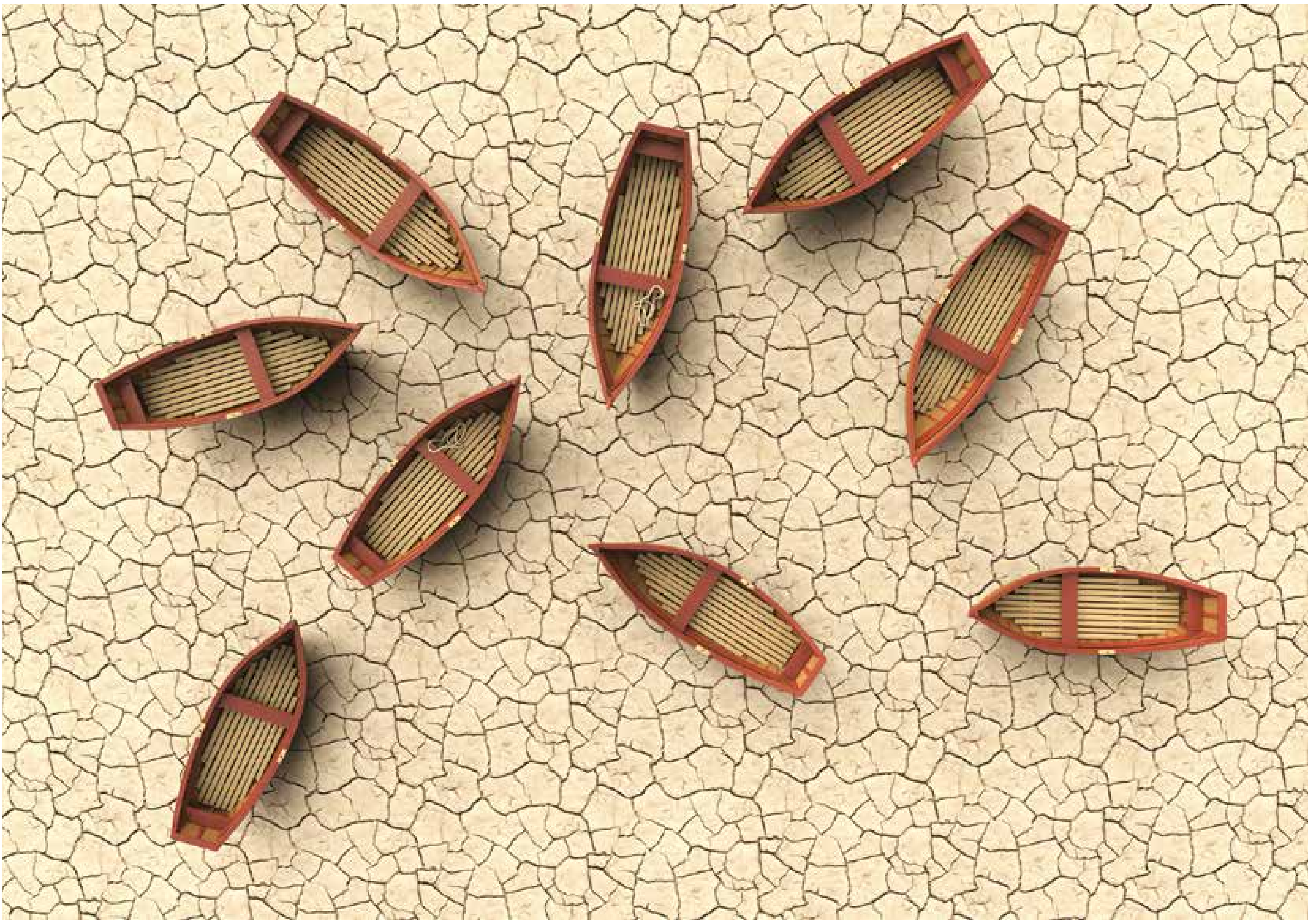
COACCH

CO-DESIGNING THE ASSESSMENT OF CLIMATE CHANGE COSTS



The Economic Cost of Climate Change in Europe:

Synthesis Report on COACCH Interim 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 synthesises the latest results from the COACCH project on the economic costs of climate change in Europe and identifies areas of possible discussion to explore with stakeholders at the second COACCH workshop.

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, corresponding to a certain increase of the level of total radiative forcing (W/m2) in the year 2100 with respect to the preindustrial equilibrium. The first RCP is a deep mitigation scenario that leads to a very low forcing level of 2.6 W/m² (RCP2.6), only marginally higher compared to today (2.29 W/m², 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.

