COACCH

CO-DESIGNING THE ASSESSMENT OF CLIMATE CHANGE COSTS

The Economic Cost of Climate Change in Europe

Synthesis Report on COACCH Sector Results

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

COACCH: CO-designing the Assessment of Climate CHange costs.

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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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 (**C**O-designing the **A**ssessment of **C**limate **CH**ange 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 sector impact results from the COACCH project on the economic costs of climate change in Europe.

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.

Climate Models and Scenarios

Analysis of the future impacts and economic costs of climate change requires climate models. These in turn require inputs of future greenhouse gas (GHG) emissions, to make projections of future changes in temperature, precipitation and other variables. COACCH uses the downscaled climate projections for Europe that are available from EUROCORDEX.

As well as climate projections, analysis of future impacts and costs requires scenarios. These provide qualitative and quantitative descriptions of how socio-economic parameters may evolve in the future. These influence the economic costs that arise from climate change, for example, the population affected or the assets at risk. Most studies assess the impacts of future climate change on future socio-economic projections, as a failure to do so implies that future climate change will take place in a world similar to today

The COACCH project is producing sector estimates of the economic costs of climate change, and then feeding these into macro-economic models. This requires the use of consistent climate model projections and socio-economic scenarios. COACCH used the Representative Concentration Pathways (the RCPs), combined with the Shared Socio-economic Pathways (SSPs). These are set out in the box below.

However, this leads to a large number of potential combinations of RCP-SSPs, with too many to analyse in detail. Therefore, COACCH agreed a set of RCP-SSP combinations, focusing on a minimum core set of scenarios for use by all modelling teams. These core runs were chosen using a set of criteria, along with participatory discussion with the COACCH stakeholders on the selection.

The first criterion was the need to assess the different effects of alternative climate scenarios relative to a common socio-economic scenario. The COACCH stakeholders identified SSP2, and agreed it was useful to consider alternative climate scenarios (RCP2.6, RCP4.5 and RCP 6.0) for this scenario. Stakeholders identified SSP2-RCP4.5 and SSP2-RCP2.6 as of particular importance, and these are therefore the central scenarios of

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The Representative Concentration Pathways (RCPs)

The four RCPs span a range of possible future emission trajectories over the next century, with each corresponding to a level of total radiative forcing (W/m^2) in the year 2100. The first RCP is a deep mitigation scenario that leads to a very low forcing level of 2.6 W/m^2 (RCP2.6), only marginally higher compared to today (2.29 W/m^2, IPCC, 2013). It is a “peak-and-decline” scenario and is representative of scenarios that lead to very low greenhouse gas concentration levels. This scenario has a good chance of achieving the 2°C goal.

There are also two stabilization scenarios (RCP4.5 and RCP6). RCP4.5 is a medium-low emission scenario in which forcing is stabilised by 2100. It is similar to the A1B scenario from the SRES. Even in this scenario, annual emissions (of CO_2) will need to sharply reduce in the second half of the century, which will require significant climate policy (mitigation). Finally, there is one rising (non-stabilisation) scenario (RCP8.5), representative of a non-climate policy scenario, in which GHGs carry on increasing over the century. Leading to very high concentrations by 2100. Note that achieving RCP4.5 or below always requires mitigation, but more is required under SSP3 and SSP5. There are also new RCP 2.0 pathways being constructed for a 1.5°C pathway.

The Shared Socio-economic Pathways (SSPs)

The Shared Socio-economic Pathways (SSPs) provides a new set of socio-economic data for alternative future pathways. They include differing estimates of future population and human resources, economic development, human development, technology, lifestyles, environmental and natural resources and policies and institutions. Note that the SSPs include a quantitative and qualitative component.

Five alternative future SSPs are provided, each with a unique set of socio-economic data and assumptions. SSP2 is the central, Business As Usual (BAU) scenario, as it relies on the extrapolation of current trends. The SSPs are presented along the dimensions of challenges to mitigation and adaptation. For example, in a world in which economic growth is high, there are sufficient resources to adapt, but the challenges in mitigation are high.

SSP1	Sustainability	Adaptation: low	Mitigation: low
SSP2	Middle of the Road	Adaptation: moderate	Mitigation: moderate
SSP3	Regional Rivalry	Adaptation: high	Mitigation: high
SSP4	Inequality	Adaptation: high	Mitigation: low
SSP5	Fossil-fuel Development	Adaptation: low	Mitigation: high

Finally, to analyze the effect of mitigation strategies (for specified forcing levels), different **Shared climate Policy Assumptions (SPAs)** have been identified, which use carbon taxes to achieve the required emission levels, but consider different tax regimes (global versus rich countries, different pricing of land use emissions, etc.).

the COACCH project. For these scenarios, a more detailed analysis of climate model uncertainty and different adaptation assumptions are undertaken.

However, both stakeholders and researchers considered it was important to explore extreme scenario combinations. For this reason, the choice of SSP5-RCP8.5 was agreed to analyze the important aspect of impacts under high-climate change futures and SSP1-RCP2.6 under low climate change futures.

The second criterion was the need to unpick the effects of different socio-economic effects (i.e. SSPs). For this reason, a single climate projection (RCP4.5) was selected for analysis with SSP1, SSP2 (core), SSP3 and SSP5. This allows the project to separate out the relative importance of

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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.

climate versus the socio-economic signal. Finally, the project included SSP3-RCP2.6 and SSP3-RCP4.5, to provide inter-comparison data with the central scenario combinations. The final selection of RCP-SSP combinations are summarized in the Table.

Climate Projections for Europe

The COACCH project uses existing climate projections, but to provide background context, the findings are summarised in this section. The latest climate model projections find that Europe will warm more than the global average, i.e. Europe will experience more than 2°C of warming (relative to pre-industrial levels) even if the Paris goal is achieved in terms of emissions. However, the patterns of climate change differ across Europe.

At 2°C of global mean warming, the Iberian Peninsula and other parts of the Mediterranean could experience 3°C of warming in summer, and Scandinavia and the Baltic 4°C of warming in winter. These areas will also reach 2°C of local warming much earlier in time i.e. in the next couple of decades. These trends are exacerbated under higher warming scenarios.

There are also projected increases in extreme events in Europe even for 2°C of global change, which will cause more frequent and severe impacts. This includes increases in daily maximum temperature, extremely hot days and heatwaves over much of Southern and South-Eastern Europe, although relative to current temperatures, there will also be large increases in heat extremes in North-East Europe.

There are also robust model findings of increases in heavy precipitation in Europe, in both summer and winter, with (ensemble mean) intensity increasing by +5% to 15% (and in some areas, even more), even under the 2°C scenario. The projected increase in heavy precipitation is expected also over regions experiencing a reduction of the average precipitation (such as southern Europe). These increases drive potential increases in flood risk.

The change in average precipitation from different climate simulations varies considerably by model. On average, increases of +10-15% in winter precipitation are projected for Central and Northern Europe for 2°C, and increases in summer precipitation for Northern Europe. At the same time, decreases in summer precipitation, of the order of –10-20%, are projected for Central and Southern Europe.

This is of high policy relevance: even if the 2°C goal is achieved, Europe will still experience large potential impacts.

It is highlighted that these results involve 'uncertainty'. One unknown factor affecting future climate is the GHG emission path (the

