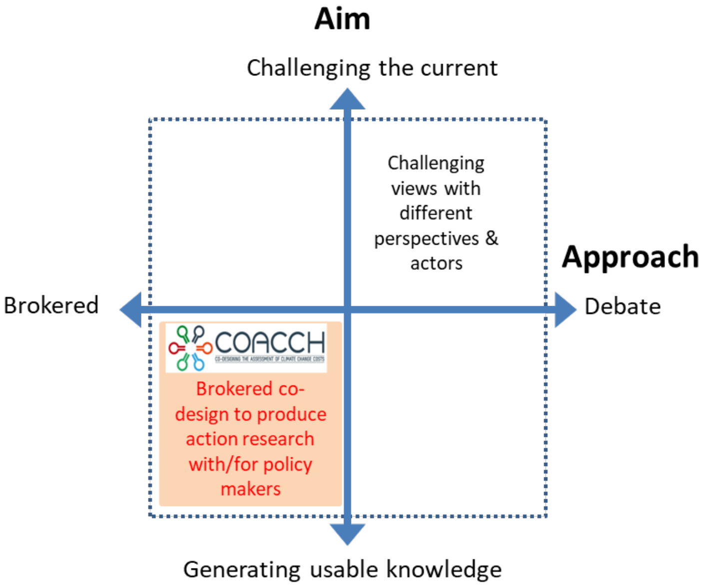
- Process orientated;
- Objective and outcome led, with clearly identified roles and responsibilities;
- Targeted, ensuring representative stakeholders;
- User and decision orientated, with the aim to meet produce information of relevance for decisions and decision makers;
- Joint product orientated, using outputs to help build the engagement process;
- Iterative, with an ongoing process of review, learning and update regularly throughout.

Co-design (cooperative design) is the participatory design of a research project with stakeholders (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 participatory approaches and trans-disciplinary research.



The most important benefits of co-design were found to be the improved relevance of research outputs for uptake and use (in decisions) and the improvement in the dissemination and communication of research outputs.

However, compared to a traditional research project, co-design was found to involve considerably more resources and time, particularly at the start of the project

The use of knowledge brokers was also found to be critical, and the co-production process was found to work best when there was deep and regulator engagement, and use of case studies.

Finally, based on the experience and lessons of the project, the COACCH project has produced a set of co-design guidance, available for future research.

Modelling Approach

Climate change will lead to wide ranging impacts on the natural and man-made environment across different sectors and regions. These impacts will, in turn, lead to economic costs in market and non-market sectors.

The COACCH project has undertaken detailed sector by sector analysis of the potential economic costs of climate change in Europe. This includes analysis of energy demand and supply, labour productivity, agriculture, forestry, fisheries, transport, sea level rise, and riverine floods.

These sector results have subsequently been fed into a macro-economic model, the ICES macroeconomic computable general equilibrium (CGE) model. This allows the analysis of the higher order economic implications of climate change impacts, within the economic system, and captures the linkages between sectors and trade flows of domestic and international goods and services.

This analysis was undertaken for a range of future warming scenarios to consider uncertainty, captured by the Representative Concentration Pathways (RCPs), as well as future socioeconomic development, using the Shared Socioeconomic Pathways (SSPs). The combination of RCPs and SSPs are shown below. Further, the analysis of RCPs took account of climate model uncertainty.

Complementing this, COACCH has also undertaken new work on climate and socio-economic tipping points, i.e. low-likelihood, high-impact events, and their potential impact on Europe.

The project has also looked at the economics of adaptation. This has involved a number of sectoral assessments on adaptation, and the consideration of the macro-economic effects of adaptation on the public finance.

These results are summarised in this policy brief. Further details are available from a series of longer technical policy briefs on the COACCH website, and the project deliverables.

Table 1: Selected scenario combinations to be used in the COACCH project

	SSP1 (Green Growth)	SSP2 (Middle of the road)	SSP3 (Regional rivalry)	SSP4 (Inequality)	SSP5 (Fossil fuel development)
RCP8.5					🟡
RCP6.0		🟡			
RCP4.5	🟡	🟢 🟡 🔴 🔵	🟡		🟡
RCP2.6	🟡	🟢 🟡 🔴 🔵	🟡		

🟢 = "low signal" climate model; 🟡 = "average" climate model; 🔴 = "high signal" climate model;
🔵 = fixed adaptation, "average" climate model

* The "low signal" and "high signal" climate model refers to, respectively, choosing a model which leads to relatively low/high temperature change and/or to low/high precipitation changes.

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Results – economic costs of climate change by sector

The COACCH project produced new sector estimates of the economic costs of climate change, using a suite of sectoral models and econometric analysis (see framework below).

The analysis of future impacts was taken for the set of RCP-SSP scenarios (see previous page) to allow a harmonised approach for use in subsequent Integrated analysis. However, some of the models also generate direct damage costs that provide valuable policy insights.

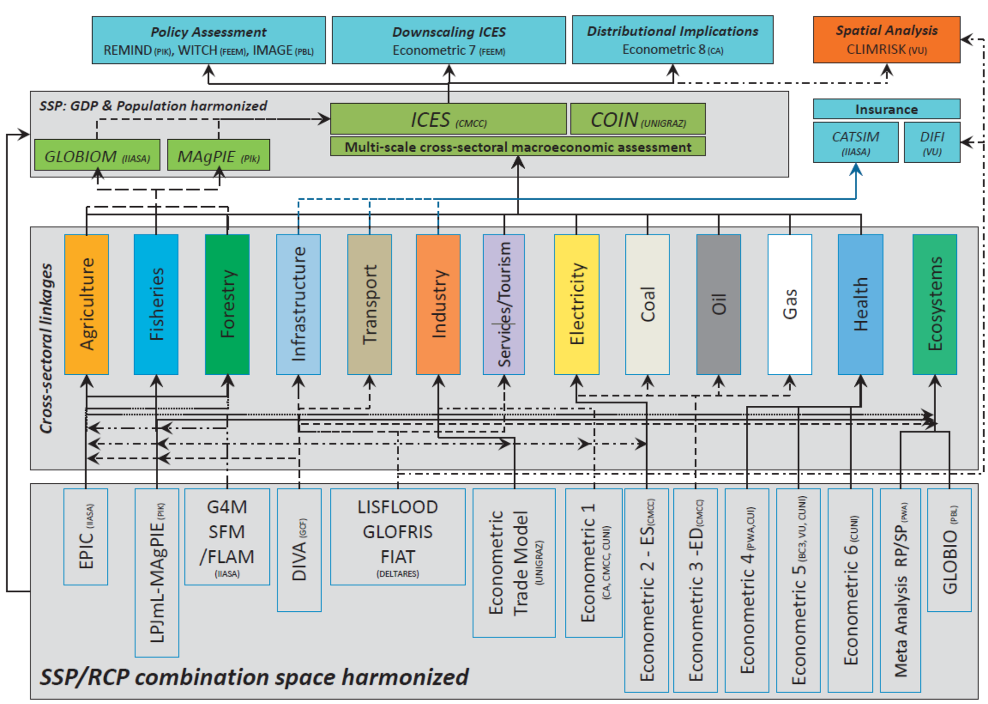
The analysis assessed the impacts of climate change in terms of social welfare, to capture the costs and benefits to society, including both market and non-market impacts. These estimates are presented in terms of current prices (Euros) for future time periods, without adjustment or discounting, to facilitate direct comparison, over time and between sectors.

A first finding is that the economic costs of climate change in Europe are estimated to be very large in future years.

The largest impacts are projected from flooding, with the combined impact of coastal and river flooding estimated to lead to damages in excess of €100 billion/year by the 2050s, even under a moderate warming scenario (RCP4.5) [combined impact of climate and socio-economic change, with no adaptation, current prices, undiscounted].

There are also very large non-market impacts projected, for example the impacts of additional heat related mortality are of a similar level, in excess of €100 billion/year by the 2050s [RCP4.5, combined impact of climate and socio-economic change, with no adaptation, VSL valuation, current prices, undiscounted]. It is noted that these are not captured in the macro-economic analysis in the next section, and are important to consider alongside impacts on GDP.

These damages increase strongly over time, and accelerate significantly for higher warming scenarios by the late century.



The COACCH modelling framework.

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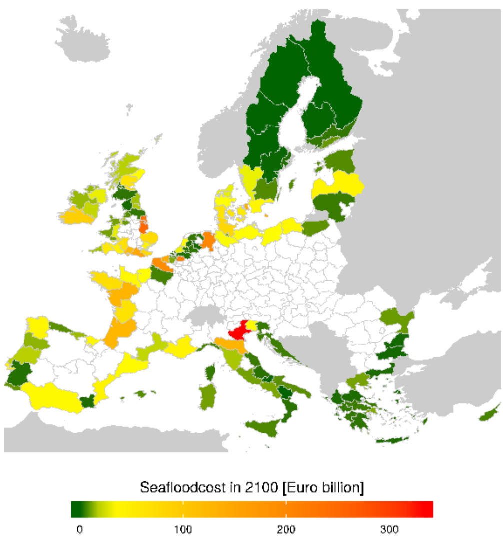
The results also show the large benefits of mitigation, as shown by the comparison of different RCP scenarios. There are very large benefits in moving from a RCP6.0 to RCP2.6 scenario, and even large benefits in moving from RCP4.5 to RCP2.6. However, these mitigation benefits mostly arise after 2050. Further, even with mitigation in place, there are high residual annual damages in Europe (i.e. tens of €billions/year under RCP2.6 scenarios).

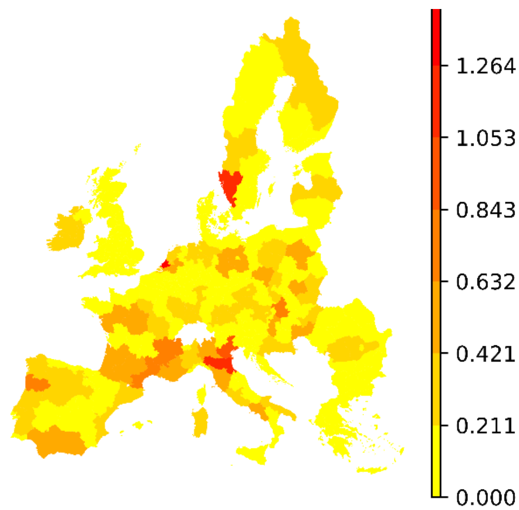
There are also strong spatial patterns of these risks across Europe, with higher costs generally projected for most risks in south and south-eastern Europe as shown below, the exception being for coastal impacts.

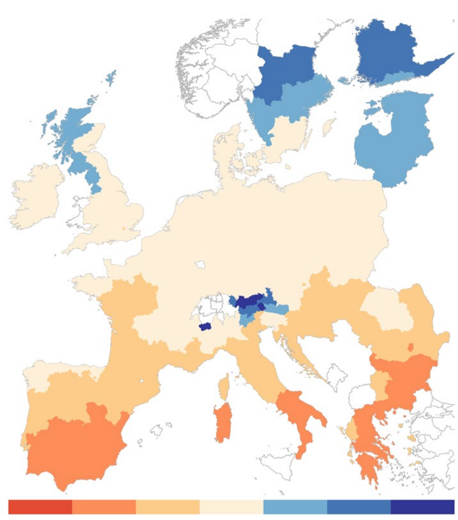
More details are available in the sectoral results policy brief and project deliverables.