SSP	Description	Challenge for Adaptation	Challenge for Mitigation
SSP1	Sustainability	Low	Low
SSP2	Middle of the Road	Moderate	Moderate
SSP3	Regional Rivalry	High	High
SSP4	Inequality	High	Low
SSP5	Fossil-fuel Development	Low	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	SSP2	SSP3	SSP4	SSP5
	(Green Growth)	(Middle of the road)	(Regional rivalry)	(Inequality)	(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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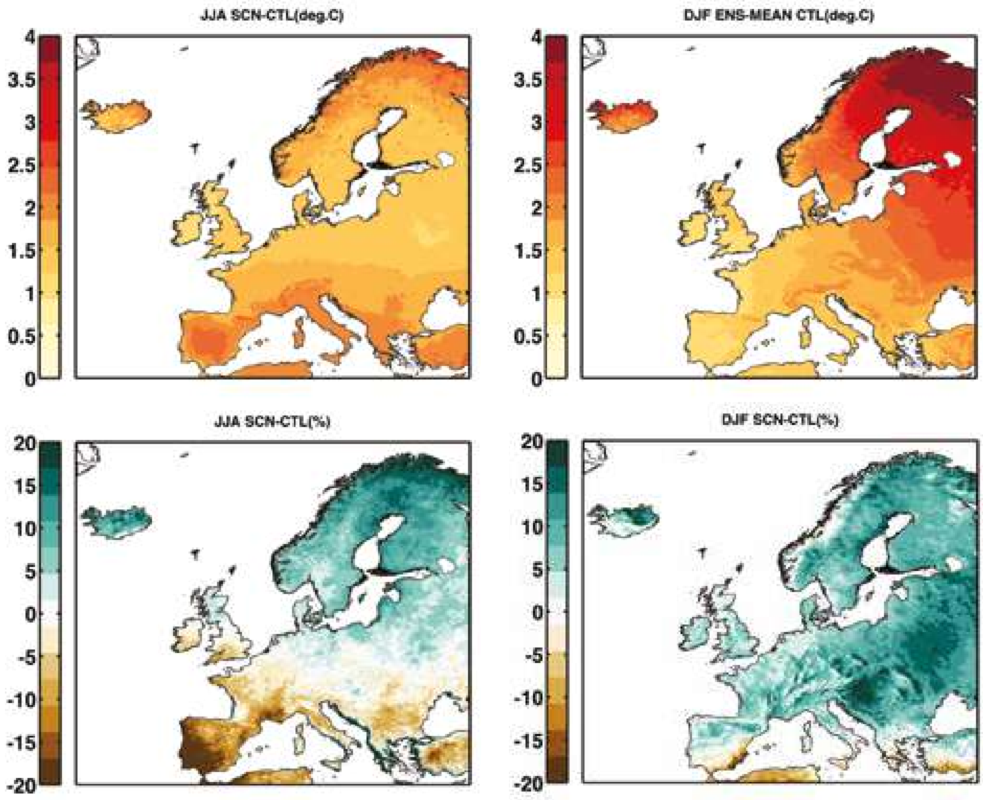

Projected changes in temperature and rainfall from climate change in Europe

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.

COACCH Results: Sector Economic Costs

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. In some sectors, early analysis of the costs and benefits of adaptation has been assessed.

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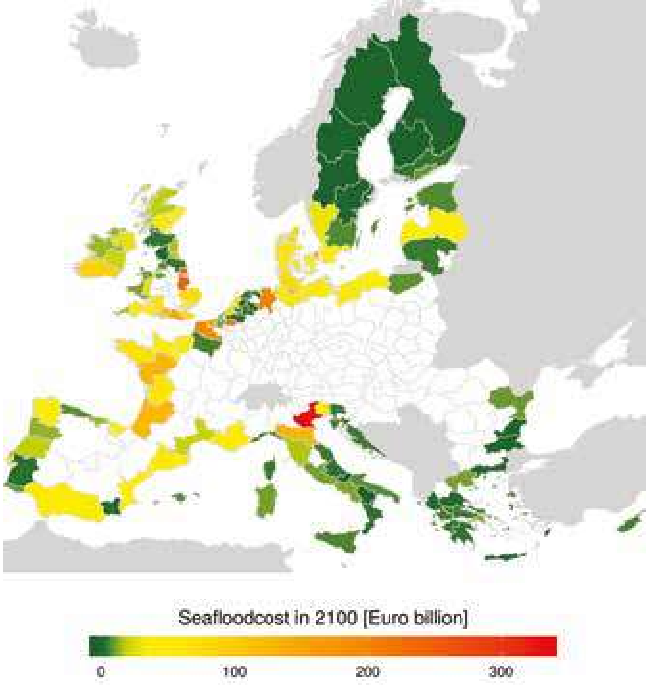
COACCH Economic Cost Estimates. COACCH has assessed the potential impacts and economic costs of sea-level rise in Europe, and the costs and benefits of adaptation. The analysis has considered future climate and socio-economic change. As floods are probabilistic events, the results are presented as expected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

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 (e.g. erosion), leads to high economic costs, shown below. The annual expected damage costs in Europe are estimated at €135 billion to €145 billion (mid estimates for RCP2.6 and RCP4.5 respectively for the 2050s (combined effects of climate and socio-economic change, based on current prices, with no discounting), rising to €450 billion to €650 billion by the 2080s. These costs include direct impacts and costs of land loss (with direct changes clearly dominating the overall cost by several orders of magnitude). Additional unquantified costs will occur due to ecosystem losses and possible knock-on effects of damage on supply chains.