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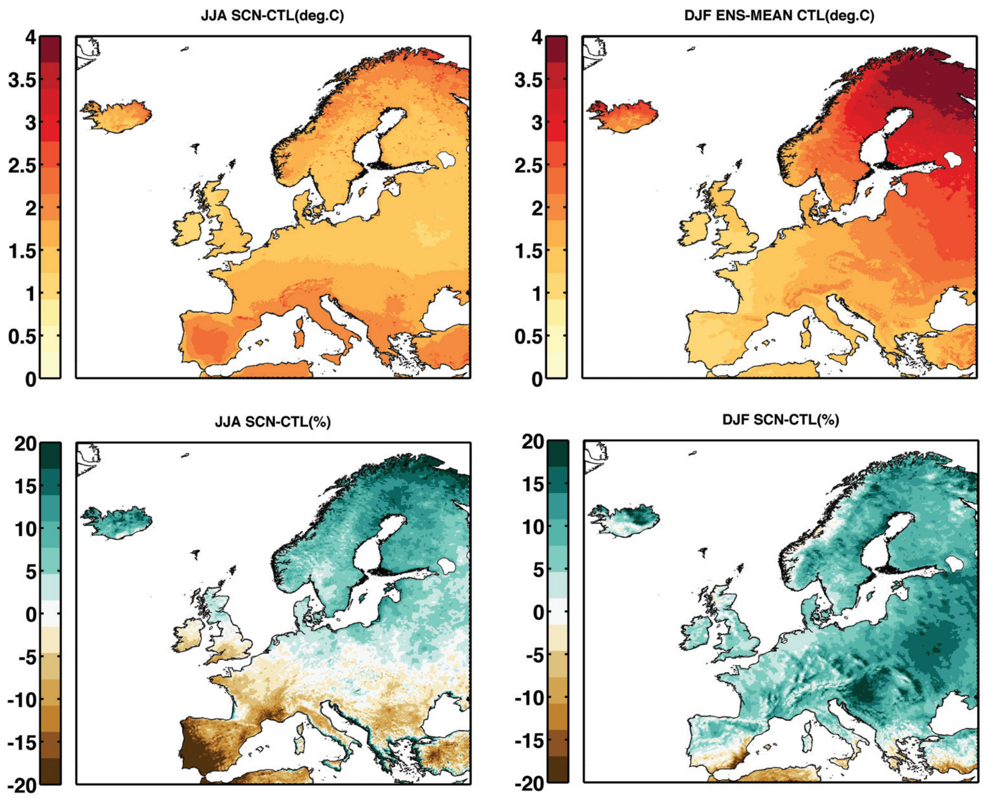

The increase in seasonal temperature (from 1971–2000) (Top) and Seasonal Precipitation (Bottom) across Europe at 2°C of global average warming. Left (summer). Right (winter).

Average RCM simulated precipitation between the reference period (1971–2000) and period corresponding to global temperature difference of 2°C. Source: Stefan Sobolowski et al, 2014. IMPACT2C project.

future RCP), though this can be considered with multiple scenarios (see Table 1 above). Another factor is that climate models do not all give the same results, though this can be considered by using different models. It is essential to recognise this uncertainty, not to ignore it or use it as a reason for inaction. This is captured by the consideration of different climate models for the core scenarios, see Table 1.

New COACH Sector Economic Cost Estimates

The COACCH project has produced new sector estimates of the economic costs of climate change. These are presented in this section, reported as the monetised impacts in terms of social welfare. This captures the costs and benefits to society, i.e. market and non-market impacts. These estimates are presented in terms of current prices (Euros) for future time periods, without adjustment or discounting. This facilitates direct comparison, over time and between sectors. Where possible, results are reported as the combined impacts of future climate and socio-economic change together, along with a commentary on the importance of climate versus socio-economics in the estimates. Where possible, analysis of the costs and benefits of adaptation has been included.

Coastal flooding

Introduction. Coastal zones contain high population densities, significant economic activities and provide important ecosystem services. Climate change has the potential to increase risks to these coastal zones in the future, from a combination of sea level rise, storm surge and increasing wind speeds, which will lead in turn to flooding, loss of land, coastal erosion, salt water intrusion and impacts on coastal wetlands.

The economic costs of coastal impacts – and adaptation – are among most comprehensively covered areas. Methods for assessing large scale coastal flood risks have developed and been widely applied, at multiple scales. COACCH has further developed the global integrated assessment model DIVA, to provide European and national estimates of the impacts of sea-level rise on coastal areas.

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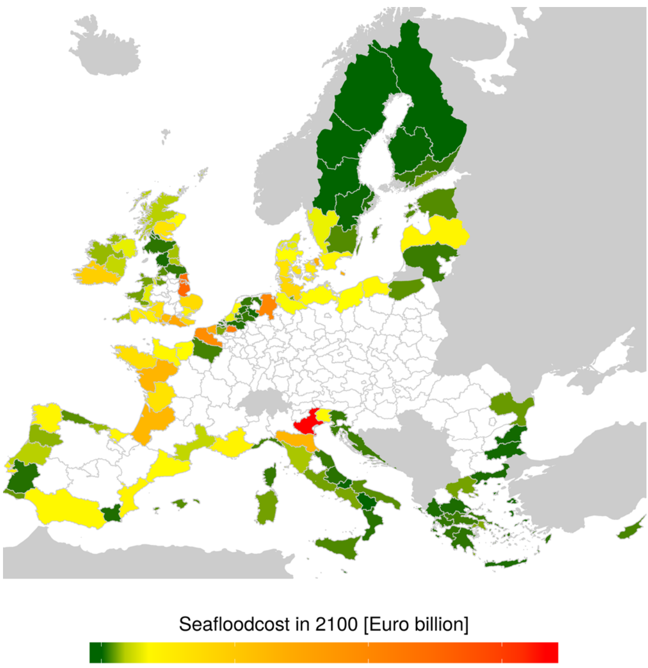
COACCH Economic Cost Estimates.
COACCH has assessed the potential impacts and economic costs of sea-level rise in Europe, and the costs and benefits of adaptation. The analysis has considered future climate and socio-economic change. As floods are probabilistic events, the results are presented as expected annual damage (EAD) costs (undiscounted).



Seaflood cost map

The study estimates that, annually that the number of people flooded in the EU could range from 1.8 million (RCP2.6) to 2.9 million (RCP8.5) by the 2050s and, potentially, 4.7 million (RCP2.6) to 9.6 million (RCP8.5) by the 2080s, if there is no investment in adaptation.

This flooding, along with other impacts of sea- level rise such as erosion, leads to high economic costs in the case of no adaptation, shown in the table over the page. The expected damage costs in Europe (EU28) from the combination of climate and socio-economic change are estimated at €135 billion/year to €145 billion/year for the 2050s (mid estimates for RCP2.6 and RCP4.5 respectively), rising to €450 billion/year to €650 billion/year by the 2080s for the same scenarios. These costs include direct impacts. Additional unquantified costs will occur due to ecosystem losses and possible knock-on effects of damage on other sectors.

There are major differences in the damage costs borne by different Member States, with strong distributional patterns across Europe, as shown in the map of coastal damages. The greatest costs are projected to occur around the North Sea (Belgium, France, Netherlands, Germany and the UK) and some regions in Northern Italy, if no adaptation occurs.

These costs are projected to rise rapidly by the late century, notably for the higher emission RCP6.0 and especially for the RCP8.5 scenario. The latter shows a disproportionate increase in costs in the second half of the century. This highlights the benefits of mitigation strategies, as shown by the low damage costs in the low emission scenario (RCP2.6), which is broadly consistent with the Paris Agreement of limiting temperature to well below 2°C above pre-industrial levels.

The new COACCH numbers are higher than earlier studies, especially for the late century, high-end scenarios. This reflects the higher increases in sea-level rise projected in recent assessments, but also the influence of socio-economic drivers (especially in the SSP5 scenario).

It is stressed that there is a wide range of uncertainty around the central estimates,

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European Coastal Damage Costs for Various RCP scenarios (no adaptation).

Coastal damage	RCP2.6-SSP2	RCP4.5-SSP2	RCP8.5-SSP5
2050s / mid century	€115-210 Bill/yr	€130-235 Bill/yr	€310 Bill/yr
2080s /end century	€365-795 Bill/yr	€510-1,200 Bill/yr	€2,400 Bill/yr

European Coastal Damage Costs for Various RCP scenarios WITH ADAPTATION

With Adaptation	RCP2.6-SSP2	RCP4.5-SSP2	RCP8.5-SSP5
2050s / mid century	€ 28-29 Bill /yr	€ 28-30 Bill/yr	44 Bill/yr
2080s /end century	€ 46-50 Bill /yr	€ 46-53 Bill/yr	110 Bill /yr

Coastal adaptation costs €/yr

Coastal Adap. Cost	RCP2.6-SSP2	RCP4.5-SSP2	RCP8.5-SSP5
2050s / mid century	€14-16 Bill/yr	€15-17 Bill/yr	€17 Bill/yr
2080s / end century	€15-17 Bill/yr	€16-19 Bill/yr	€33 Bill/yr

Values are presented as additional impacts or costs relative to the baseline period for the EU 28, from the combination of climate and socio-economic change, and are presented as undiscounted values in future years in current prices.

reflecting the underlying uncertainty in global temperatures and the sea- level response, as well as the role of ice sheet melt. Analysis of extreme sea-level rise, i.e. of projections estimating over 1.5m by 2100, are presented separately in the COACCH tipping points briefing note.

COACCH Adaptation Economic Estimates. The DIVA model has also been used to look at coastal adaptation in Europe and estimate potential costs and benefits. Adaptation can reduce the number of people flooded very significantly, for example, with adaptation, the number of people flooded annually in the EU28 would fall from several millions to around 230,000 – 290,000 in the 2050s.