European Coastal Flood Impact (€).



European River Flood Impact (€).





Impact on Industrial Labour Productivity

European Heat related mortality (No)

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Results - macro-economic costs of climate change

The sector results from COACCH were fed into a macro-economic model, the ICES macroeconomic computable general equilibrium (CGE) model. This allows an analysis of the effect of climate change on the economic performance of a country or region (including on GDP).

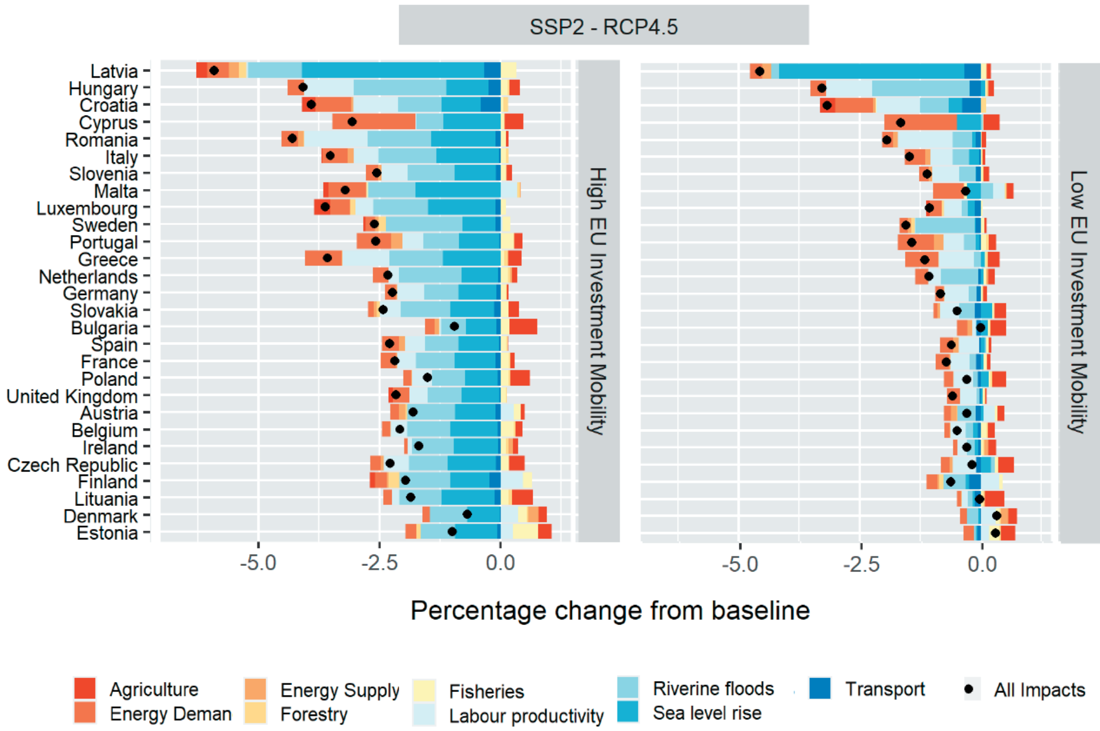
This considers how climate change affects economic output, in terms of capital, labour and productivity, as well as the impact on economic growth from changes in capital investment, productivity and technological improvement. This allows an assessment of how climate change affects the drivers of growth, and thus might alter economic growth rates. Such impacts can lead to cumulative effects over time, which are much larger than from reductions in output alone.

The COACCH project undertook such an analysis, and developed the ICES model results to produced downscaled results at a sub-national level, looking at combinations of future scenarios (RCPs) socioeconomic development (SSPs).

To account for uncertainty, results from the sectoral studies for a “low”, “medium” and “high” cases were considered, to account for important sensitivities.

The central aggregated results at the country level for mid-century for the RCP4.5 – SSP 2 scenario are shown below. The overall results, when all sectoral effects are considered, show important losses in GDP across Europe. This contrasts with earlier modelling studies, which estimated more modest impacts for the continent.

Two different assumptions of investment mobility were considered. The first represents a highly integrated EU (shown left), where investments can rapidly move. In this case, economic shocks, especially those associated with capital stocks such as from floods, propagate more easily within the EU. The second case assumes lower inter-regional mobility of investment, (shown right) implying that negative impacts tend to “stay” within the region where they occur.

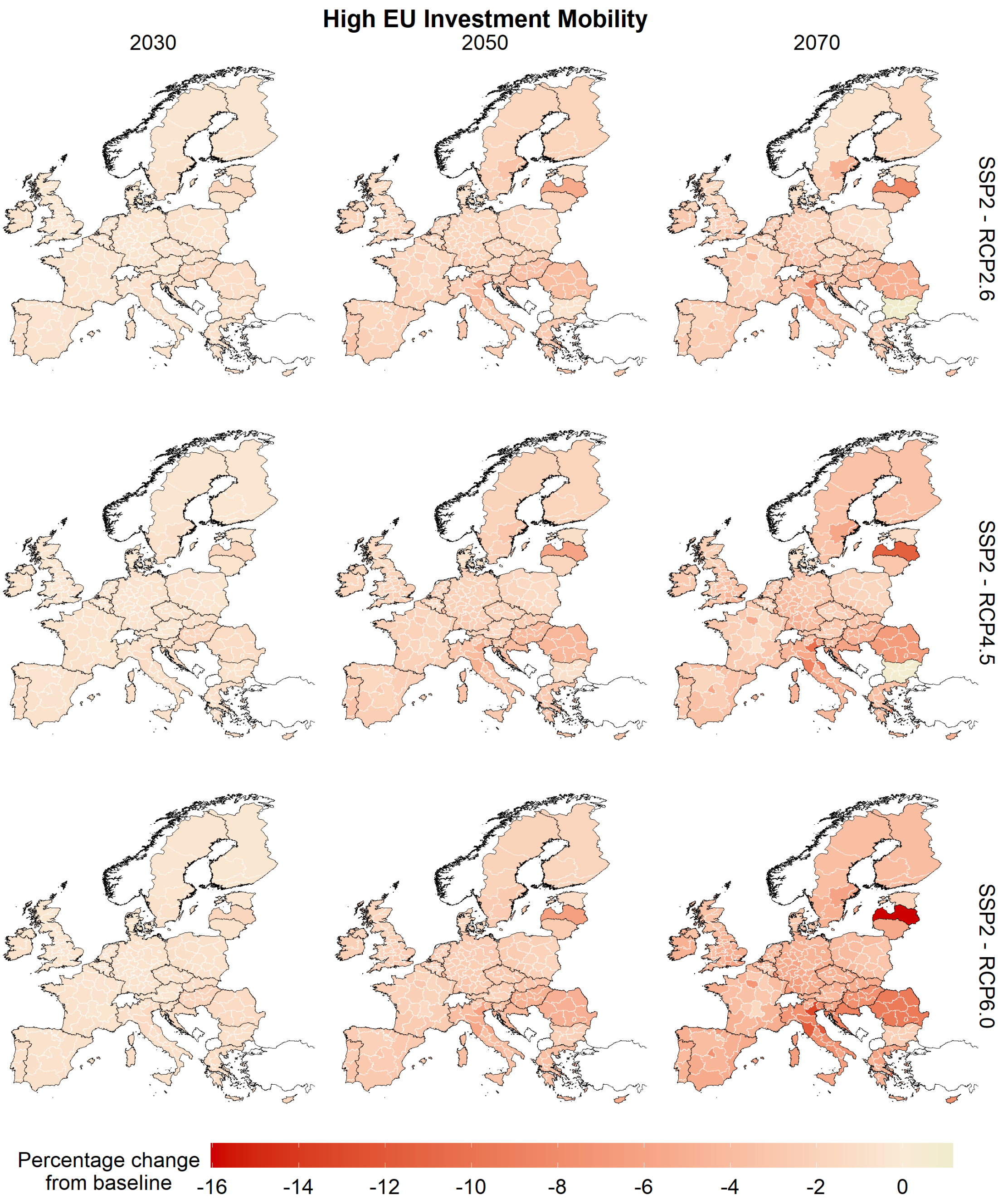


Climate change impacts on GDP by country in 2050, RCP4.5-SSP2, medium impact (left, high investment mobility upper panel, right, low investment mobility). Dots are total net effect. Values in percentage change from the baseline.

The results are also shown for different warming scenarios (RCP2.6, 4.5 and 6.0 scenarios) for the same socio-economic scenario (SSP2, a middle of the road socio-economic scenario) over time. The high investment mobility scenario is shown.

Up to 2050, there is relatively little difference between RCP scenarios as the climate signal does not differ much, though there is a large difference across the low, medium and high sensitivity cases, reflecting uncertainty in climate projections and impact models.

In the 2070s, there are very large differences across scenarios as well as across the sensitivity runs. In the higher warming scenario (RCP6.0, bottom), there are significant losses in the majority of countries.



Climate change impacts on GDP by region, medium impact case (high investment mobility) SSP2 for various RCP combinations. Values in percentage change from the baseline

The main drivers of macroeconomic impacts and GDP losses are from sea-level rise (although SLR impacts drop dramatically under the adaptation scenario), river floods and crop yield changes.