Seaflood cost map

Importantly, there are major differences in the damage costs borne by different Member States, with strong distributional patterns across Europe. 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. This is shown in the map of coastal damages.

These costs rise rapidly by the late century, notably for the high emission RCP8.5 scenario. The results show a disproportionate increase in costs for higher warming scenarios in the second half of the century under such scenarios. This highlights the benefits of mitigation strategies. For example, there are large benefits of moving from a high emission scenario (RCP8.5) to a 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.

When compared to earlier studies that have also used the DIVA models, the new COACCH numbers are much higher, especially for the late century, and particularly for high-end scenarios. This reflects the higher increases in sea-level rise, but also the socio-economic drivers (especially in the SSP5 scenario).

It is stressed that there is a wide range of uncertainty around these mid estimates, reflecting the underlying uncertainty in the sea-level response to a given emissions scenario and temperature outcome, and the role of ice sheet melt. Analysis of extreme sea-level rise, i.e. of projections estimating over 1.5m by 2100, are considered in the tipping points section later in this paper.

Coastal damage/yr	**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

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Coastal adaptation €/yr	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

COACCH Adaptation Economic Estimates. The DIVA model has also been used extensively to look at coastal adaptation 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 annualy would fall from several millions to around 230,000 – 290,000 in the 2050s.

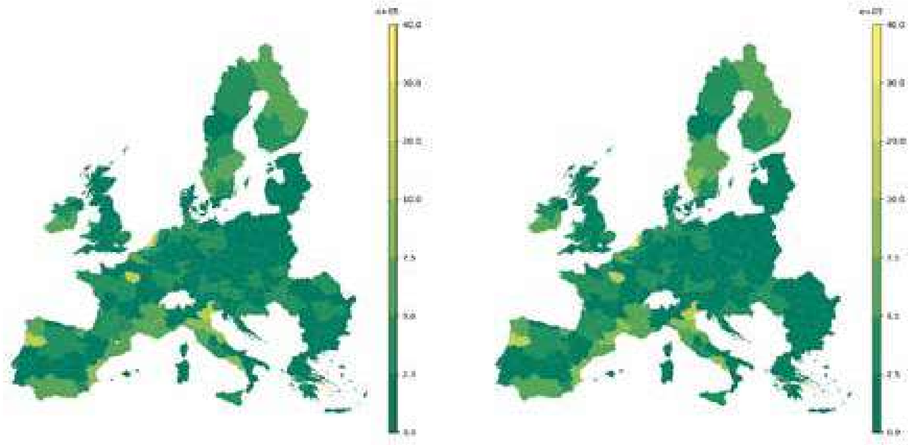
Adaptation would also significantly reduce damage costs. The analysis finds that adaptation is an extremely cost-effective response, with hard (dike building) and soft (beach nourishment) significantly reducing costs down to very low levels. Adaptation can reduce the annual damage costs shown above drastically (by two to three orders of magnitude), but adaptation to rising sea-level might cost between 15 and 40 billion EUR every year in 2100 in the EU. The benefit-to-cost ratios increase throughout the 21st century. However, hard defences need ongoing maintenance to operate efficiently and to keep risk at a low or acceptable level, thus as the stock of coastal protection grows throughout the 21st century, so will annual maintenance costs.

It should be noted that the costs of adaptation vary significantly with the level of future climate change, the level of acceptable risk protection and the framework of analysis (protection versus economic efficiency). The climate and socio-economic uncertainty makes a large difference to the actual adaptation response at a country level. The need to recognise and work with uncertainty – as part of integrated and sustainable policies – requires an iterative and flexible approach. Climate change is only one aspect of coastal management policy in the EU and adaptation to it needs to be positioned within a broader integrated coastal-zone management policy framework.

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 required to assess and reduce risk to vulnerable areas, including adaptation plans.

River Flooding

Introduction. 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



The projected population located in a 1/100 year floodplain for 2050 (left) and 2080 (right), under RCP4.5-SSP2.