Adaptation is also projected to significantly reduce damage costs. The analysis finds that adaptation is an extremely cost-effective response, with hard (dike building) and soft (beach nourishment) reducing impacts to very low levels, as shown in the table above. Subtracting the two scenarios (with and without adaptation), it can be seen that the economic benefits of adaptation are very large, estimated at €87-181 Bill /yr (RCP2.6) to €102-205 Bill /yr (RCP4.5) in the 2050s, and much larger than this under extreme SLR scenarios (RCP8.5), although some residual damage still remains even with adaptation.

However, this will require additional investment in adaptation, and, hard defences need ongoing maintenance to operate efficiently and to keep risk at a low or acceptable level. Therefore, the stock (and costs) of coastal protection grows throughout the 21st century, as do annual maintenance costs. Adaptation to rising sea-level in Europe is projected to cost between 15 and 20 billion Euro every year by the mid-century, and much more than this later in the century under higher warming scenarios. Nonetheless, the benefit- to-cost ratios of coastal adaptation are very large, and increase throughout the century.

It should be noted that these costs vary significantly with the level of future climate change, and the objectives and framing used for adaptation decisions, notably whether to plan to acceptable level of risk protection or based on economic efficiency. Furthermore, there is a need to recognise and work with uncertainty. This requires an iterative and flexible approach for adaptation planning, noting that this needs to be positioned within a broader integrated coastal-zone management policy framework.

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These results reinforce the message that the most appropriate response to sea-level rise for coastal areas is a combination of adaptation to deal with the inevitable rise and mitigation to limit the long-term rise to a manageable level. More detailed, local-scale assessments are also required to assess and reduce risk to vulnerable areas, including adaptation plans.

River Flooding

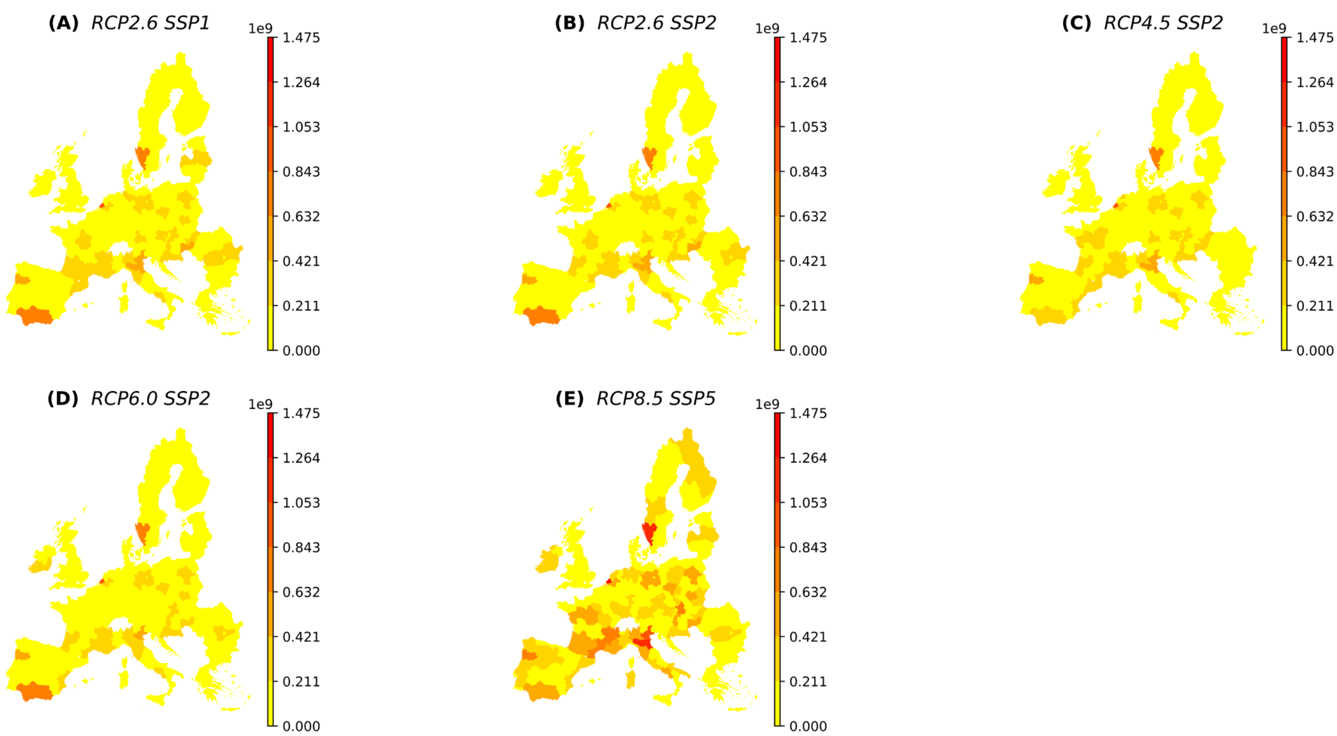
Introduction. River floods are one of the most important weather-related loss events in Europe and have large economic impacts, as reported in recent severe flooding events. Climate change will intensify the hydrological cycle and increase the magnitude and frequency of intense precipitation events in many parts of Europe. These events lead to tangible direct damage such as physical damage to buildings, but also intangible direct impacts in non-market sectors (such as health). They also lead to indirect impacts to the economy, such as transport or electricity disruption, and major events can have macro-economic impacts.

COACCH Economic Cost Estimates. The COACCH project has used the GLOFRIS model to assess the potential direct impacts of climate change on floods in Europe. As floods are probabilistic events, the results are presented as expected annual damage (EAD) costs (undiscounted).
The annual expected damage costs in Europe

European River Flood Damage Costs (EAD) for Various RCP scenarios (no adaptation).

Flood damage	RCP2.6-SSP2	RCP4.5-SSP2	RCP8.5-SSP5
2050s / mid century	€11 Bill/yr	€12 Bill/yr	€18 Bill/yr
2080s /end century	€18 Bill/yr	€20 Bill/yr	€42 Bill/yr

Values are presented as additional impacts or costs relative to the baseline period for the EU28, from the combination of climate and socio-economic change, and are presented as undiscounted values in future years in current prices.



EU28 river flood cost (€) in 2080 on NUTS2 level for selected RCP/SSP combinations.

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European River Flood Damage Costs (EAD) for Various RCP scenarios (WITH Optimal adaptation).

With Adaptation	RCP2.6-SSP2	RCP4.5-SSP2	RCP8.5-SSP5
Optimal			
2050s / mid century	€4.6 Bill/yr	€4.7 Bill/yr	€7.7 Bill/yr
2080s /end century	€7.7 Bill/yr	€8.0 Bill/yr	€18.2 Bill/yr

Values are presented as additional impacts or costs relative to the baseline period for the EU 28, from the combination of climate and socio-economic change, and are presented as undiscounted values in future years in current prices.

(EU28) with climate change are projected to increase to approximately €12 billion by the 2050s (for the mid estimates for both RCP2.6 and RCP4.5), rising to approximately €20 billion by the 2080s. These estimates include the combined effects of climate and socio-economic change, and are based on current prices, with no discounting. It should be noted that the damages reported here only include direct physical losses and could, therefore, be conservative.

The costs rise rapidly in the late century, especially for higher emissions pathways, and estimated damages double for the RCP8.5-SSP5 scenario. This highlights the benefits of mitigation strategies, i.e. there are large economic benefits from moving from a high emission scenario (RCP8.5) to an ambitious mitigation scenario (RCP2.6).

It is stressed there is a very wide range around these central (mean) estimates, representing the range of results from different climate models. These differences are even more significant at the country level. This highlights the need to consider this variability (uncertainty) in formulating adaptation strategies.

The results also show that flood risks are distributed unequally over the EU28. River flood damages are higher for regions on the Iberian Peninsula, in the South of France, and in the North of Finland/ Sweden.

COACCH Adaptation Estimates. The analysis has also assessed the potential costs and benefits of adaptation using the GLOFRIS model (Ignjacevic et al., 2020). This has assessed a scenario where optimal protection standards are determined based on a cost-benefit analysis. The results are shown below and demonstrate that adaptation is extremely cost-effective in reducing the damage costs above to low levels, and also has high benefit to cost ratios (Tiggeloven et al., 2020).