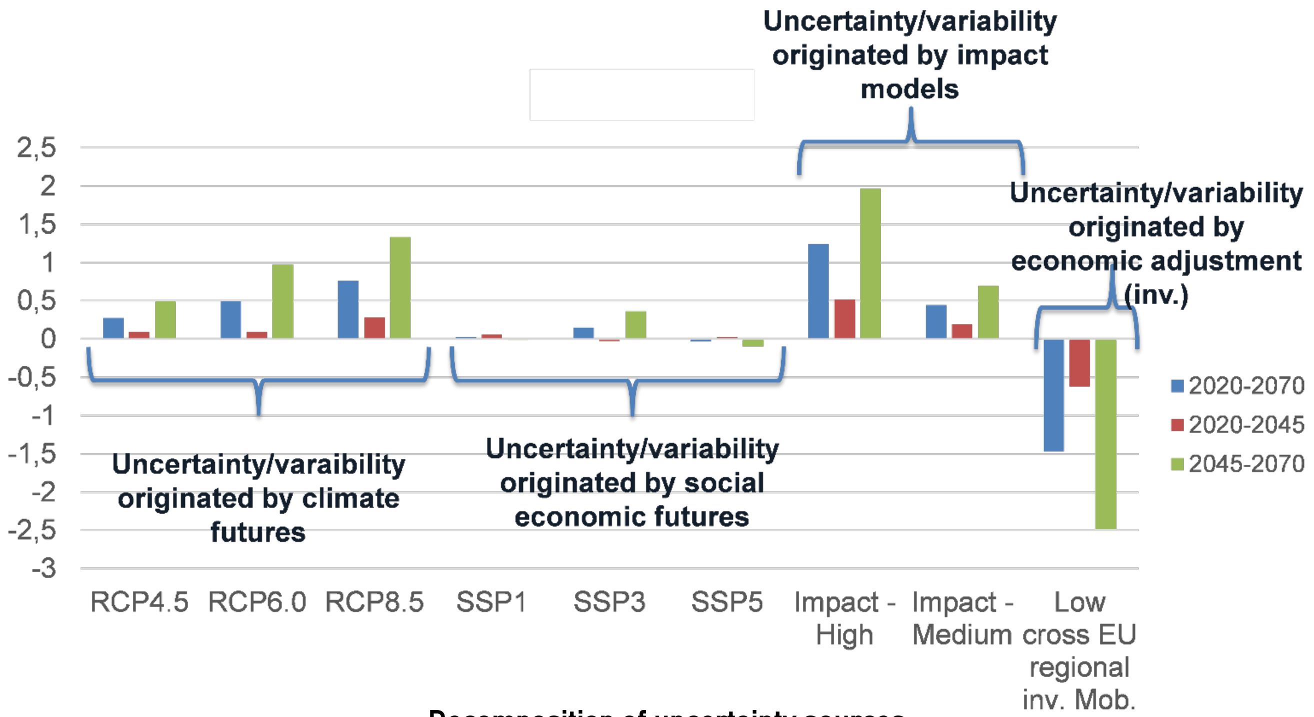
There are also important impacts from labour productivity, energy supply and energy demand, but these tend to be more pronounced in southern Europe. The impacts on fishery and forestry are generally more modest, and in many regions could involve potential gains. The impacts of transport are low, but these only cover direct effects. As highlighted above, these results do not include impacts on health or biodiversity and ecosystem services.

There is a large difference according to the mobility assumptions. Lower inter-regional mobility of investment tends to decrease GDP losses, as impacts spread less across regions. However, this effect is important when impacts concern capital assets and, thus, for sea-level rise and river floods.

Diving down to the sources of uncertainty, there are large differences between sensitivity runs, shown below. The climate scenario (RCP) is more important than the social-economic path (SSP). However, even larger uncertainty arises from the differences in climate and impact models (and assumptions), and there are large differences between the low, medium and high sensitivity cases. There is also large uncertainty from the specific type of economic adjustment (investment mobility).

This uncertainty highlights a key message – it is still possible to experience high economic impacts in low warming climate change scenarios. This is a further incentive to implement aggressive mitigation policy, as even a fraction of a degree avoided can make a large difference.

More details on the results are presented in the macro-economic results policy brief and project deliverable.



Decomposition of uncertainty sources.

The y-axis reports coefficients of the "Analysis of Variance" test. The higher the bar the higher the contribution to the economic impact. The RCPs are measured relative to RCP2.6, SSPs relative to SSP2, impact specifications relative to "low impact", investment mobility role is measured against "high investment mobility".

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Results – climate and socio-economic tipping points

In addition to the sectoral and macro-economic impacts above, there are a set of additional potential impacts from climate change, associated with low-likelihood, high-impact events, often termed tipping points.

Climate tipping points relate to critical thresholds at which a small change can alter the state of a system. A number of global (earth-system) climate tipping elements have been identified, which could pass tipping points as a result of climate change, leading to large-scale consequences. These may be triggered by self-amplifying processes and they can be potentially abrupt, non-linear and irreversible.

These 'bio-physical' climate tipping points provide a further justification for global mitigation policy, yet they are poorly represented in economic assessments of climate change.

The COACCH project has been analysing the potential climate tipping points of most concern for Europe. These are focusing on three tipping points that are relevant this century.

The COACCH project ran the DIVA model to estimate the potential economic costs for Europe for extreme sea-level rise scenarios. This considered a high-end scenario with global coastal average sea-level rise of 170cm by 2100, to illustrate the effects of high end sea-level rise.

Under this scenario, coastal SLR and floods were found to have severe effects with an expected 30 million people flooded each year, and EU expected annual damages of 13 trillion EUR. This is driven by the combination of higher climate change and the SSP5 scenario.

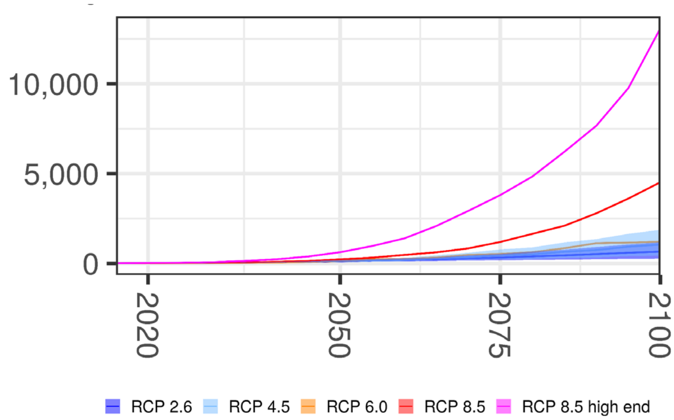
It is noted, however, that adaptation could reduce these costs down significantly, to €44 billion per year – but under such high SLR there could be technological and economic limits to adaptation that prevent adaptation at some locations.

COACCH also assessed projections of Arctic sea ice loss, and how these might evolve over this century, based on CMIP5 models.

These indicate that under RCP8.5, summer ice sheet loss is projected by mid-century, but that for some models, this might also occur within this time frame under RCP4.5. These would have potential impacts from changes in extreme cold conditions, and possible windstorms, with potentially important economic costs for Europe.

The project also considered the risks to Alpine glaciers, and glacier melting and retreat with warmer temperatures, exacerbated by ice-albedo feedback. The analysis found that under all RCPs, there is a projected reduction of about 50% of the glacier volume over the Alps by the 2050s, and much higher reductions later in the century, especially under high warming scenarios.

These will have economic costs from the decline in summer river flows, affecting water availability, hydropower, river transport and stability (landslide risk), as well as the loss of ecosystem services from Alpine species and habitats.



Example of Climate Tipping Point..
EU28 sea flood cost (Annual Billion Euro) and protection cost over 21st century, showing also the effect of extreme SLR.

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The COACCH project has also developed a new concept of socio-economic tipping points (SETP). This idea recognises that even gradual climate change may abruptly and significantly alter the functioning of socioeconomic systems, which can lead to major economic costs, especially at a more local level. These changes may arise directly in Europe, but may also involve global events that subsequently spill-over into Europe.

These may involve a case where climate change triggers a large-scale socio-economic event (a major shock). It might also involve a case where climate change pushes a socio-economic system above a threshold, affecting its functioning. Either of these socio-economic tipping points can trigger a rapid increase in costs, e.g. as measured by a large drop in the GDP of a local area or region.

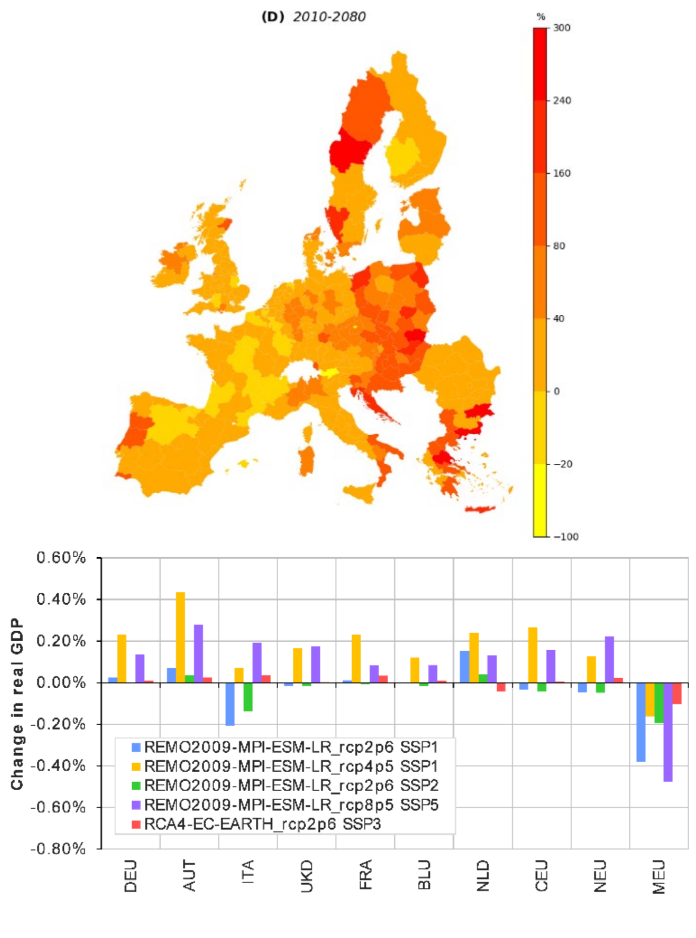
A number of these SETPs were assessed in the project

- Climate induced agriculture and food shocks, and potential land abandonment and price spikes;
- Migration induced tipping points, including from coastal areas due to extreme sea level rise, and from major climatic shocks;
- Energy and Transport tipping points, with analysis of wildfire related energy supply shocks, as well as multiple floods and transport disruption;
- Extreme sea-level rise, including transformational adaptation;
- Economic tipping points, including the potential for large macro-economic impacts,
- Financial tipping points , including the potential collapse of insurance markets from extreme weather risks, as well as major impacts on countries and financial markets.

The results indicate that smaller-scale SETP are likely to happen earlier and with greater certainty, but there are also potential major events that could occur in Europe. A further finding is that these SETPs often have strong distributional patterns, i.e. for specific regions of Europe or particular groups.

While it is difficult to assign the likelihood of these events, the modelling shows these events are associated with high-end (RCP8.5) scenarios, though also sometimes at lower warming scenarios. They can include very large impacts, that would have major policy consequences at the European scale.

Importantly, these socio-economic tipping point events are currently omitted in policy discussions and further consideration of them is considered a priority, alongside climate tipping points.
More details on the results are presented in the tipping points policy brief and project deliverables.



Examples of socio-economic tipping points.

Top. Percentage change in unaffordability of flood insurance for households for 2010–2080 (RCP8.5-SSP5).

Bottom. Changes in real GDP in 2050 due to combined effect of changed cropland availability + yield changes.

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Results – economic benefits of adaptation

Even if the Paris Goals are achieved, there will still be high economic costs of climate change in Europe over the next two decades.

The COACCH project has explored the potential for adaptation in reducing these impacts. This has used a number of the sectoral models, extended the analysis look at the benefits of adaptation (i.e. the reduction in anticipated impacts) as compared to the costs.

The adaptation analysis was undertaken for the major impact categories, including coastal and river floods, as well as for non-market impacts with the analysis of health.