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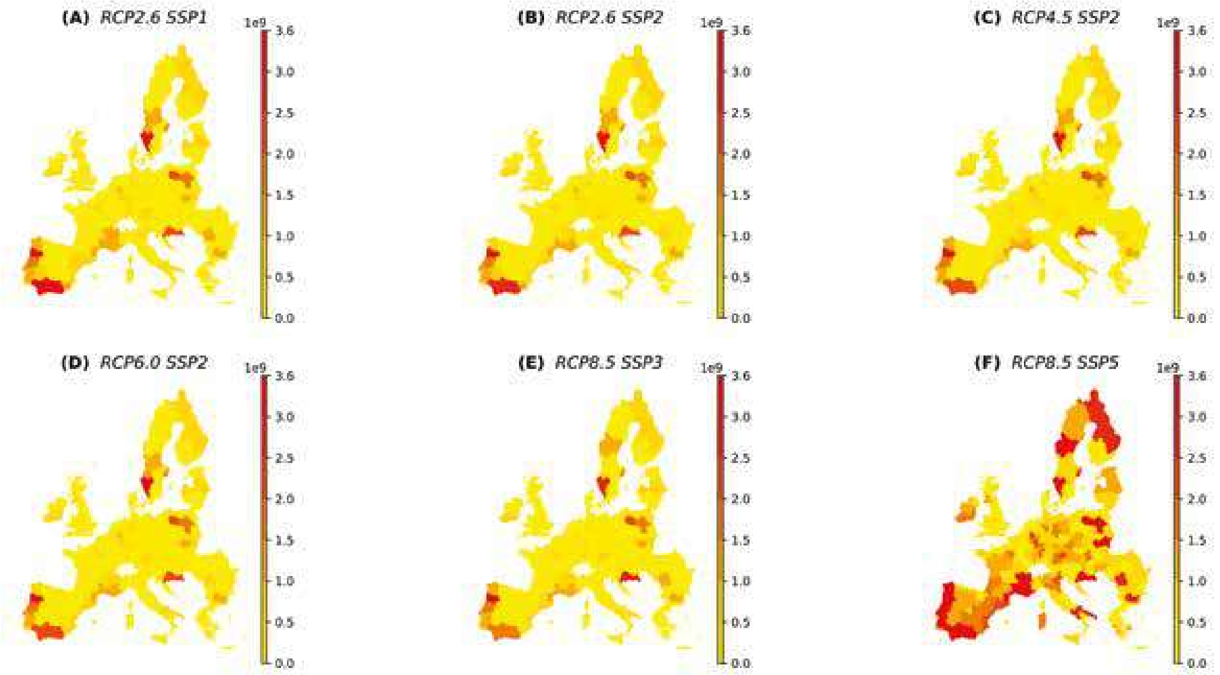
River flood cost / yr	RCP2.6-SSP2	RCP4.5-SSP2	RCP8.5-SSP5
2050s / mid century	€33 Bill/yr	€32 Bill/yr	€66 Bill/yr
2080s / end century	€75 Bill/yr	€75 Bill/yr	€225 Bill/yr



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

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 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 starting point for the analysis is to assess the levels of flooding, including the number of people flooded. This is shown below.

The annual expected damage costs in Europe are estimated to increase from around 9.5 billion EUR currently to approximately €33 billion by the 2050s (for the mid estimates for both RCP2.6 and RCP4.5), rising to approximately €75 billion by the 2080s (these estimates include the combined effects of climate and socio-economic change, 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 results show flood risks are distributed unequally over the EU28. River flood risk is higher for regions on the Iberian Peninsula, in the South of France, and in the North of Finland/ Sweden.

These costs rise rapidly by the late century, especially for higher emissions pathways, notably for the high emission RCP8.5-SSP5 scenario, rising to potential hundreds of €billions by late century. This highlights the benefits of mitigation strategies, i.e. the benefits of moving from a high emission scenario (RCP8.5) to the Paris Goal (RCP2.6).

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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.

When compared to previous studies (ClimateCost, IMPACT2C, BASE), the new COACCH analysis of river flood damages are much higher for the high end (RCP8.5) scenarios, due to a combination of the higher climate signal, but also the SSP5 socio-economic drivers. This highlights the combined influence from climate change acting on socio-economic change.

COACCH Adaptation Estimates Work is now underway to assess adaptation and estimate potential costs and benefits. Early analysis indicates that flood damages could be significantly lower with adaptation and that the adaptation cost itself is potential an order of magnitude lower than the avoided damages.