Subtracting the two scenarios (with and without adaptation), it can be seen that the economic benefits of adaptation are large, estimated at €6.4 Bill /yr (RCP2.6) to €6.9 Bill /yr (RCP4.5) in the 2050s, and much larger than this for the extreme scenario (RCP8.5). However, adaptation will involve significant investment over the century and thus high adaptation costs, which are estimated at hundreds of billions of Euro in Europe (cumulatively, over time).

As with the coastal adaptation, costs vary significantly with the level of future climate change, and as shown above, with the objectives and framing used for adaptation decisions, and there is a need to recognise and work with uncertainty, as well as to progress detailed, local scale assessments.

Transport

Introduction. The risks of climate change for the transport sector primarily arise from extreme events, such as flooding, heat waves, droughts and storms, especially where these exceed the design range. As well as direct damage costs to infrastructure, these extremes have economic costs from passenger and freight transport disruption (travel time) and accidents. There are also wider indirect effects from transport disruption, affecting the supply of goods and services, which can be significant for major events.

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European Flood Impacts on Transport (Direct Impacts only) in Europe (no adaptation).

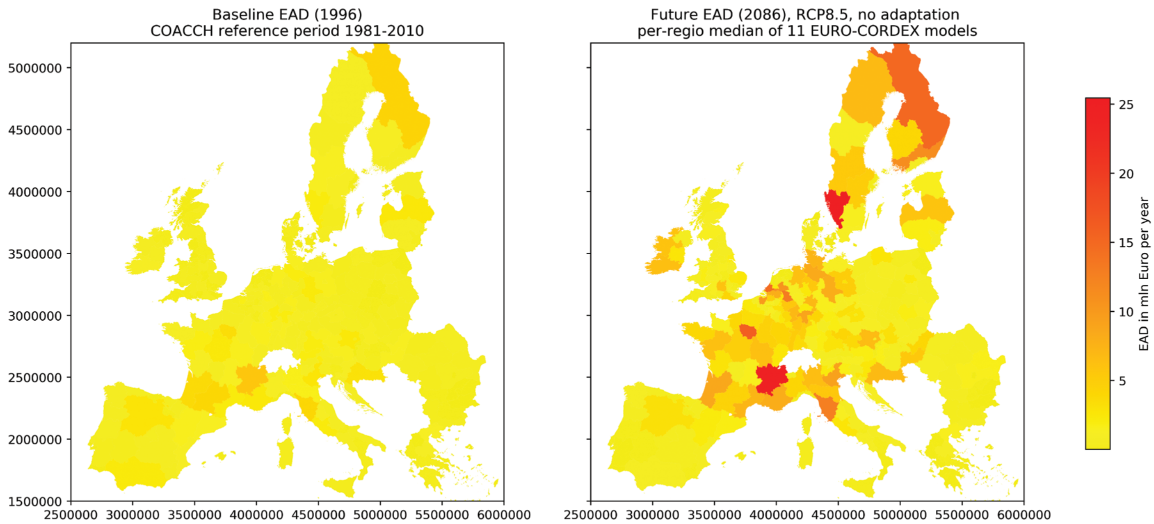
	RCP4.5-SSP2	RCP8.5-SSP5
2050s / mid century	€954 M/yr	€1147 M/yr
2080s /end century	€1469 M/yr	€2286 M/yr

Values are presented as additional impacts or costs relative to the baseline period, from the combination of climate and socio-economic change, and are presented as undiscounted values in future years in current prices.

European Flood Impacts on Transport (Direct Impacts only) in Europe (WITH adaptation).

	RCP4.5-SSP2	RCP8.5-SSP5
2050s / mid century	€392 M/yr	€502 M/yr
2080s /end century	€592 M/yr	€888 M/yr

Values are presented as additional impacts or costs relative to the baseline period, from the combination of climate and socio-economic change, and are presented as undiscounted values in future years in current prices.



Expected annual damage (EAD) to road infrastructure in 1996 and 2086, aggregated on NUTS-2 level.

Economic cost estimates. For the COACCH project, a new continental scale flood risk model was developed on European road infrastructure, OSdaMage. The primary focus was on impacts from river flooding. Expected annual damage (EAD) was calculated for direct damage to road infrastructure in the EU28. The baseline analysis identified direct costs of ~€200 million per year.

These damages increase under climate change. The values are shown below for the combination of climate and socio-economic change (no discounting, no adaptation). It can be seen that in the late century, there are much higher damages under the high emission RCP8.5 scenario.

The spatial distribution of damages under climate change is presented in the figure. This shows Germany, France and Italy exposed to the highest risks.

When river flood adaptation is included, as analysed in the earlier river flood section,

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the damages to the transport sector are also reduced significantly, shown in the table.

Subtracting the two scenarios (with and without adaptation), it can be seen that the economic benefits of adaptation are large, estimated at €562 Mill /yr (RCP2.6) to €645 Mill /yr (RCP8.5) in the 2050s.

However, as highlighted in the earlier section, this requires significant investment costs in river flood protection, that will rise over the century.

Business, Services and Industry

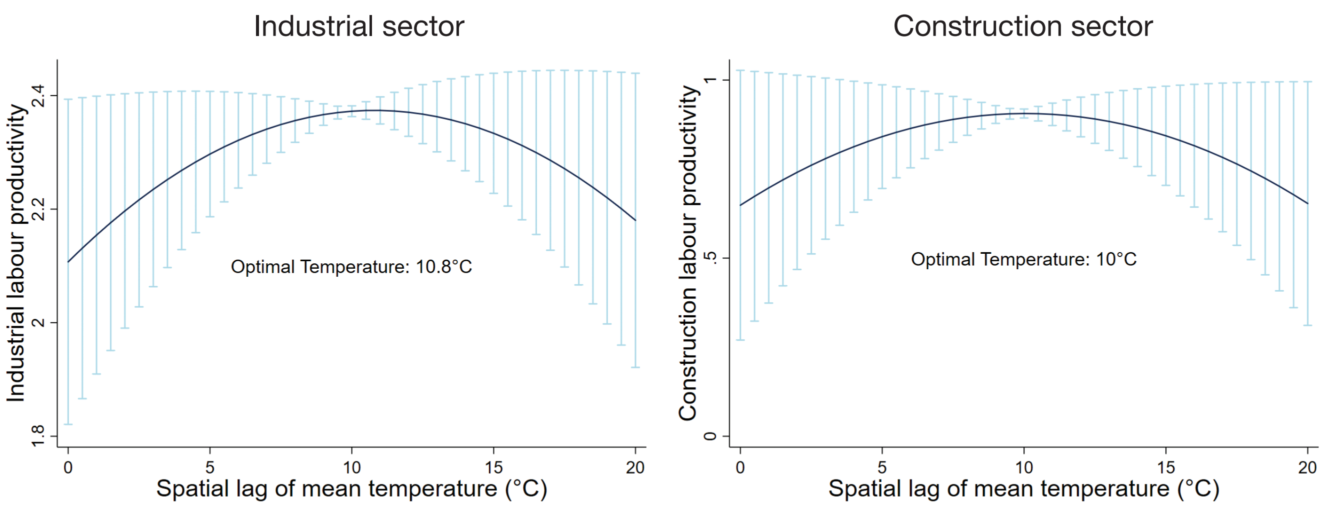
Introduction. Climate change impacts such as floods, high temperatures, and water availability, will all impact business and industry. The balance of risks will vary with sub-sectors and locations, and sites and operations will be affected differently. Risks also extend along supply chains, with impacts in non-European countries affecting production and transport of raw materials and intermediate goods. There will also be shifts in demand for goods, services, and trade. All of these may affect business costs, profitability, competitiveness, employment and sector economic performance.

The COACCH project has developed new estimates of the impacts of climate change on the industry and service sectors using econometric analysis. It has combined (spatial) information on sectoral labour productivity (for different sectors) with high resolution meteorological data (sub-national) to investigate the impacts of changes in temperature and heatwaves.

COACCH Economic Cost Estimates. The analysis has identified that the current optimal annual average temperature (productivity maximising) in the industry and construction sectors are 10.8°C and 10.0°C, respectively. The relationships are shown in the figure below. Interestingly, the study did not pick up large statistically significant effects for the services sector, although the results did indicate a higher optimum of 16.3°C. The optimal temperature for the services sectors is higher, as workers are not as exposed to outside temperatures, noting also that higher temperatures benefit the attractiveness of certain sectors, such as summer tourism.

The results show labour productivity falls at both relatively low and high temperatures, which are the result of various worker responses. The analysis also found significant negative direct impacts of temperature extremes on both industrial and construction labour productivity, suggesting that both higher average and extreme events (heat-waves) affect productivity.