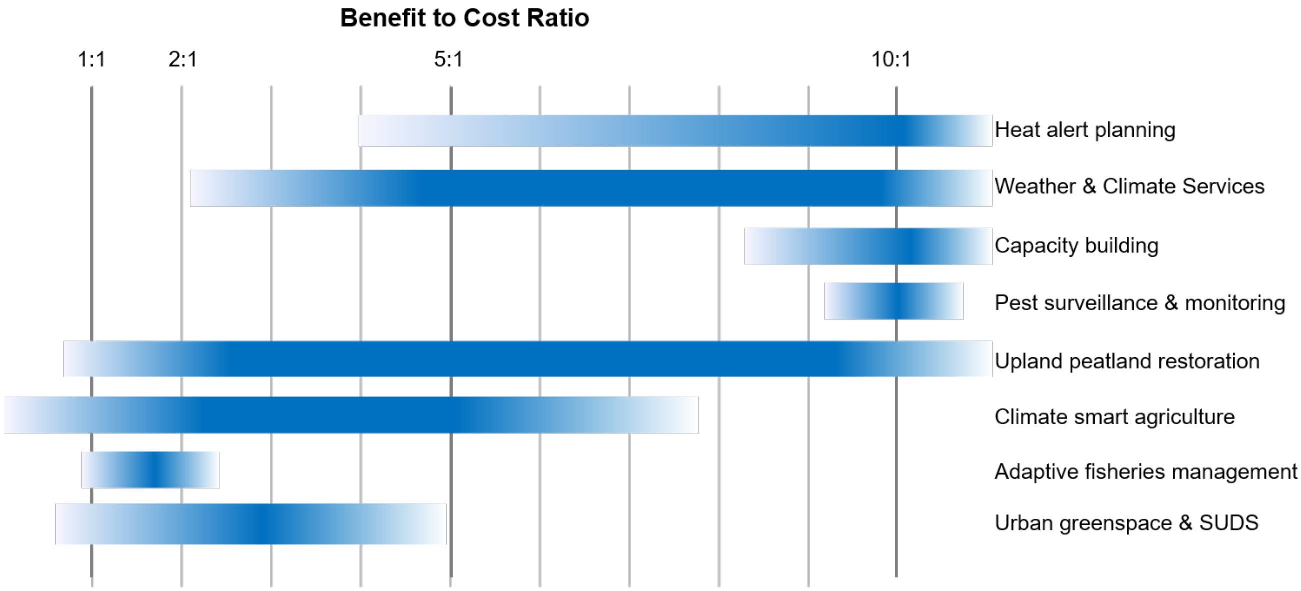
The first key finding is that adaptation has large economic benefits in reducing future impacts, often reducing damage costs by a factor of 2 to 5. Importantly, the level of reduction depends on the objectives set for adaptation, and whether this to the economically optimal level (considering the trade-off between benefits, costs and residual damage) or to pre-determined levels of acceptable risk or damage.

Nonetheless, some residual damage still remains even with adaptation, though in the medium to long term, this is much lower under ambitious mitigation scenarios, highlighting the complementary nature of mitigation and adaptation. The analysis finds that while adaptation has high benefits, it requires significant additional investment in Europe, with rising costs over the century.

As one of the applied policy assessments, further work was undertaken to support national adaptation planning, with a detailed review of the potential costs and benefits of early adaptation. This looked at the economic case for adaptation, based on analysis of the benefit to cost ratios (BCRs).

This analysis identified a larger number of no and low-regret options (with BCRs above 1), across market and non-market sectors (shown below).

The COACCH project also undertook new analysis to look at the macro-economic effects of climate change and adaptation at the national level.



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This analysis built on the climate change impacts estimated for Europe, which are estimated to be several % of GDP in most countries. These climate change impacts will affect the public finances. This will have impacts from higher public expenditures for disaster relief and a lower tax base due to reduced economic activity.

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 macroeconomic implications of impacts and adaptation in an integrated framework.

The COACCH project assessed these effects, using a multi-sectoral, multi-regional comparative static Computable General Equilibrium (CGE) model (COIN-INT) model.

The analysis looked at the macroeconomic 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.

The analysis considered a baseline which assessed the economy-wide repercussions and budgetary consequences of climate change using results from COACCH. It then looked at the effectiveness of adaptation in reducing these risks, based on public adaptation expenditures through to 2050. However, while adaptation can reduce baseline impacts, it has an additional cost, increasing public sector expenditure.

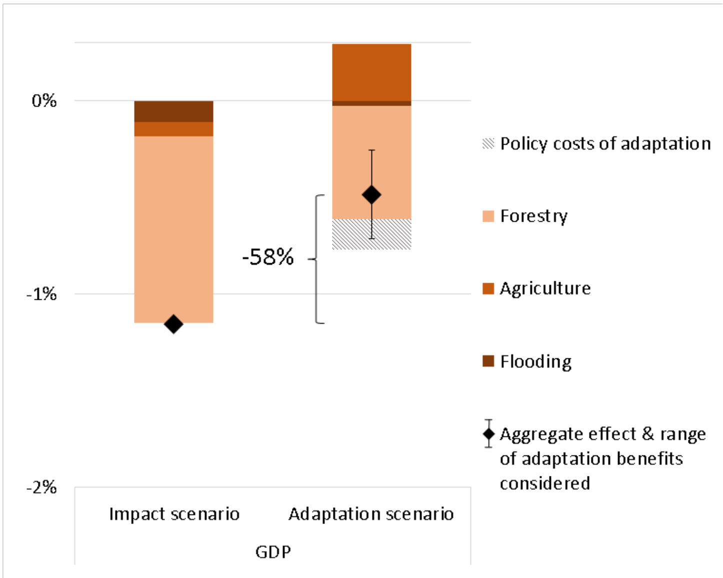
The analysis then looked at the overall effects on government budgets, looking at both direct (expenditures) and indirect effects (e.g. changes to the tax base from changes in economic output, labour and capital income).

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 was estimated to reduce these impacts by more than 50%.

The second key finding was 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 means that adaptation leads to net positive outcomes for public budgets, even though it requires public expenditure, due to the benefits of adaptation on government revenues.

More details on the results are presented in the policy results brief and project deliverable.



% Effect of the baseline impact and adaptation scenario on GDP for Austria

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WHO WE ARE

Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici
Italy

PBL Netherlands Environmental Assessment Agency,
Netherlands

Paul Watkiss Associates Ltd
United Kingdom

Basque Centre for Climate Change – Klima Aldaketa Ikergai,
Spain

Internationales Institut fuer Angewandte Systemanalyse
Austria

Climate Analytics gemeinnützige GmbH,
Germany

Universitaet Graz
Austria

Stichting Deltares,
The Netherlands

Stichting VU
Netherlands

Global Climate Forum
Germany

Ecologic Institut gemeinnützige GmbH
Germany

Potsdam Institut fuer Klimafolgenforschung
Germany

Univerzita Karlova
Czech Republic

www.coacch.eu @coacch.eu @coacch_eu

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/

Contributing authors:
Paul Watkiss, Michelle Watkiss, Alistair Hunt, PWA.
Elisa Sainz de Murieta, Aline Chiabai, Marc Neumann, Joseph Spadaro, BC3
Francesco Bosello, Ramiro Parrado, Enrico Scoccimarro, Gabriele Standardi, Shouro Dasgupta, CMCC
Milan Ščasný, Iva Zveˇrˇinová, Levan Bezhanishvili, CUNI
Jessie Ruth Schleypen, Climate Analytics
Jenny Troeltzsch, Katriona McGlade, Jack Tarpey, Ecologic Institute
Daniel Lincke, Jochen Hinkel, GCF
Kees van Ginkel, Ad Jeuken, Deltares
Gabriel Bachner, Birgit Bednar-Friedl, Stefan Borsky, Hannah Hennighausen, Martin Jury, Nina Knittel, Eva Preinfalk, Joachim Raich, Karl Steininger Uni Graz
Esther Boere, Petr Havlik, Miroslav Batka, Dmitry Schepaschenko, Anatoly Shvidenko, Oskar Franklin, IIASA
Andries Hoff, Detlef van Vuuren, Kaj-Ivar van der Wijst, PBL
Benjamin Leon Bodirsky, Miodrag Stevanovic, PIK
Wouter Botzen, Onno Kuik, Predrag Ignjacevic, Max Tesselaar, VU

Citation. COACCH (2021). The Economic Cost of Climate Change in Europe: European Results. Policy brief by the COACCH project. Published November 2021. Copyright: COACCH, 2021.

The COACCH project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776479

COACCH

CO-DESIGNING THE ASSESSMENT OF CLIMATE CHANGE COSTS

The Economic Cost of Climate Change

Policy Summary Global Results

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

Key Messages - Global

- Climate change will lead to impacts across a wide range of sectors, with associated economic costs. These costs can be investigated using Integrated Assessment Models.
- The COACCH project has developed new estimates of the economic costs of climate change, drawing on new evidence and bottom-up damage functions, and applied these in three IAMs.
- The results show higher economic costs than earlier studies, even without the consideration of more extreme scenarios, tipping points, and biodiversity impacts. The estimated costs for a business-as-usual scenario (RCP6.0) indicate global damage costs of approximately 2 to 3% of GDP/year by 2050, rising to 10% to 12% by 2100.
- Importantly, these climate change impacts are not evenly distributed across the world. There are much higher relative impacts (% of GDP) projected in Sub Saharan Africa and South Asia, where damages could be 1.5 times higher than the global average.
- These costs are projected to fall significantly under a mitigation scenario (RCP2.6) that is broadly consistent with the Paris Agreement goals. Under this scenario, global damage costs fall to under 2% of GDP/year by 2050 and to 2% to 4% by 2100, demonstrating the economic benefits of global mitigation.
- The IAMs have also been used to investigate the costs and benefits of mitigation policies and explore the potential 'economically optimal' global mitigation level. The results indicate that based on central values, the 'optimal' end-of-century temperature is ~1.8°C above pre-industrial.
- When the uncertainty range from the models is considered, which reflect the potential risk of even higher damages, the economically optimal peak temperature falls to ~1.4 – 1.7°C above pre-industrial. These results demonstrate that with the updated estimates of the economic costs of climate change, ambitious mitigation scenarios can be justified.

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/

Contributing authors :
Francesco Bosello, Ramiro Parrado, Gabriele Standardi, CMCC
Andries Hof, Detlef van Vuuren, Kaj-Ivar van der Wijst, PBL
Franziska Piontek, PIK
Paul Watkiss, Michelle Watkiss, PWA. (Editors)

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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 (CO-designing the Assessment of Climate CHange costs) is to produce an improved downscaled assessment of the risks and costs of climate change. 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.

This brief summarises the results of the study on the global economic costs of climate change, and the analysis of mitigation policy. More details are available in the project deliverable.

Definitions

The following definitions are used in COACCH:

Co-design (cooperative design) is the participatory design of a research project with stakeholders (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 participatory approaches and trans-disciplinary research.

Modelling Approach

Climate change will lead to wide ranging impacts on the natural and man-made environment across different sectors and regions. These impacts will, in turn, lead to economic costs in market and non-market sectors.

These economic costs can be estimated using global integrated assessment models (IAMs), see the Box over the page. These use a consistent framework that allows modelling of baseline and climate futures, socio-economic development, and economic impacts.

These models can estimate the potential economic costs of climate change, either as aggregate values (which can be expressed an equivalent % of GDP) or as a social cost of carbon (the marginal cost of a tonne of additional carbon emitted, i.e. $\$/tCO_2$). They also allow for the subsequent exploration of mitigation policy choices, and how these can reduce these impacts.