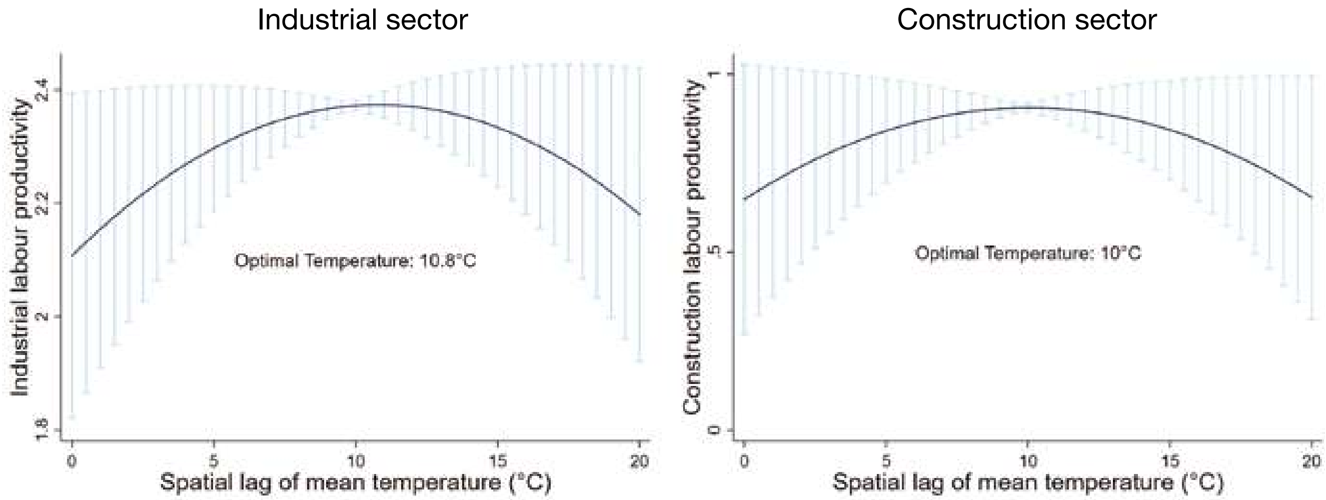
Business, Services and Industry

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



Change in labour productivity, against mean temperature (controlling for the spatial correlation with temperature in the neighbouring regions) at NUTS-2 level including 95% confidence interval (light blue).

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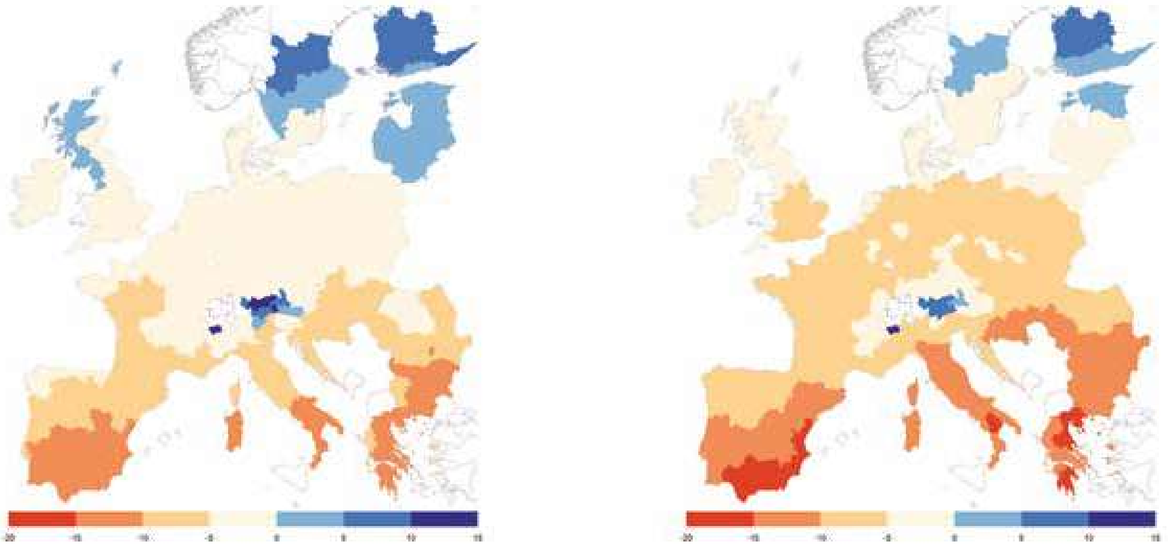

Percentage change in labour productivity due to climate change under RCP8.5 on industrial (left-panel) and construction productivity (right-panel) by 2070, compared to reference period of 1985–2005.

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 under the high-warming RCP 8.5 pathway by 4.3% and 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.

However, the threshold levels vary from region to region. The association between temperature and arrivals is not the same across the regions. 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. In EAST and WEST, increase in maximum monthly temperature has stronger effect than an increase in average temperature. Tourists coming to countries grouped in EAST are in particular sensitive to changes in average temperature beyond 35 °C. The project is now using these relationships to look at future climate change. 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.

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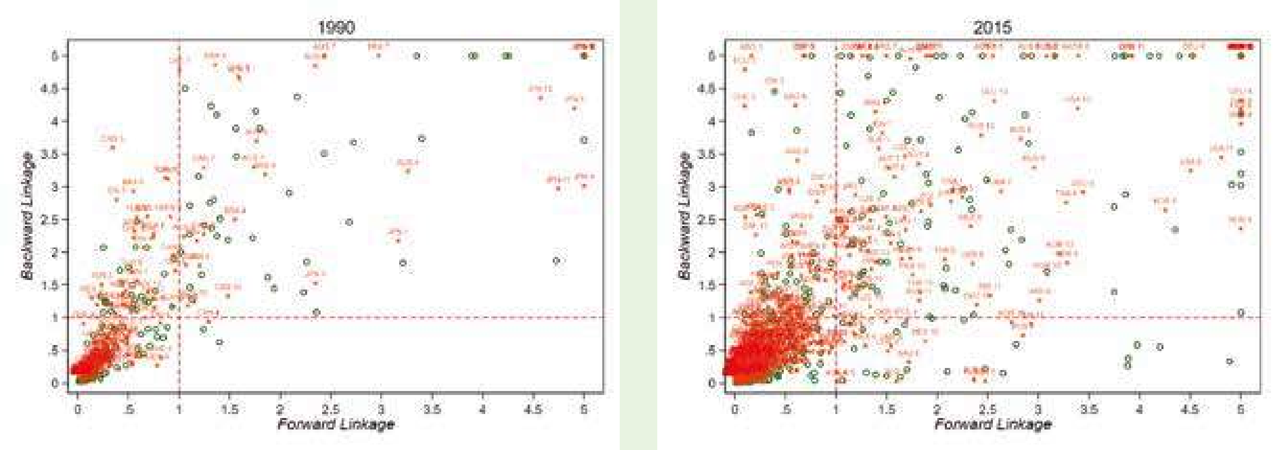
Sectoral Exports, Supply Chain Shocks and Climate Change