The analysis then looked at the future changes in labour productivity under climate change. The results estimate that climate change could reduce industrial labour productivity by 4.3% and



The relationship between mean temperature and productivity at the NUTS-2 level, including 95% confidence interval (light blue spikes).

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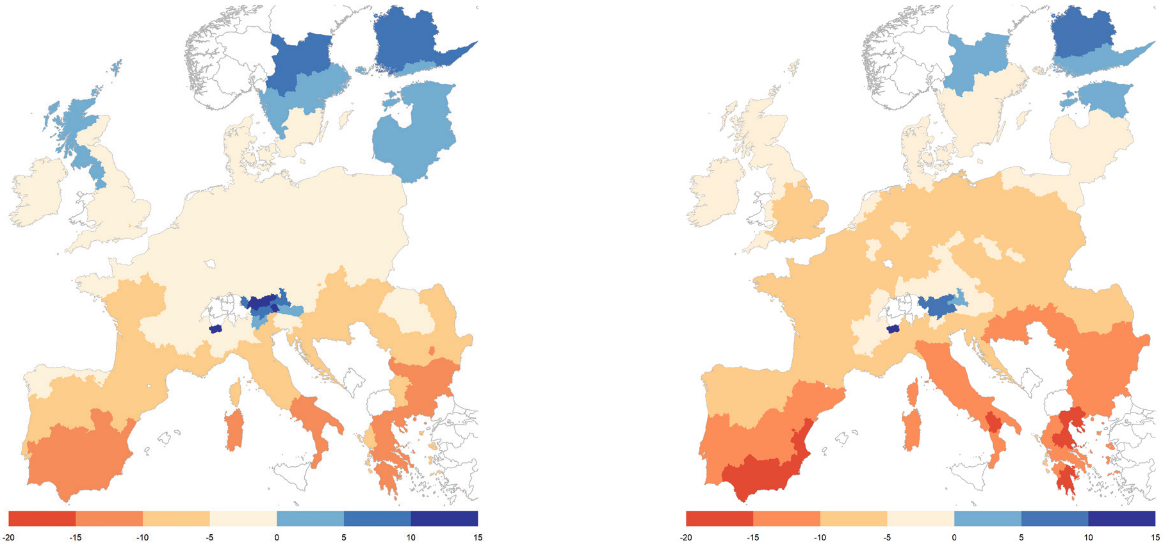

Future impact under RCP8.5 on industrial (left-panel) and construction productivity (right-panel) by 2070. The impacts are computed using the Delta method and a reference period of 1985–2005.

construction sector labour productivity by 6.6% by the late century (assuming the relationships above are constant over time). Under a more moderate warming scenario of RCP4.5, industrial and construction sector productivity will decline by 2.7% and 3.1%, respectively by the end of the century. This highlights the benefits of mitigation strategies.

The results have a strong distributional pattern across Europe, as seen in the figure above. The highest declines will occur in Greece (Peloponnese, Thessaly, and Attica), Italy (Puglia), Spain (Region of Murcia and Andalusia), and Portugal (Algarve). However, some colder regions in Austria, Estonia, Finland, Sweden, and the north-eastern and north-western Italian regions will gain.

COACCH has also undertaken new econometric analysis to investigate the impact of weather change on tourism. This has worked at the regional level across Europe (North, West, East, South, and Balkan). The analysis has assessed the effect of temperature and climate extremes on tourism in Europe during the summer months (June to September). The effect of temperature was found to have an inverted U-shape form, reflecting the suitability range and optimum of the temperature-tourism relationship.

The analysis of current **tourism** and climate data found that average and maximum temperature correlates with tourist flows (arrivals, nights spent) positively up to a temperature optimum but declines above this, with very sharp decreases at high values. However, the threshold levels varies with region. In countries that are relatively cold (North), the effect of increasing temperature is always positive, increasing attractiveness. In other regions, increasing maximum temperatures generally have negative effects, and a particular issue was found for Southern Europe, which is very close to the thresholds associated with high impacts already. The project is now using these relationships to look at future climate change.

Finally, the analysis has determined the potential impacts of climate change on the interplay of supply chains shocks and a sector's export value. The findings are that all countries' sectoral exports are negatively affected by climate change, and it could additionally reduce a sector's export value by up to 16 percent. However, these findings vary strongly between countries as well as sectors. The largest impacts occur in the tropics and sub-tropics, due to the stronger projected climate impacts, which are then transmitted over interregional supply chain connections. The findings suggest that

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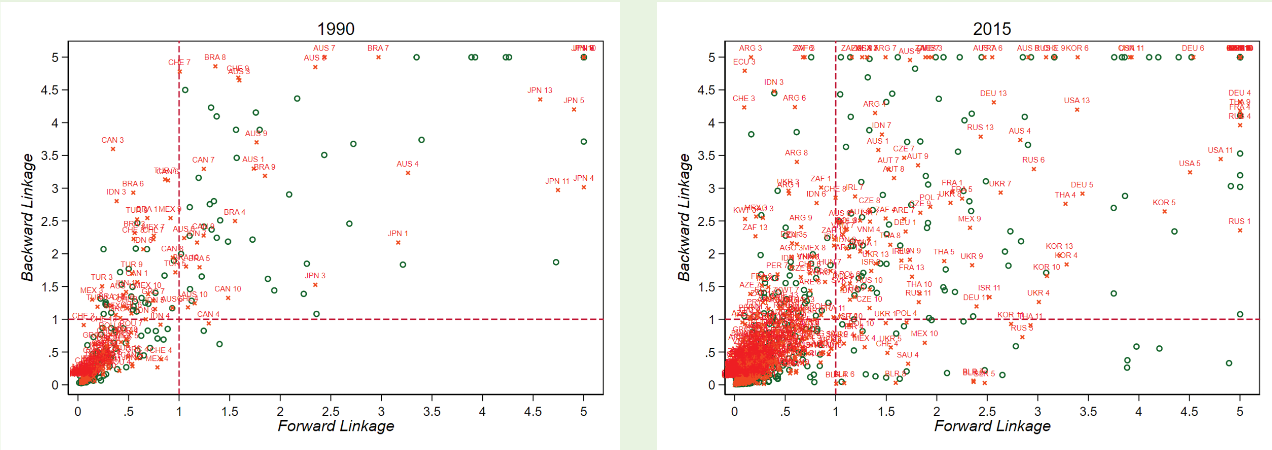
Sectoral Exports, Supply Chain Shocks and Climate Change

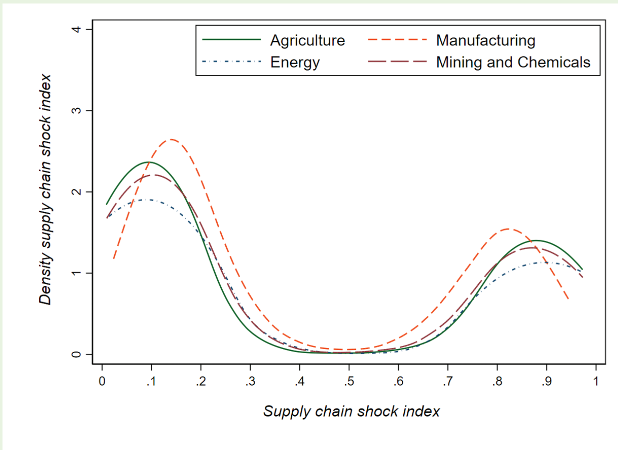
The production of a final good in a country is based on many input-output interlinkages domestically as well as internationally. This means that disturbances in one country can propagate along the supply chain, leading indirectly to a change in other countries' macroeconomic outcomes. The COACCH project has undertaken new analysis on the transmission of climate shocks in international supply chains. This assessed input-output connectivity between sectors and countries, along with data on extreme weather. The findings show the increase in international supply chains over time (from 1990 to 2015), and that sectors with strong supply chain interlinkages are regularly hit by natural disasters (sectors to the upper right of the figure and marked with red).



Sectoral forward and backward linkages and disaster shocks

The analysis then assessed the distribution of received supply chain shocks for regions and sectors. This leads to some interesting findings. The EU – due to the single market and stronger export orientation – receives more supply chains shocks from abroad than the USA. The effects are largest for manufacturing and agriculture.

The analysis looked at the impact of supply chain shocks on a sector's export performance. It found that productivity shocks transmitted over the supply chain significantly reduce a sector's export performance: on average a one standard deviation increase in supply chain shocks reduces a sector's export value by around 11%.