Earlier IAM studies reported modest economic global impacts from climate change, e.g. with only a 1 to 2% welfare-equivalent income loss, for 2 – 3°C of warming.

The COACCH project has developed new estimates of the economic costs of climate change, as well as the costs and benefits of policy options. The project has produced a new set of damage functions (see Box) for use in IAMs, based on the new information generated from the COACCH sector modelling results. These provide a significant improvement from the current literature in terms of (a) sectoral detail, (b) transparency, (c) regional granularity, and (d) the representation of uncertainty.

These new COACCH damage functions were then used in three Integrated Assessment Models (IAMs): MIMOSA, WITCH and REMIND. These were then run to explore two key issues. The first was to estimate global and regional GDP losses from climate change taking into full account the climate-economy feedbacks. The second was to examine mitigation policy costs and benefits under the light of the new damage estimates.

Integrated Assessment Models

Estimating the global economic costs of climate change is difficult. This is because of the complexity of trying to assess and value the impacts of climate change for multiple hazards (for slow-onset change, as well as shifts in the frequency and intensity of extreme events), for both market and non-market sectors, for all countries globally, over long time-spans.

Integrated assessment models combine the scientific and economic aspects of climate change within a single, iterative analytical framework, that allow an exploration of these costs. The advantage of these models is that they link emissions, temperature and other climatic change impacts and economic costs in a consistent and integrated framework. However, to make such analysis manageable, they often use simplified descriptions of climate projections and use simplified impact relationships in the form of damage functions

The COACCH project has derived a new set of damage functions for IAMs. These are available for 14 macro-regions across the world, for both global mean temperature increases and for sea-level rise, and an even higher resolution for Europe. The functions include uncertainty sources from scenarios, climate and impact models.

The new COACCH damage functions generate higher central estimates for the economic costs of climate change than earlier studies. This reflects the higher impact estimates in more recent literature, e.g. in terms of extreme events, increased sea-level rise, as well as the inclusion of indirect effects.

The project then integrated these new functions in three IAMs. These are similar models in that they all capture the interlinkages between the economic and systems, but they differ in structure and levels of complexity. The use of different models is thus particularly useful for an inter-comparison of the results and their robustness.

▪MIMOSA-6 is a recent IAM based on IMAGE-FAIR7 with 26 regions covering the world. It is a relatively simple Cost-Benefit IAM.

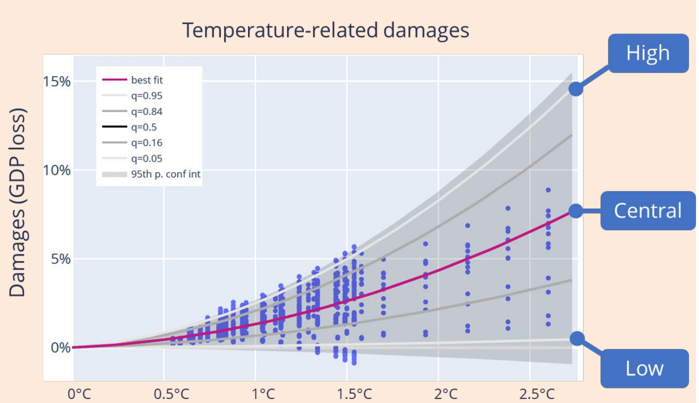
▪ WITCH8 is a dynamic optimisation IAM of intermediate complexity linking a top-down optimal growth model with a bottom-up energy system model, with 17 world regions.

▪ REMIND9 is an energy-economy general equilibrium model linking a macro-economic growth model with a bottom-up engineering-based energy system model based on 12 world regions.

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

It is emphasized that all current studies are partial, in that they include only a subset of the economic costs of climate change. A further issue is the lack of empirical evidence on climate change impacts and economic costs at higher temperatures, and thus whether there will be a step-change in impacts, including the potential risks from the risk of large-scale, non-linear global discontinuities, often called tipping points.

Finally, the results of any study are affected by the assumptions made. This includes aggregating assumptions, notably on whether and how to add up or adjust effects in different regions and time periods, including positive and negative values, and whether to account for equity/inequality aversion. When expressing economic costs as a social cost of carbon or in present value terms, there is a further issue around the appropriate discount rate to use.



Global damage function for temperature related impacts without SLR damages

The Economic Costs of Climate Change

The COACCH analysis has assessed the potential future economic costs of climate change. The level of these costs will depend on global mitigation agreements and implementation. The study compared two alternative scenarios.

The first scenario looked at a business-as-usual or baseline future. This is represented by the RCP6.0 scenario, which is associated with relatively high warming pathways.

The second looked at a mitigation scenario (RCP2.6). The Paris Agreement (of 2015) set the goal of limiting global warming to well below 2 degrees Celsius (°C), compared to pre-industrial levels, and pursuing efforts to limit warming to 1.5°C. RCP2.6 is broadly in line with a 2°C pathway.

The results are disaggregated to show the breakdown of damages between:
i) immediate effects due to temperature (no SLR);
ii) immediate effects of SLR; and
iii) dynamic effects (indirect), which are the accumulated GDP effects from impacts on growth.

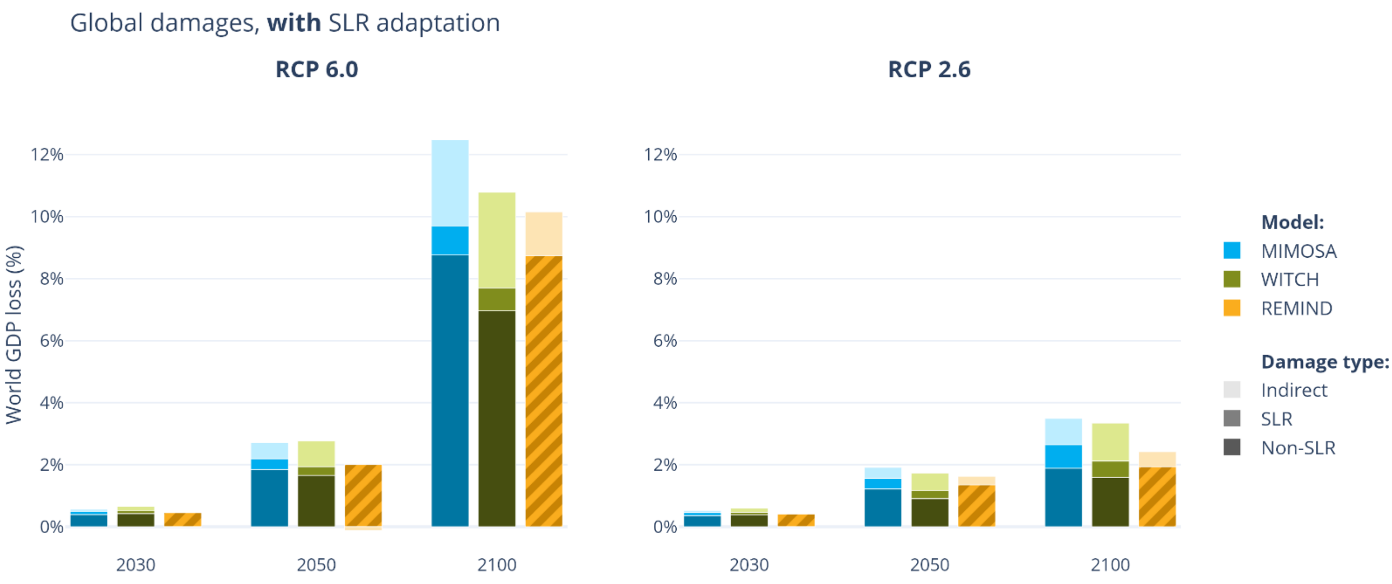
For the business-as-usual scenario (RCP6.0), the models indicate average global damage costs of approximately 2 to 3% by 2050 (central estimate) rising to 10% to 12% by 2100.

This finding is robust across the three models, and all three give similar results (though MIMOSA gives slightly higher damages and REMIND slightly lower). These values are much higher than results from earlier modelling studies.

Direct effects (non-SLR) dominate the costs, while the indirect effects due to the macroeconomic effects add about 10 to 20%.

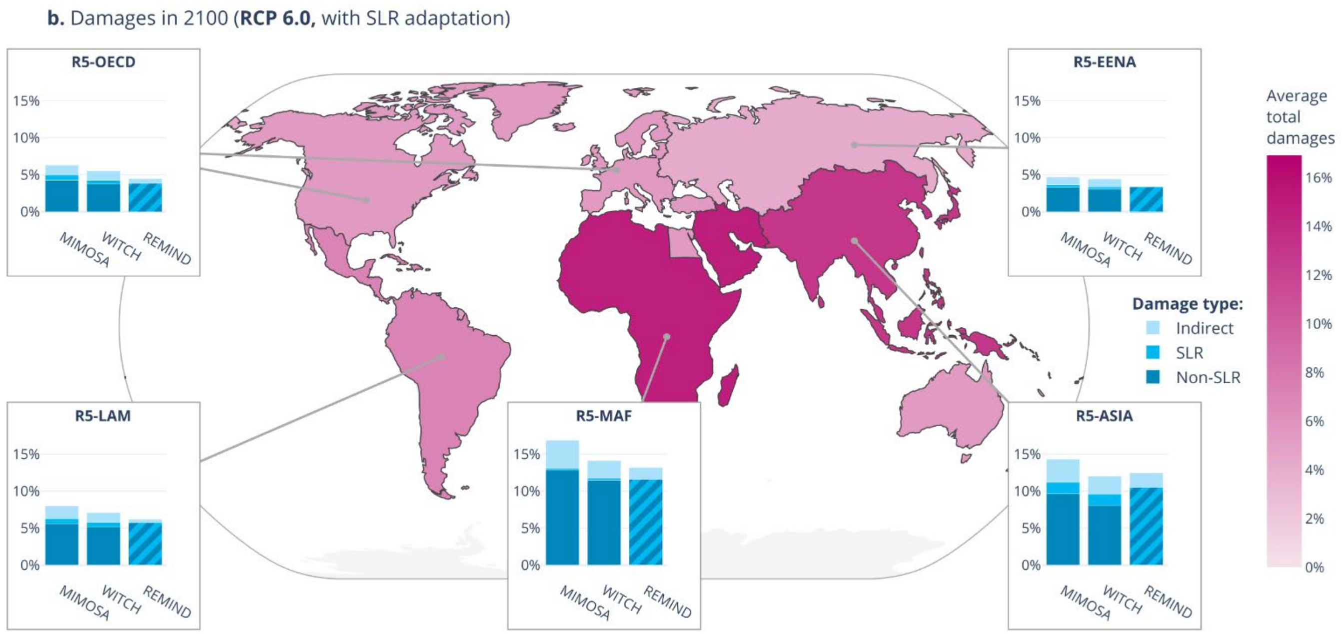
These findings can be compared with the mitigation scenario, RCP2.6. Under this scenario, the global economic costs of climate change fall significantly. This scenario reduces global damage costs to under 2% by 2050 (central estimate) and to 2% to 4% by 2100. The benefits of mitigation can be seen by comparing the two figures, i.e. the difference between the RCP6.0 and RCP2.6 estimates.