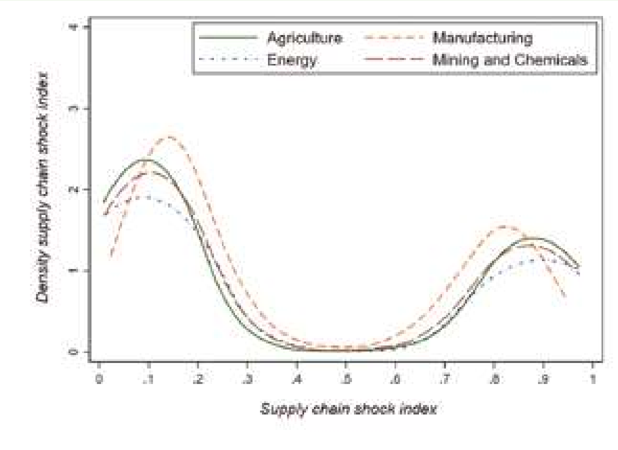
The production of a final good in a country is based on many input-output interlinkages domestically as well as internationally. This means that disturbances in one country can propagate along the supply chain, leading indirectly to a change in other countries' macroeconomic outcomes. The COACCH project 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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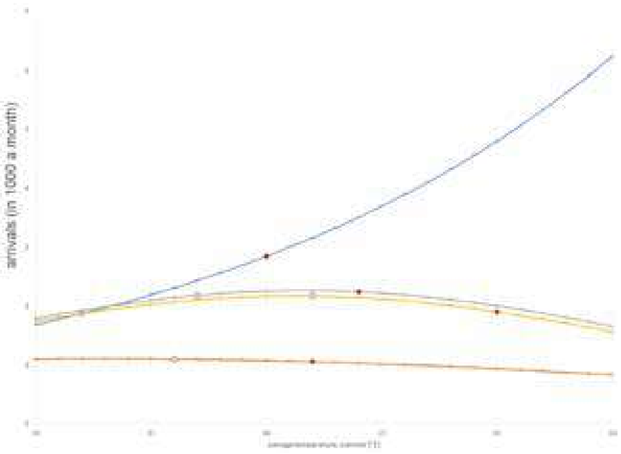
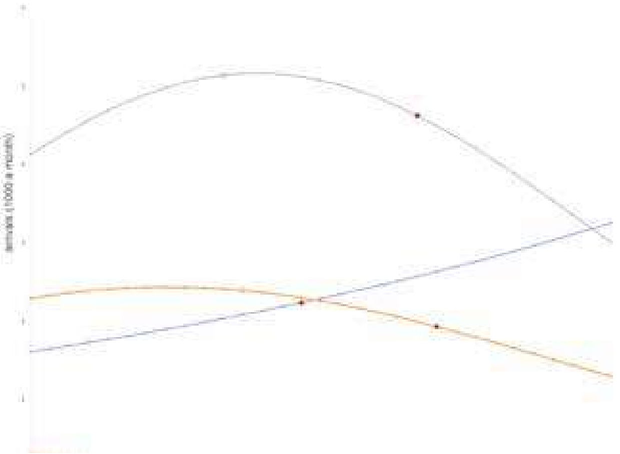


Effect of mean temperature on tourists arrivals



Effect of maximum temperature on tourists arrivals

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 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 significicant share of electricity production in each of these countries. These impacts increase by the end of