Distribution of supply chain shock index by sector in Europe

Finally, the analysis assessed the potential impacts of climate change on the interplay of supply chains shocks and a sector's export value. The findings are that all countries' sectoral exports are negatively affected by climate change, and it could reduce a sector's export value by up to 16 percent. However, these impacts vary strongly between countries and sectors. The largest impacts occur in the tropics and sub-tropics, due to the stronger projected climate impacts, which are then transmitted over interregional supply chain connections. The findings suggest that policy makers as well as companies need to the take account of the rising risk of supply chain disruptions due to climate change. Potential adaptation measures could include a geographical diversification in global supply chain networks, intensification in the use of storage facilities or firm-level insurance against risks.

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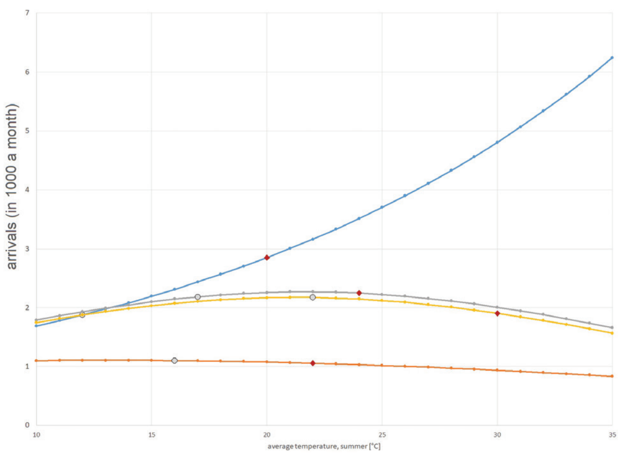
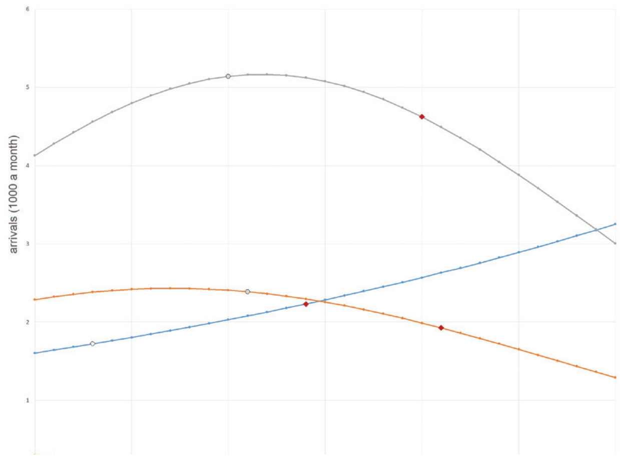


Effect of mean temperature on tourists arrivals



Effect of maximum temperature on tourists arrivals

policy makers as well as companies need to the take account of the rising risk of supply chain disruptions due to climate change. Potential adaptation measures could be, for example, a geographical diversification in global supply chain networks, intensification in the use of storage facilities or firm-level insurance against supply chain risks.

Energy

Introduction. Temperature is one of the major drivers of energy demand in Europe, affecting summer cooling and winter heating for residential properties and business/industry. Climate change will affect future energy demand, increasing summer cooling but reducing winter heating. These responses are largely autonomous and can be considered as an impact or an adaptation. Climate change will also have effects on energy supply, notably on hydro-electric generation, but also on wind, solar, biomass, and thermal power (nuclear and fossil).

COACCH Economic Cost Estimates.
COACCH has undertaken new econometric analysis to investigate the effects on wind energy. Results find that the wind load factor capacity over Europe is maximised at 10 m/s, above which generation declines. Air density also has a positive impact on load factor capacity, as increased air density exerts added pressure on the turbines, thereby increasing power generation.

These relationships have been applied to future climate change projections. Under the RCP4.5 projections, load factor capacity from wind power is projected to decline by 5.6% by 2050, and by 7.3% towards the end of the century. The biggest declines in load factor capacity due to changing wind patterns are projected for northern Austria, northeast Italy, and eastern Switzerland, with wind power generation projected to increase in parts of the United Kingdom and Ireland. These projected impacts are slightly higher than previous studies (Tobin et al. 2014). Under an unmitigated climate change scenario of RCP8.5, load factor capacity is projected to decline by 6.9% by 2050 increasing by 2070 to 9.7%, with the highest decline in eastern and western Sweden, and in Andalusia, Spain.

COACCH has also modelled the projected changes in hydropower production in Europe and globally. Under a moderate warming scenario of RCP4.5, the highest declines will be in Finland (6.3%), Estonia (6.2%) and Serbia (5.9%), noting hydropower is a significant share of electricity production in each of these countries. These impacts increase by the end of the century, with large projected impacts (10%) estimated for Slovenia, Croatia and Austria. These impacts increase under high warming scenarios (RCP8.5) especially in the later part of the century. By the end of the century, for a high warming scenario, decreases in hydropower generation are estimated to be 13% in Serbia, Romania, Hungary and Sweden.

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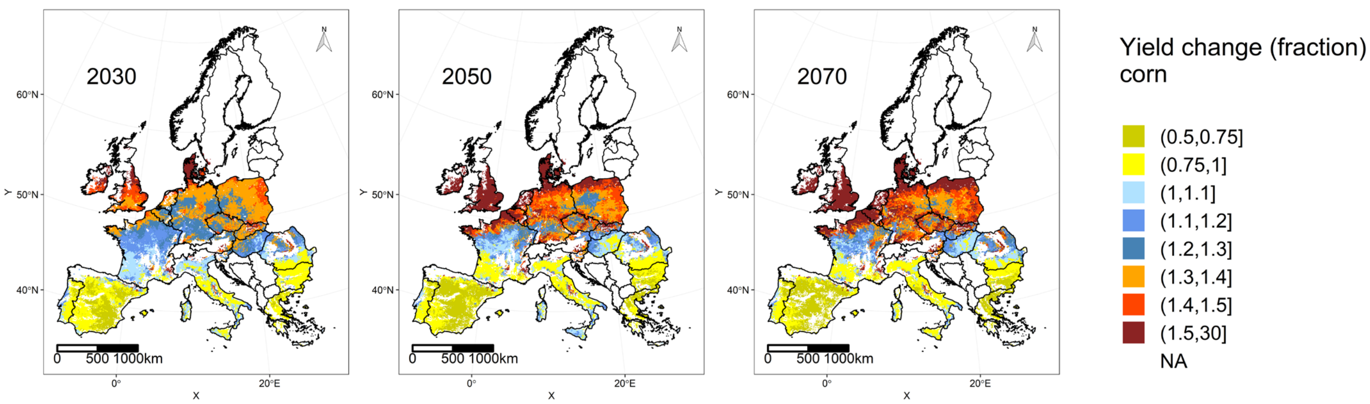
Agriculture

Introduction. Climate change has the potential to affect the agricultural sector, both negatively (e.g. from lower rainfall, increasing variability, extreme heat) and positively (e.g. from CO_2 fertilization, extended seasons). These effects will arise from gradual climate change and extreme events that will directly affect crop production, but also from indirect effects, e.g. changes in prevalence of pests and diseases. These will affect crop yields and, in turn, agricultural production, consumption, prices, trade and decision-making on land-use.

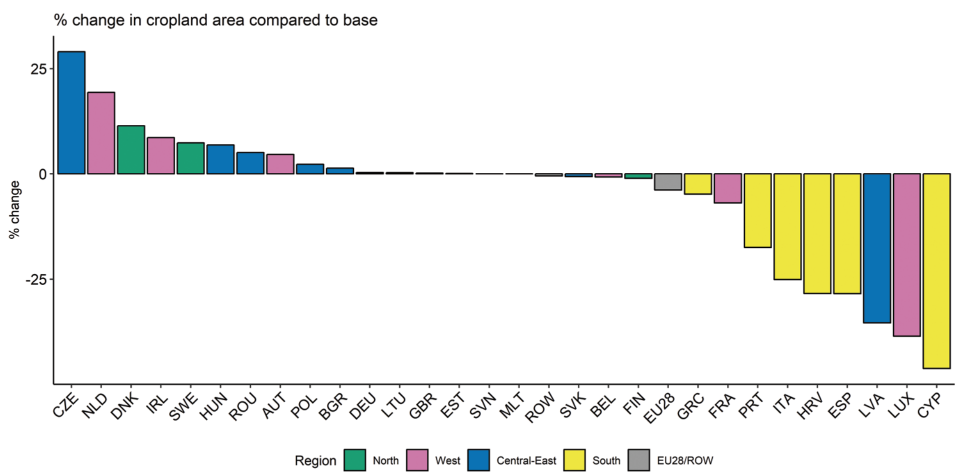
COACCH has developed new estimates, using a suite of models and assumptions to quantify the costs of climate change. This uses a range of GCMs, three crop models (EPIC, GEPIC and LPJmL), and two bio-economic models (MAgPIE and GLOBIOM) covering the agricultural, forestry and fisheries sector. The impact of factors that impact uncertainty, such as CO_2 fertilization, have been quantified.