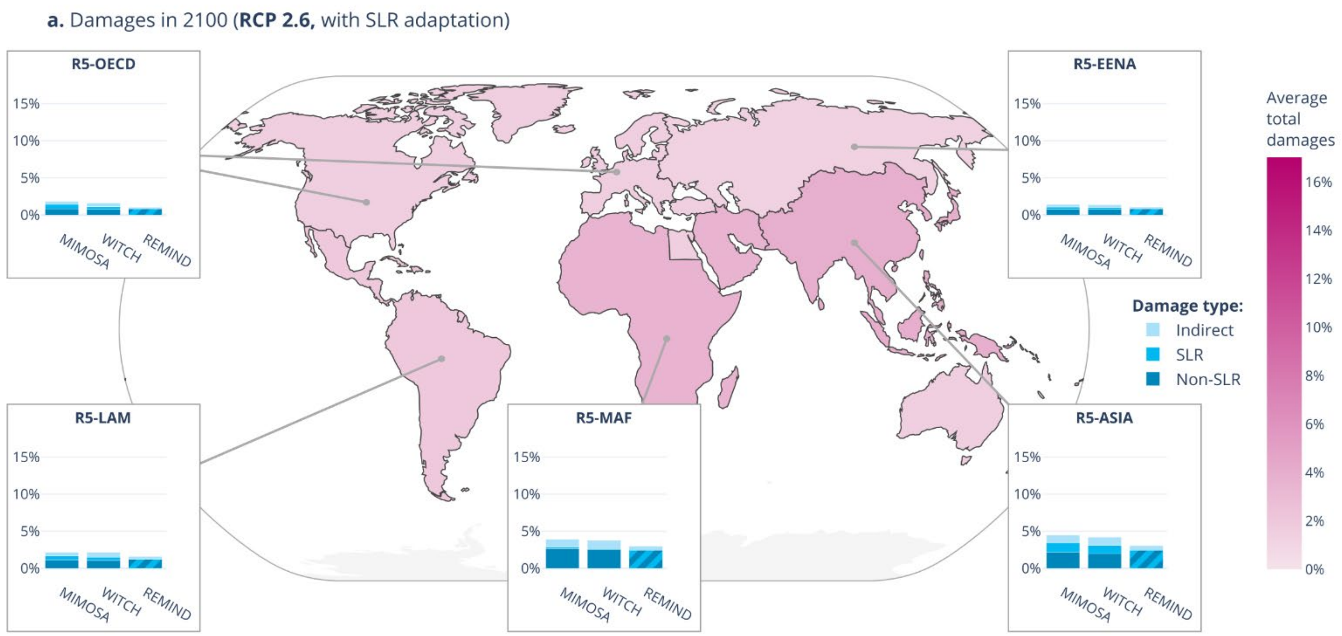
It is stressed that these values do not include biodiversity impacts pr major earth-system discontinuities, i.e. tipping points. However, they do consider uncertainty ranges which provide insights on worst-case scenarios. These show much higher damages are possible, e.g. for RCP6.0, global damages rise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



Importantly, these impacts are not distributed evenly across the world. There are much higher relative impacts (% of GDP) projected in Sub Saharan Africa and South Asia. This is shown in the figure below for the year 2100. This is shown in the figure below for 2100. Under the RCP6.0 scenario (top), the highest damages are projected in the Middle East and Africa region, at 13% to 17% of GDP, followed by Asia at 12% to 14%.

Under the RCP2.6 scenario, damages are reduced in all regions, and this mitigation scenario prevents the higher damages found in some regions in the baseline run. The RCP 2.6 scenario reduces the damages to a regional maximum of 4.5%, as compared to 20% for RCP 6.0. The results show that mitigation is extremely beneficial in reducing the more severe impacts of climate change.





Regional breakdown of damages as GDP losses (%) in 2100 in world regions for top RCP6.0 and bottom RCP2.6. Values are presented for the with SLR adaptation: values would be higher for the no SLR-adaptation scenario. The boxes show the results for each of the three models, and the breakdown by direct, SLR, and indirect effects.

The Costs and Benefits of Mitigation Policy

Two of the IAM models have also been used to investigate the costs and benefits of mitigation policies that reduce GHG emissions, and further, to explore the potential economic 'optimal' global mitigation level.

It is stressed that IAMs do not capture all the economic costs of climate change, and there are important ethical as well as economic considerations when setting mitigation policy. The results, therefore, should only be seen as experiments to provide policy insights.

The analysis looked at the optimal level of mitigation by considering i) the reduction in global damage costs (the benefits) of mitigation, ii) the costs of mitigation and iii) the residual damage, i.e. the cost after mitigation.

The results are shown first for the central projections of warming and damages. The results indicate that the modelled 'optimal' end-of-century temperature is approximately 1.8°C above pre-industrial (central projections).

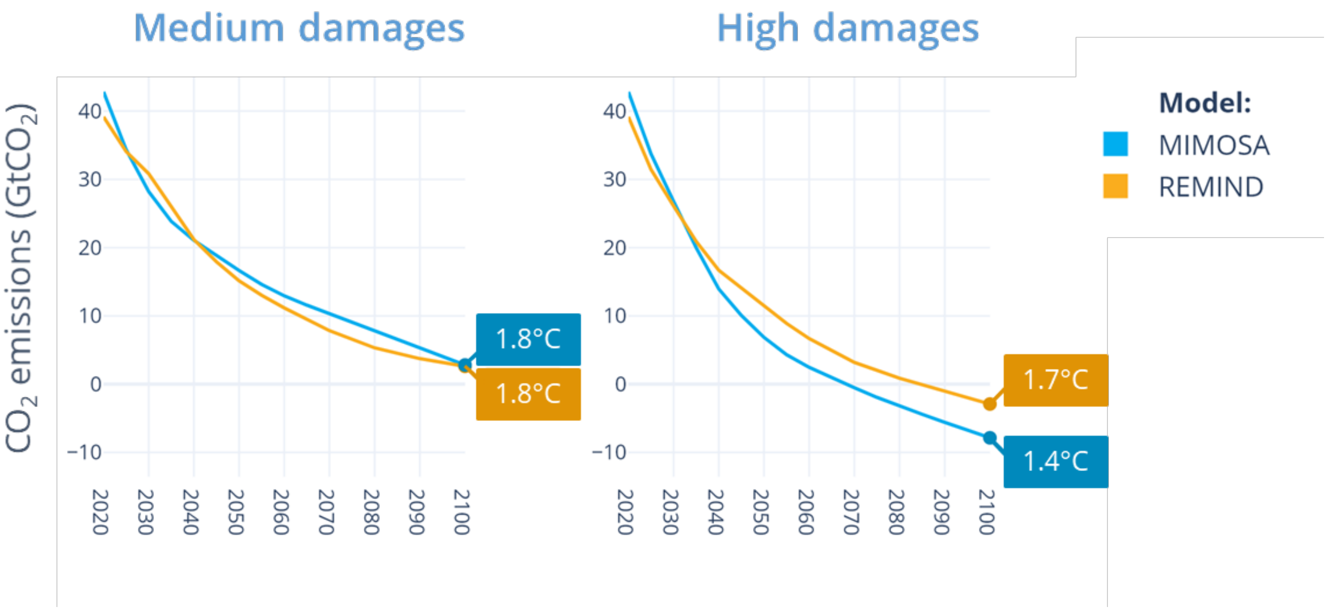
This is in line with the Paris Agreement to limit warming to below 2°C.

This shows that the 2°C goal can be justified even with the central estimates from the model. This analysis does not consider the potential for non-market impacts and major earth system tipping points. However, it is possible to explore the potential effects of these by considering the uncertainty ranges which provide insights on a worst-case scenario.

Under these high damage scenarios, the models project much higher damage cost, and the optimal temperature falls to 1.4-1.7°C, which is in line with the higher Paris Agreement ambition to limit warming towards 1.5°C.

This analysis demonstrates that with the updated estimates of the economic costs of climate change, ambitious mitigation scenarios can be justified.

For the MIMOSA IAM, an additional analysis has been made to look at the benefit to cost ratio of mitigation (the net present value of benefits/ costs), considering values of 0.1%, 1.5%r and 3% for the pure rate of time preference for the discount rate scheme



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. Note the analysis uses a Pure Rate of Time Preference (PRTP) of 1.5% and an elasticity of marginal utility of 1.

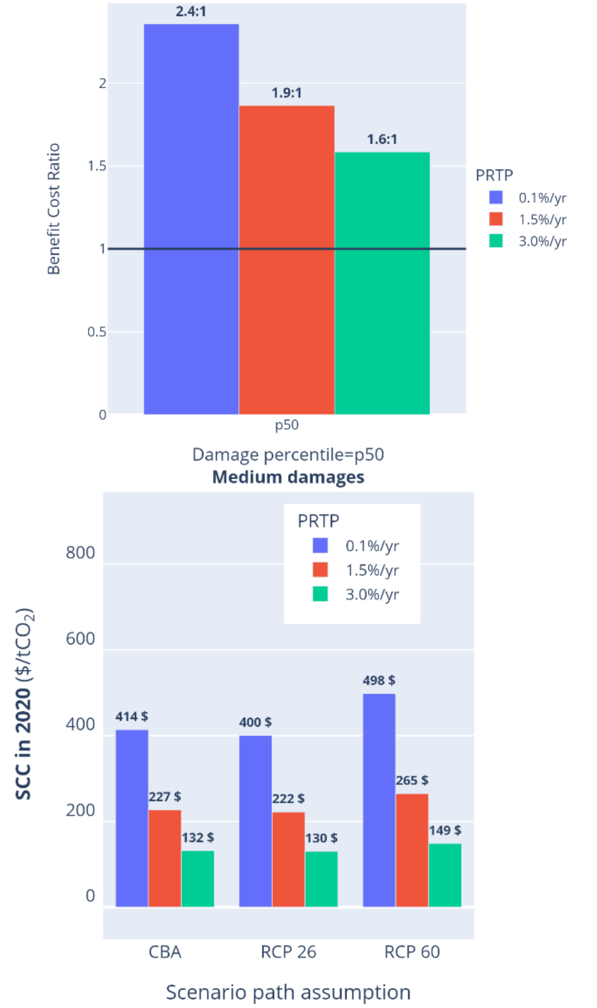
For the medium damage results, this analysis finds a benefit-cost-ratio of approximately 2 to 1.