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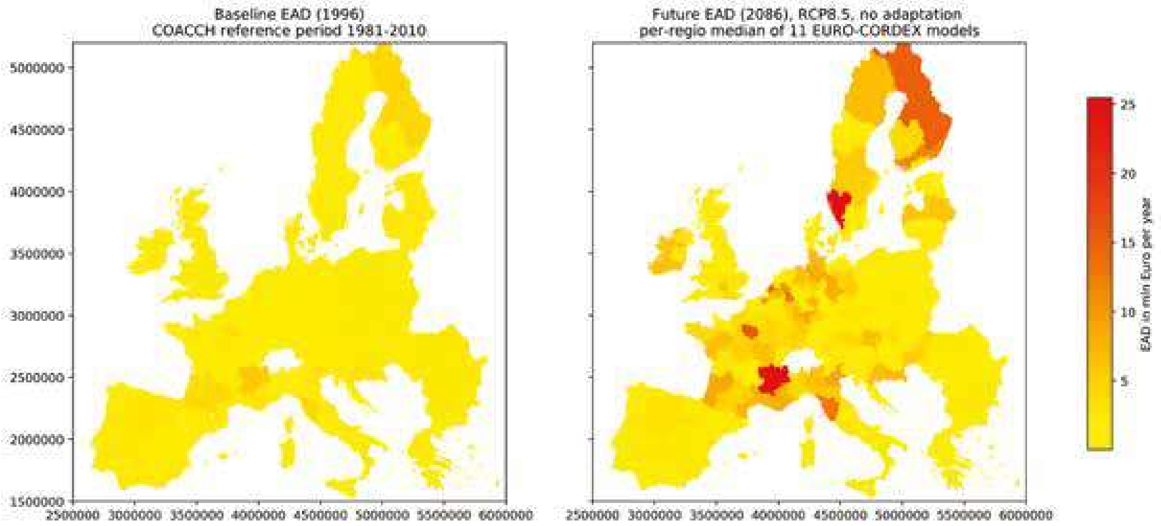

Expected annual damage (EAD) to road infrastructure in 1996 and 2086, aggregated on NUTS-2 level.

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.

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.

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, with Germany, France and Italy exposed to the highest risks.

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.

When adaptation is included, the damages drop back down close to current levels. This would, however, require significant investment costs to improve flood protection infrastructure. The spatial distribution of damages under climate change is presented in the figure below.

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

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

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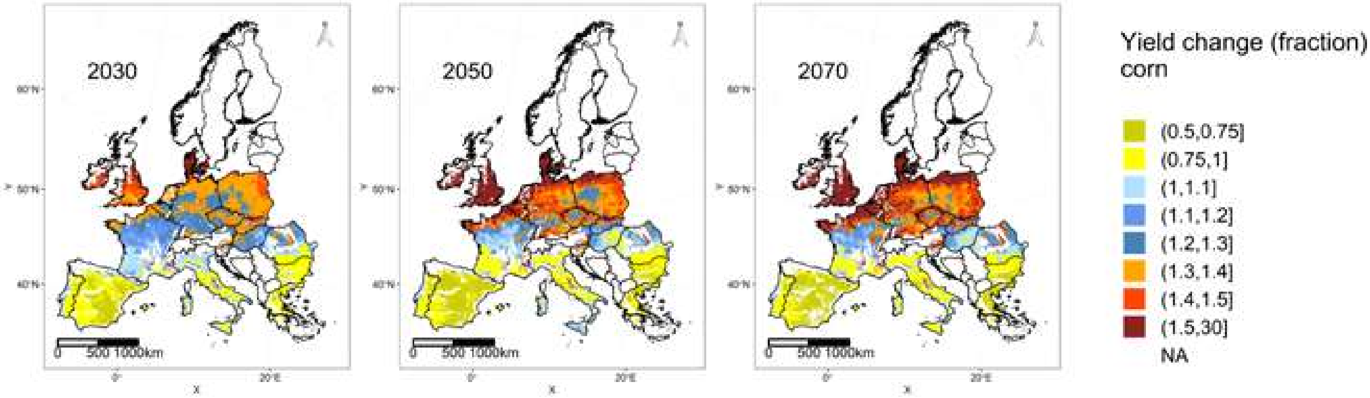
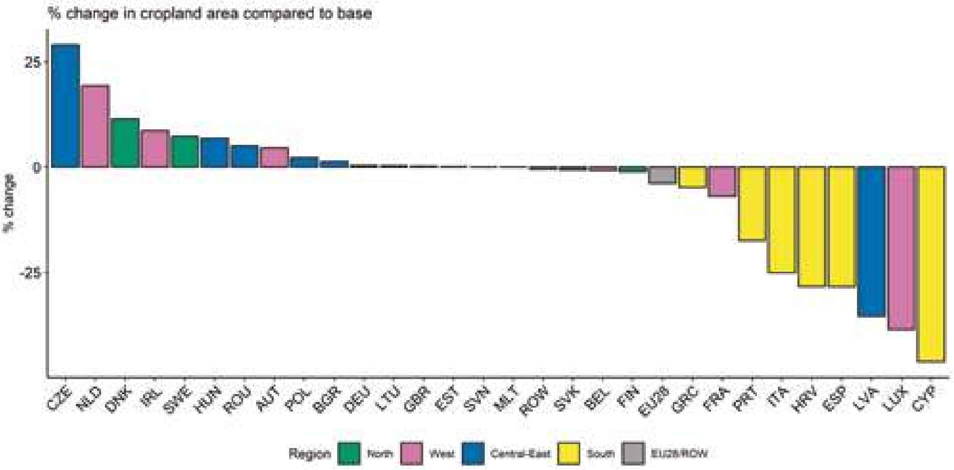


Fraction of yield change due to climate for corn productivity under RCP4.5, HadGEM-ES.