COACCH Economic Cost Estimates. The GLOBIOM model was used to estimate the impact of climate change on EU-28 production, area, and yield, looking at individual crops and broad agricultural categories. The results produced different estimates to previous studies.

In all scenarios (low, medium and high warming scenarios), when CO_2 fertilization is included, crop productivity increases on average in Europe, but shows large differences between crop types, as well as spatial differences within Europe. The biophysical crop model EPIC shows that large negative impacts are expected especially for corn in Southern Europe, whereas cereals such as wheat are more resilient against



Fraction of yield change due to climate for corn productivity under RCP4.5, HadGEM-ES.



Percentage change in cropland by country under RCP4.5, HadGEM-ES in 2050.

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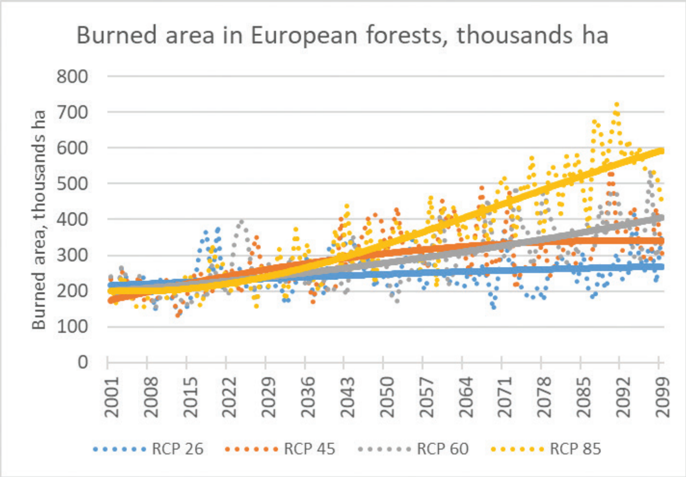
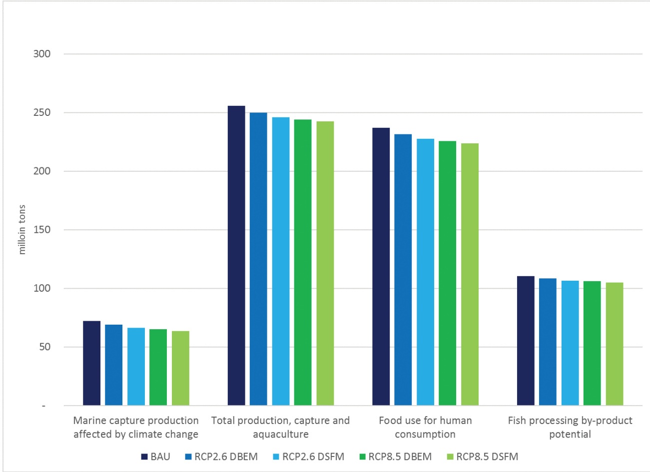


Projected burned areas in European forests.



Model projections of the impacts of climate change on marine capture fisheries.

climate change. This is due to their response to CO_2 concentrations.

The bio-economic model GLOBIOM shows that the large losses for maize production under different RCP combinations lead to increases in area cultivated with the same crop; however, not enough to compensate for the loss in production. Small yield gains in cereals and oil seeds on the other hand lead to small area reductions in for these crops. Furthermore, the change in relative competitiveness under climate change induces a reallocation of agricultural practices between European countries; cropland area especially reduces in the South of Europe, whereas it increases in the North, West and Central-Eastern countries.

Highest negative impacts on both crop yields and the agricultural sector in general, are found under a high emission scenario (RCP8.5) whenCO_2 fertilisation is not considered. GLOBIOM estimates that under this scenario, the production costs of climate change are in the order of 906 million Euros for arable production and 831 million Euros for the agricultural sector in 2050. These estimates consider the fact that the negative impacts of climate change are more profound in the rest of the world compared to Europe, leading to a relative improvement in Europe's export position, but also increasing pressure on European resources such as land and water.

Forestry and Fisheries

Introduction. Forestry is a sector with long life-times, and thus high risk from climate change. As with agriculture, forest growth may be enhanced by some processes but impacted by others, with the latter including changes in water availability, extremes (droughts, wind storms) and pests and diseases. Additional impacts can arise from changes in forest ecosystem health, and from increasing forest fires, affecting managed and natural forests. Climate change will also impact **fisheries**, with changes in abiotic (sea temperature, acidification, etc.) and biotic conditions (primary production, food webs, etc), affecting reproductive success and growth, as well as the distribution of species. Similar risks exist for freshwater fisheries and aquaculture. While human fishing activities are the dominant factor for commercial fisheries, climate change will add additional pressure.

Climate change affects the forest sector in two ways; first, through the impact on biomass accumulation and the growth rates on forests, and second, through the enhanced risk of forest fires. The biophysical forest model G4M estimates that increased temperature and decreased precipitation cause a reduction in the biomass and growth rate of forests in Southern Europe, especially towards 2070 under RCP8.5. In the short-term, smaller gains on biomass growth can be expected mostly in Northern Europe.

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For forestry, the Wildfire Climate Impacts and Adaptation Model (FLAM) is used to capture impacts of climate, population, and fuel availability on burned areas along with IIASA's global forestry model G4M. For fisheries, COACCH uses the GLOBIOM model to look at changes in annual catch and the redistribution of stocks or catch potential.

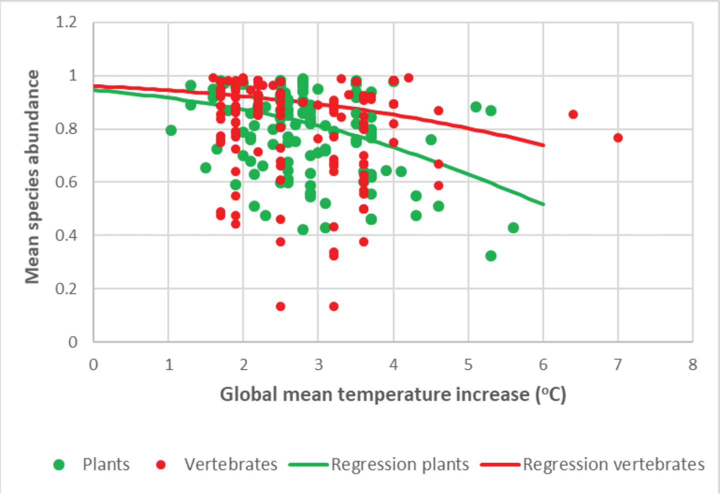
COACCH Economic Cost Estimates. Under RCP8.5 and without CO_2 fertilization, GLOBIOM estimates that the costs of climate change for forest production, related to the loss of biomass, amount to 62 million Euros in 2050 and 112 million Euros in 2070. In addition, forest fires currently affect more than half a million hectares each year in Europe, with estimated annual economic damages of €1.5 billion (San-Miguel-Ayanz et al, 2010). The new analysis in COACCH estimates that the potential burned area in Europe will increase significantly in Europe (see below), especially under the RCP8.5 scenario. The areas (in ha) are estimated to be Portugal, Spain, South of France and Greece. The COACCH project has also looked at potential adaptation options (prescribed burning, improved fire suppression), which have been found to significantly reduce the annual burned areas.

For capture fisheries, the analysis in COACCH indicates that under all scenarios, there is a decline in capture production globally, although there are strong regional differences. Fish stocks are highly mobile and are able to partly mitigate negative changes: this means that fisheries near the equator are affected more negatively, while some higher latitudes may gain. Nonetheless, all Member States are projected to experience declines in marine productive capacity, with the most serious impacts occurring in Denmark, Spain, France, and the UK. GLOBIOM estimates that for the EU28, a reduction of between 0.7 and 1.2 million tones is estimated for RCP2.6 and between 0.8 and 1.0 million tons for RCP8.5 (in 2050). It is noted that these estimates do not take into account additional impacts from marine extremes and ocean acidification.