The Social Cost of Carbon and Optimal Carbon Tax

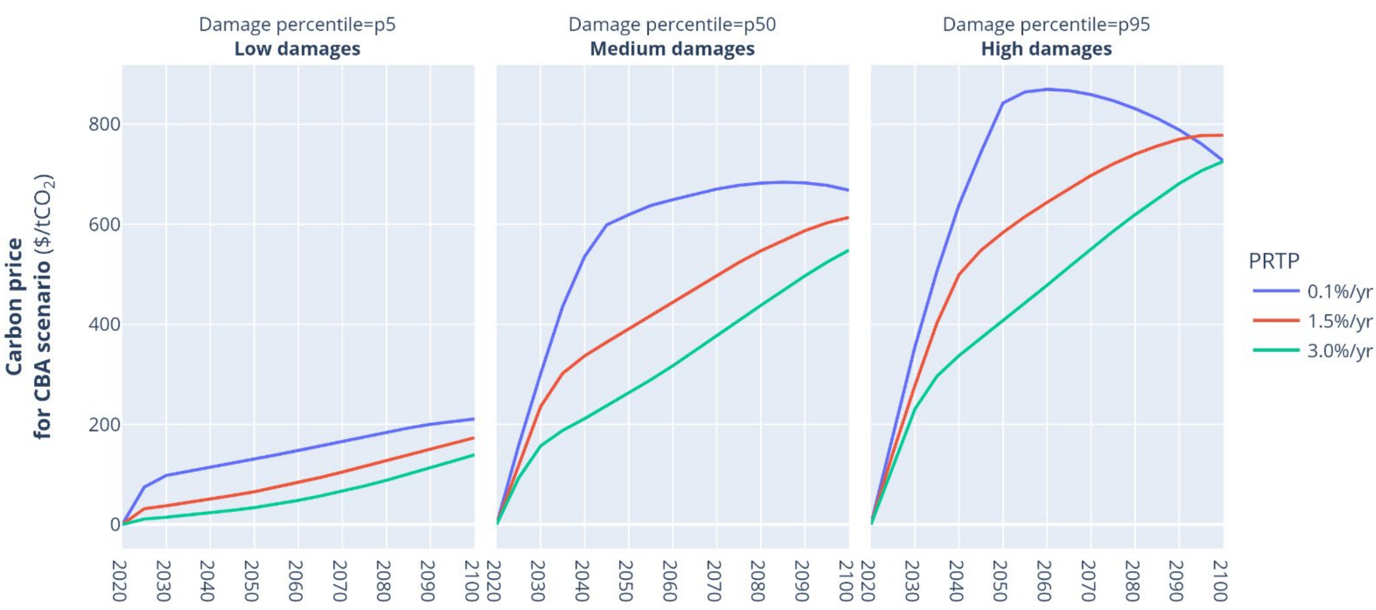
The IAMs can also be used to estimate the social cost of carbon, the marginal net economic cost of carbon (or CO_2) per tonne emitted. This is the global (net) damage from the impacts of climate change impacts over the next 100 years or so, from one additional tonne of carbon (or CO_2) emitted today, aggregated over time and discounted back to the present. The SCC can also be interpreted as the marginal benefit of reducing emissions by one tonne.

These values are estimated by running MIMOSA with an additional pulse of emissions. The resulting values are highly sensitive to the assumptions around discount rate, aggregation rules, and equity, but they always exceed USD 130/tCO_2. These are significantly higher SCC values than earlier literature, which typically had values around USD25 - 100/tCO_2 .

Finally, the IAM model cost-benefit analysis has also been used to explore the potential economic 'optimal' global carbon price over time, i.e. to provide insights carbon taxes, and can be used as shadow prices for policy appraisal. The shadow carbon price is lower in the early decades than the SCC, due to inertia in the model.



BCR (top) and Social Cost of Carbon $t/$CO_2$ (bottom: pulse, 2020) from MIMOSA for different scenarios, medium damages



Shadow Prices $t/$CO_2$ from MIMOSA for different scenarios

WHO WE ARE

Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici
Italy

Paul Watkiss Associates Ltd
United Kingdom

Internationales Institut fuer Angewandte Systemanalyse
Austria

Universitaet Graz
Austria

Stichting VU
Netherlands

Ecologic Institut gemeinnützige GmbH
Germany

Univerzita Karlova
Czech Republic

PBL Netherlands Environmental Assessment Agency,
Netherlands

Basque Centre for Climate Change – Klima Aldaketa Ikergai,
Spain

Climate Analytics gemeinnützige GmbH,
Germany

Stichting Deltares,
The Netherlands

Global Climate Forum
Germany

Potsdam Institut fuer Klimafolgenforschung
Germany

FOLLOW US

www.coacch.eu @coacch.eu @coacch_eu

CONTACT US AND SUBSCRIBE TO OUR NEWSLETTER:

info@coacch.eu

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COACCH

CO-DESIGNING THE ASSESSMENT OF CLIMATE CHANGE COSTS

The Economic Cost of Climate Change in Europe

Policy Summary

Business

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

Key Messages - Business

- Climate Change is now recognised as a financial risk for business and industry. The COACCH project has assessed these potential impacts, and possible adaptation responses.
- Climate change is projected to increase floods in Europe, leading to high direct costs on business from impacts on buildings and assets, rising insurance costs, potential collapse in insurance markets in some areas, and indirect costs from disruption to transport.
- Higher temperatures are projected to reduce labour productivity, increasing business costs. These impacts have a strong pattern across Europe, impacting particularly in the South.
- Climate change will lead to risks to business from extreme weather shocks overseas, as these can propagate along supply chains. COACCH has undertaken a new analysis and finds that supply chain shocks will increase with climate change, and this will impact on exports internationally, (including imports to the EU).
- These supply chain impacts will also reduce export performance from European countries. Having a diversified supply chain contributes to resilience against extreme weather shock in supplier countries.
- Adaptation can reduce the risks and economic costs of climate change for business, but this has to address a large variety of climate hazards, arising in many locations including internationally. It therefore requires a diverse set of possible responses, and long-term planning as well.
- The COACCH project has undertaken a detailed literature review and identified a comprehensive set of possible adaptation responses for business. This provides a much larger set of options than currently being implemented. The analysis has also identified the relevant roles of the public as well as the private sector, to enhance the scale-up of business adaptation.

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Contributing authors :
Birgit Bednar-Friedl, Stefan Borsky, Hannah Hennighausen, Nina Knittel, Karl Steininger, Gabriel Bachner, Martin Jury, University of Graz
Jessie Ruth Schleypen, Climate Analytics
Daniel Lincke, Jochen Hinkel, Global Climate Forum
Ad Jeuken, Kees van Ginkel, Deltares
Shouro Dasgupta, CMCC
Wouter Botzen, Onno Kuik, Predrag Ignjacevic, Max Tesselaar, VU
Paul Watkiss, Michelle Watkiss, PWA. (Editors)

Citation. COACCH (2021). The Economic Cost of Climate Change in Europe: Business Policy brief by the COACCH project. Published November 2021.

The COACCH project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776479

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. This document summarises the various results from the COACCH project on the economic costs of climate change to business in Europe.

Definitions

The following definitions are used in COACCH:

Co-design (cooperative design) is the participatory design of a research project with stakeholders (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.

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Practice orientated research aims to help inform decisions and/or decision makers. It uses participatory approaches and trans-disciplinary research.

Climate Change and Business

Climate change can affect businesses in multiple ways. It has the potential to damage business assets, increase operating and maintenance costs, and/or reduce revenues, all of which can affect company performance and profit. These risks can include impacts that occur in Europe, but also internationally, especially with the increasingly global nature of many supply chains.

This is leading to greater interest and analysis of these risks. The Task Force on Climate-related Financial Disclosures (TCFD), established by the G20's Financial Stability Board, is seeking to improve and increase reporting of climate-related financial information. The TCFD identifies that climate change can have two types of risks. First, those arising from climate change impacts (physical risks) and second, those arising from changes in policy, legal, technology, and market changes from the transition to a low-carbon economy (transition risk).

While much of the focus has been on transition risks and carbon prices, the physical risks of climate change to business are also important, with recent reports identifying it could reduce market values of companies by 2 to 4%.

At the same time, climate change may lead to new opportunities, either for new goods or services to address the risks of climate change, or from climate change affecting other parts of the world, and thus their comparative advantage relative to Europe. These risks can be considered in terms of business function, i.e. the potential impacts of climate change on site location, capital, labour, supply chains, distributional networks and products and services.

The COACCH project commissioned a systematic literature review to map these physical climate risks to business, and understand the evidence. This is shown in the figure below. This identified a number of climate hazards are important - storms, extreme heat, droughts and floods (river and coastal), and that these affect production processes, as well as management, supply chain and procurement, and sales markets.

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	Impacts on production process					Impact on management	Supply chain and procurement risks				Demand risks/ changes in sales markets	Not specified***	Total (n)	Total (%)
	Stock and production material	Production and logistics facilities	Economic performance and costs	Employees	IT and communication		Suppliers	Transport infrastructure	Water supply	Energy supply				
Extreme precipitation	◑	◑	◕			◔	◑	○	○	◔	◔		6	16%
Droughts	●	◔	●			◑	◔	◑	●	◔	◑	◕	15	39%
Heat & heatwaves	●	◕	●	◔		●	◑	◔	◔	◔	◑	◔	14	37%
(Tropical) storms	●	●	●			◑	◕	○	◔	◑	○	◔	13	34%
Coastal flooding, sea level rise	◑	◔	◔			◑	○	○	○	◔	◔	◔	6	16%
Riverine flooding (incl. monsoon)	●	●	◑	○	○	◑	◑			○		◔	10	26%
Other*	◑	◔	◔			◕	○	○	◔	○	◑	◔	7	18%
Not specified**	○		○	○	○	◑	◔	◔	○	○	○	●	14	37%
Total (n)	15	9	13	4	2	10	7	5	8	5	4	11		
Total (%)	39%	24%	34%	11%	5%	26%	18%	13%	21%	13%	11%	29%		

*) snow and ice, landslides, change in weather patterns
**) climate change, climate variability, extreme weather
***) adaptation action in general (no specific measures)

○	1
◔	2
◑	3
◕	4
●	5+

Business Literature Review Findings.

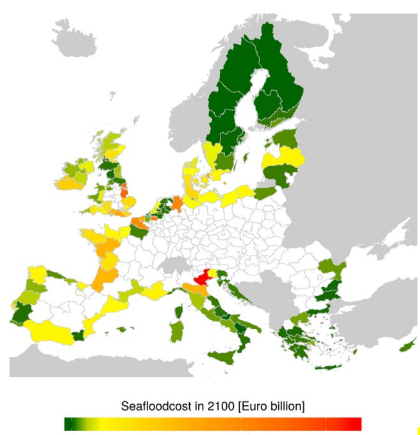
Costs to Business in Europe

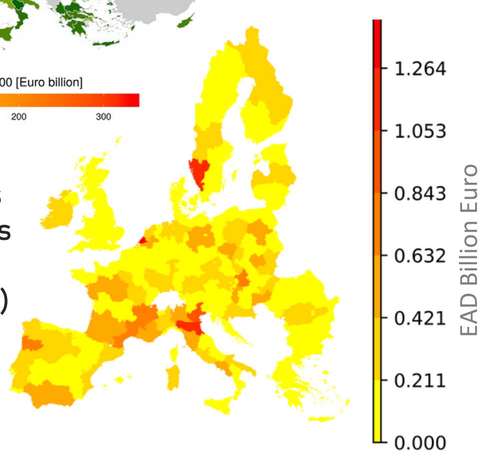
Floods are already one of the most important weather-related loss events for European business and have large economic impacts. These include the direct effects, from the flooding of business and industrial properties or sites (damage and loss of assets and contents), but also indirect effects, from the costs of disruption, lost time or lost production.

The average annual cost of river and coastal floods events is estimated at approximately Euro 10 billion/year currently, a significant proportion of which are from the costs to businesses. Climate change will intensify the hydrological cycle and increase the magnitude and frequency of intense precipitation and river flood events in many parts of Europe. At the same time, sea-level rise will increase the risks of flooding for coastal business properties.

The COACCH project has estimated the direct economic costs of coastal and river floods in Europe under climate change. These costs are projected to risk significantly, and the combined expected damage costs of coastal and river floods in Europe (EU28) is projected to increase to almost €50 billion/year by mid-century, with an upper estimate of more than double this.

There are differences in the patterns of these costs between Member States. The COACCH project has produced country specific data on the economic costs in each country – and at the subnational regional level. These are available in the project deliverables and COACCH policy tool.





Examples of regional patterns of sea-level costs (top) and river flood costs (right)

The increase in flood-related costs will also affect insurance in Europe. Climate change will influence the functioning and pricing of insurance products, and given the increases projected, flood related insurance premiums are projected to rise significantly with also potential collapse of insurance markets in some areas. This will translate into higher insurance costs for businesses.

Floods also have indirect impacts on business through the disruption of freight, leading to travel time delays and costs, and from disruption to supply chains, affecting goods and services.

The COACCH project has investigated the impacts of climate change related floods on road transport in Europe, using detailed spatial data on the road network, and assessing the sensitivity of national road networks.

This finds that transport related floods will increase with climate change, but that the effects vary by country. This is partly due to differences in the increase in risk, but also because of differences in road networks: in some countries there are hotspots where floods can disrupt a large area of the network.

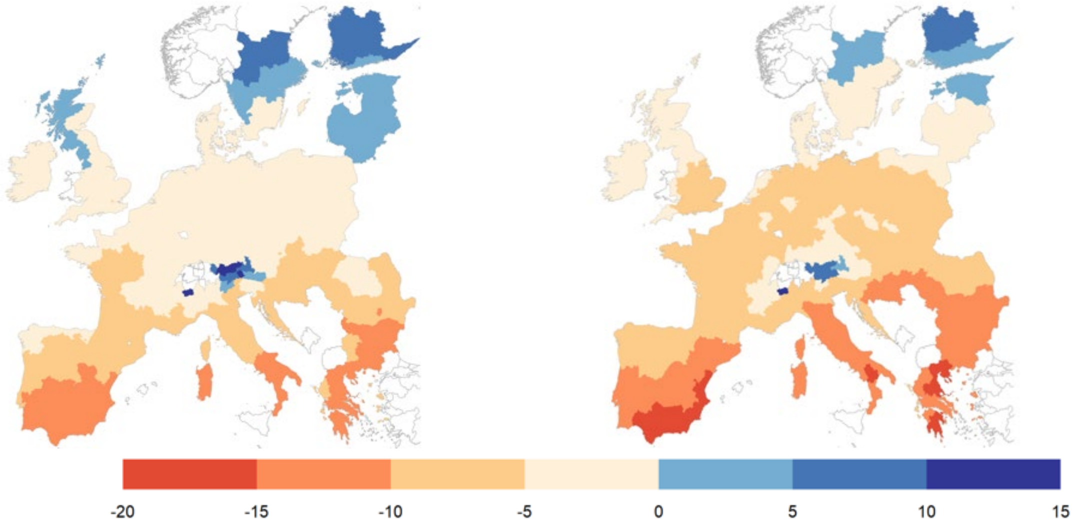
COACCH has also looked at the potential impacts of floods on transport deliveries for just-in-time systems, using a case study approach. This found that while these risks generally increase linearly, there can be some exceptions. These can arise when flood delays mean that drivers exceed legal thresholds on driving times. It can also occur when scheduled delivery time windows are missed, as this affects stock deliveries, and impacts on return-transport scheduling.

High temperatures and humidity affect work and lower employee output. These reductions in work intensity affect **labour productivity**, the measure of output per employee or unit of labour, and in extreme cases can led to heat stress and health risks. These effects apply to outdoor workers, but also to indoor workers who are not working in a temperature-controlled environment.

Climate change will increase these impacts in Europe. The COACCH project has developed new estimates of these risks, assessing the loss of productivity (days lost) from climate change at the national level.

The results find labour productivity will fall with higher temperatures. For example, climate change could reduce industrial and construction sector labour productivity by around 3% under a moderate warming scenario (RCP4.5) for Europe.

However, the results have a strong distributional pattern across Europe, as seen in the figure above, and there are much higher impacts in the South, with the highest declines projected in Greece, Italy, Spain and Portugal. In contrast, some currently cold regions in Europe will gain.



Future impact (% change)under RCP8.5 on industrial (left) and construction productivity (right) by 2070.

International Supply Chain Shocks

Climate change is projected to lead to supply chain risks for businesses in Europe. These include risks that occur from climate change in Europe, but also internationally, due to the highly globalised and interconnected nature of business supply chains. The COACCH project has 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.

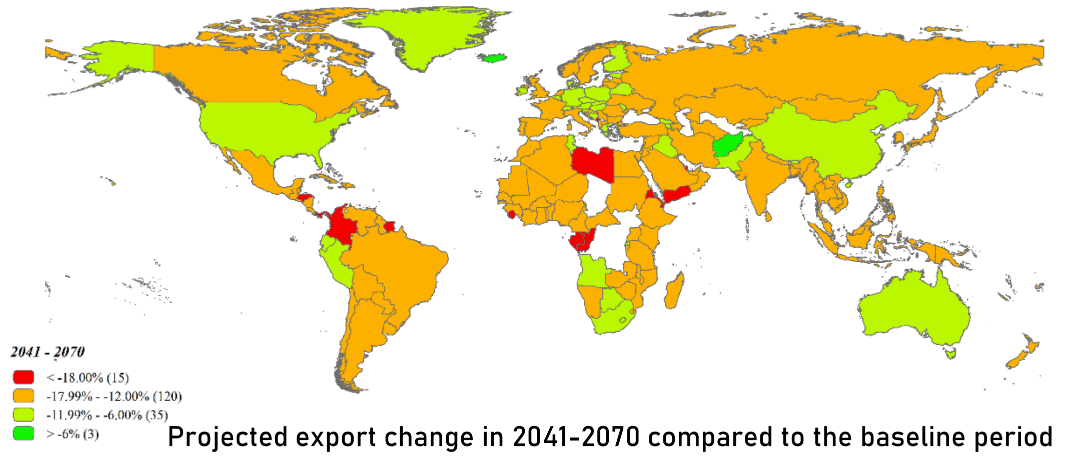
The analysis found that shocks in one country can propagate along the supply chain, leading indirectly to an adverse economic impact in another country's sector. The potential strength of impact transmission has grown over the last twenty years due to increased globalization. A larger number of input suppliers can act as layer of protection, as it enables firms to more easily find substitutes when suppliers are affected.

The study also found that climate change, and the increase in frequency of extreme weather and associated productivity shocks, will be transmitted over supply chains and will significantly reduce export performance. At the global level, these could additionally reduce a sector's export value by 8% to 11% in the short-term (2020-2040) and 8% to 15% in the medium-term (2041-2070). The largest impacts on exports were projected for the tropics and sub- tropics, due to the stronger projected climate impacts.

The COACCH project then used this same framework to explore the role of supplier concentration in the impact of supply chain disruptions for EU industries. Europe is strongly integrated in global production networks, and so has less concentrated supply chains, as compared to the Americas. Nonetheless, supply chain shocks can still lead to reduced export performance from European countries.

The study found that upstream (supplier) supply chain shocks can significantly reduce downstream trading partners' export performance. These impacts vary between countries and sectors. The largest impacts were found on the agriculture, fishing, mining and quarrying and electricity, gas and water sectors, as these have the least diversified supply chains, and consequently the most exposure to shock propagation due to large switching costs. Romania, Bulgaria and Italy were all found to have more concentrated input supply chains.

The results provide empirical evidence that having a diversified supply chain contributes to resilience against non-local extreme weather shocks. While diversification dampens shocks, and makes it easier to find substitutes, the analysis also found that it is more important to have multiple large input suppliers that can substitute for missing input, than many suppliers of all sizes. However, increased diversification, while beneficial for resilience, may involve trade-offs with supply chain efficiency in normal times.



Projected export change in 2041-2070 compared to the baseline period (1990-2015) (mean over all GCMs) - RCP 4.5

Adaptation

Adaptation can reduce the risks and economic costs of climate change for business. As highlighted in previous sections, this involves a variety of different climate hazards, arising in many locations, including internationally. Business adaptation is therefore likely to require a diverse set of possible responses.

These options can include different types of response, i.e. information, risk management. It can involve actions in different places, e.g. in the country of origin, along the trade pathway, or in the destination country. And it can involve different actors, from government as well as the private sector.

The COACCH project has undertaken a systematic literature review to identify business adaptation options. The findings are shown below. Risk management and planning was the most frequently mentioned adaptation measure, with infrastructure design or adjustment being the most frequently stated 'hard' adaptation option.

The review found that companies seem to predominantly identify risks to direct operations, while risks to supply chains seem to be underestimated and may not be sufficiently addressed. There was also a focus by companies on incremental and soft adaptation options (e.g. information provision), as these are no- or low-regret options, rather than hard (engineering) options.

The COACCH study has also mapped which actors can best take forward these adaptation options. Adaptation measures that can be taken at the company level included risk management (including supply chain management), capacity building, insurance and information.

For the public sector, R&D was the most frequently cited, followed by policies supporting adaptation (knowledge creation, planning and coordination), early warning and observation systems, and management of risks to transport infrastructure and storage.

Important gaps were identified around adaptation to external risks facing companies, such as supply chain risks, and on coordination across companies and with the public sector. It also identified further needs to explore trade-offs involved with certain options (e.g. with efficiency or sustainability).

Finally, to date, there has been much less consideration of more transformational adaptation, i.e. that would involve more systematic changes in how and where a company operates, and these are identified as a research priority.

Further details are available in the project [deliverable]().

Business adaptation options

WHO WE ARE

Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici
Italy

PBL Netherlands Environmental Assessment Agency,
Netherlands

Paul Watkiss Associates Ltd
United Kingdom

Basque Centre for Climate Change – Klima Aldaketa Ikergai,
Spain

Internationales Institut fuer Angewandte Systemanalyse
Austria

Climate Analytics gemeinnützige GmbH,
Germany

Universitaet Graz
Austria

Stichting Deltares,
The Netherlands

Stichting VU
Netherlands

Global Climate Forum
Germany

Ecologic Institut gemeinnützige GmbH
Germany

Potsdam Institut fuer Klimafolgenforschung
Germany

Univerzita Karlova
Czech Republic

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CONTACT US AND SUBSCRIBE TO OUR NEWSLETTER:

info@coacch.eu

The COACCH project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776479