Biodiversity and Ecosystem Services

Introduction. Climate change poses very large risks to terrestrial, aquatic and marine biodiversity and the ecosystem services they provide (provisioning, regulating, cultural and supporting services). It will shift geographic ranges, seasonal activities, migration patterns, reproduction, growth, abundance and species interactions, and will increase the rate of species extinction, especially in the second half of the 21st century (Settele et al., 2014). As well as terrestrial ecosystems, there are potentially large impacts on marine ecosystems, including from ocean acidification, ocean warming and sea-level rise, as well as impacts on freshwater ecosystems (rivers and lakes). However, this is one of the most challenging areas for economic cost analysis.

COACCH Economic Cost Estimates. COACCH is developng new analsis using a suite of models. This includes GLOBIO, a scenario-based gridded global model for biodiversity. This estimates the Mean Species Abundance – an indicator of biodiversity. Early results indicate that while natural vegetation cover remains broadly constant in Europe under climate change, there are projected to be movements of specific biomes. There is also projected net decline, on average, in MSA under climate change scenarios – the decline being greater under RCP8.5 than RCP2.6. These early results are being used to look at potential economic impacts, including ecosystem services.



Mean Species Abundance – pressure curve resulting from envelope model studies for both plants and vertebrates

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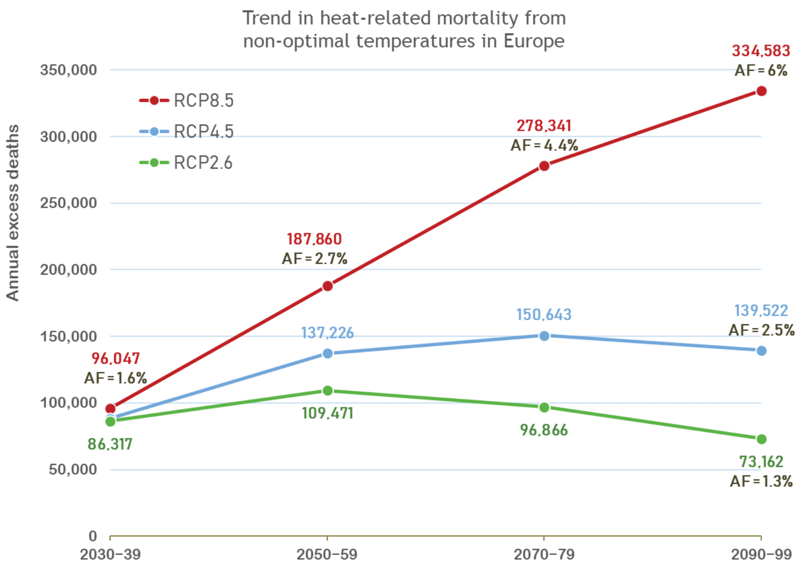
Health

Introduction. There are a number of health impacts from climate change. These include direct impacts, such as heat-related mortality, deaths and injuries from flooding, etc., but also indirect impacts, e.g. from climate change affecting vector-, food- and water-borne disease. There are also risks to the delivery of health services and health infrastructure.

COACCH Economic Cost Estimates. COACCH has assessed the impact of climate change on heat-related mortality. This has included an analysis of the urban heat island effect. When this is included, the spatial distribution of temperature projections in Europe changes, with rising risks for highly populated cities, even for low warming scenarios.

For Europe (EU28), the estimated total number of excess deaths from heat is estimated at 85,000 (RCP2.6), 145,000 (RCP4.5) and 300,000 (RCP8.5) by the end of the century. Heatwaves account for 40-50% of this total. These estimates are higher than previous estimates, reflecting updated climate projections and the inclusion of excess heat. The highest number of fatalities are projected in southern and central Europe.

Alongside this analysis, the COACCH project has also derived new estimates for the willingness to pay to reduce the risks of premature mortality, specifically for the heat-related context. This was based on contingent valuation surveys in Spain and the UK. Interesting WTP values were very similar in both countries, and the results were adjusted and transferred to provide average European values.



Trend in annual excess deaths attributable to heat (moderate and excessive).

Economic Costs of European Heat-wave-related Health Impacts for Various RCP scenarios (no adaptation or acclimatisation, VSL approach).

	RCP2.6-SSP2	RCP4.5-SSP2	RCP8.5-SSP5
2050s / mid century	€102 Bn/yr	€128 Bn/yr	€176 Bn/yr
2080s /end century	€68 Bn/yr	€130 Bn/yr	€313 Bn/yr

Values are presented as additional impacts relative to the baseline period, from the combination of climate and socio-economic change, and are presented as undiscounted values in future years in current prices.

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Distribution across Europe for RCP4.5, decade 2090-99

These new monetary values have then been applied to the impacts estimated in the figure above. However, they have only been applied to the mortality associated with excess heat/heatwaves, as this is the specific context in which the WTP values were derived. To do this the analysis assumes that on average, extreme heat is responsible for approximately 45% of total heat-related fatalities: this proportion was based on a detailed country-specific analysis in the COACCH project.

These results indicate that these non-market impacts could be very large, in fact, they are larger than the other sectors reported. This also means there are high economic benefits from mitigation policy, with very large annual economic benefits in moving from high warming (RCP8.5) to moderate (RCP4.5) and also to ambitious mitigation scenarios (RCP2.6).

However, there are a number of caveats with these estimates. First the physical impacts calculated do not take account of physiological acclimatisation to heat over time. Accounting for this would likely reduce down the estimated impacts (numbers). Second, the monetary values derived are based on the full Value of Statistical Life estimates from the WTP study. In practice, the period of life lost for many heat-wave related deaths may be short. Other studies have accounted for this by adjusting VSL estimates, for example deriving and using a Value of a Life Year Lost, combined with estimates of average life expectancy losses. The use of this type of adjusted values leads to significantly lower total economic costs from heat events, lowering the values in the table by over an order of magnitude.

The COACCH analysis has also looked at additional impacts from climate change on tick-borne diseases in Europe (Tick-borne encephalitis and Lyme disease). These ticks are sensitive to temperature, and climate change will alter their range and prevalence, including

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potential expansion into new areas. The COACCH project has undertaken a willingness to pay study, using stated preference surveys in the Czech Republic, Slovakia, and Austria, to derive new economic costs for tick-borne diseases, as well as public references for programmes to reduce the spread of tick-borne diseases.

COACCH Adaptation Economic Estimates. The COACCH study has also considered the potential benefits of adaptation, specifically heat alert systems, in reducing the excess heat related fatalities reported above. These systems are already in operation in many countries, and will have potentially greater benefits under climate change, however, they will also involve higher resource costs to operate, as they are triggered more with rising temperatures. COACCH has looked at these relative costs and benefits, assessing a case study assuming national systems operating across Europe (though it is stressed that such schemes are very site- and context-specific).

The benefit-cost ratios for implementing heat warming schemes across Europe for future climate change scenarios, using both the VSL and VOLY metrics. When the VSL metric is used, the benefit-cost ratio is very large across all European regions, under all future scenarios. When the VOLY metric is applied, the benefit to cost ratio is above one for Northern and Central Europe, but potentially below one for Southern Europe. This reflects the fact that the resource costs of responding to heat alerts in the South – from events being triggered so frequently – increase faster than benefits. This highlights that in these areas, heat alert systems on their own are unlikely to be the most efficient and effective measures, and a broader portfolios of complementary adaptation options is likely to be needed.

Macroeconomics, growth and competitiveness

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

COACCH Activities. COACCH is assessing the macro-economic effects of climate change by feeding sector results into economy-wide simulation models, notably computable general equilibrium (CGE) models. This has the advantage of capturing the whole economy (sectors, domestic and international interlinkages) and can analyse impacts on national production, welfare and GDP.

COACCH is also running a number of global and continental economic estimates provided by “hard-linked” integrated assessment models (IAMs). These provide a self-consistent integrated analysis of emissions, climate change, impacts and economic effects, including both market and non-market impacts. They report aggregate economic impacts as a % of GDP, through simplified and compact damage functions, rather than undertaking full macro-economic analysis.

The sector results reported in earlier sectors have been used to assess the macro-economic effects of climate change in Europe. This is reported in a separate policy brief (Number 4). This has also considered whether climate change might actually affect the drivers of growth (and growth rates), not just levels of outputs. Alongside this, COACCH is looking at the effects of these economic impacts on public budgets in Europe. This recognises that changing trends, as well as increasing climate shocks, may have implications for public finances.

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