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

production, but also from indirect effects, e.g. changes in the 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 of the costs of climate change on agriculture, derived from a suite of models to quantify. This uses a range of climate models, three crop models (EPIC, GEPIC and LPJmL 5) and two bio-economic models (MAgPIE 4 and GLOBIOM-EU) covering the land use and marine production sectors. The impact of additional factors such as socioeconomic pathways, level of warming, and CO_2 fertilization are also quantified.

COACCH Economic Cost Estimates. The GLOBIOM and MAgPIE models were used to estimate the impact of climate change on EU-28 production (area and yield). For crops cultivated in the EU, climate change impacts on winter wheat, oil seeds and sugar crops are lower than impacts on corn. For example, the EPIC model finds large negative impacts for corn in Southern Europe, but finds cereals such as wheat are more resilient due to their response to CO_2 concentrations. The results vary with climate model and crop model, and whether CO_2 fertilization is included.

The change in relative competitiveness under climate change induces a reallocation of agricultural practices between European countries. Changes in relative profitability result in agricultural losses in Southern and Eastern Europe, but gains in Northern, Western, and Central Europe.

The GLOBIOM model estimates that the economic costs on agriculture for producers is 1.7 billion Euros (RCP4.5 in 2050). Costs for the producers are mostly negative, but vary with model and whether CO_2 fertilization is included.

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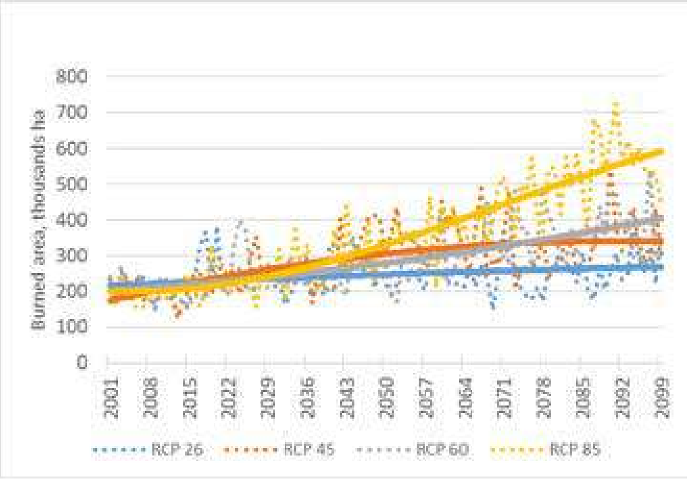
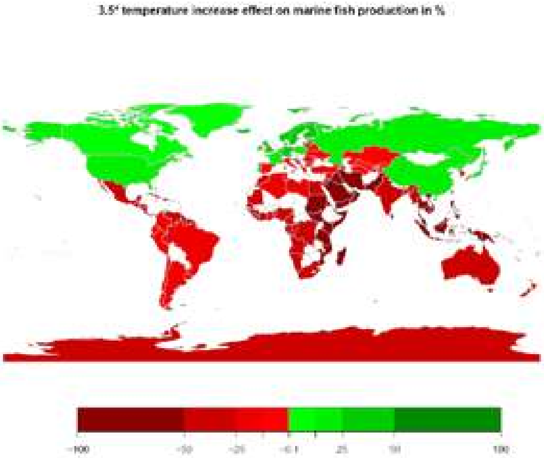


Projected burned areas in European forests.



MAgPIE percentage changes in marine fish catches due to climate change (RCP8.5 in year 2070).

Impacts on corn production represents up to a third of the agricultural losses.

There are also winners and losers, with the Southern part of Europe experiencing the largest losses, but gains for Northern and Central-Eastern countries, which benefit from a reallocation of agricultural activities. Many of the changes in Europe are driven by change in other competing production sites, world regions and cultivation options.

Forestry and Fisheries

Forestry is a sector with long life-times, and 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.

For forests, the analysis has assessed the change on forest growth and harvest potentials. The biophysical forest model G4M estimates that increased temperature and decreased precipitation could lead to a reduction in the biomass and growth rate of forests in Southern Europe, especially towards 2070 under RCP8.5. Both GLOBIOM and MAgPIE estimate that Northern parts of Europe could benefit from climate change and increase their forestry areas. Under RCP8.5 and without CO_2 fertilization, GLOBIOM estimates the costs of climate change for forest production at 63 million Euros for the producer side and 670 million Euros for the consumer side.

The analysis has also assessed the impact of climate change on forest fires, using the Wildfire Climate Impacts and Adaptation Model (FLAM) along with IIASA's global forestry model G4M. The results estimate that the burned area in Europe could increase significantly in Europe, especially under the RCP8.5 scenario, under which the burned areas could more than double compared to the present-day. The regions with the highest shares of burned areas are found in Portugal, Spain, South of France and Greece.

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 fishing activities are the dominant factor affecting fish stocks, climate change will add additional pressure.

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 can partly mitigate negative changes:

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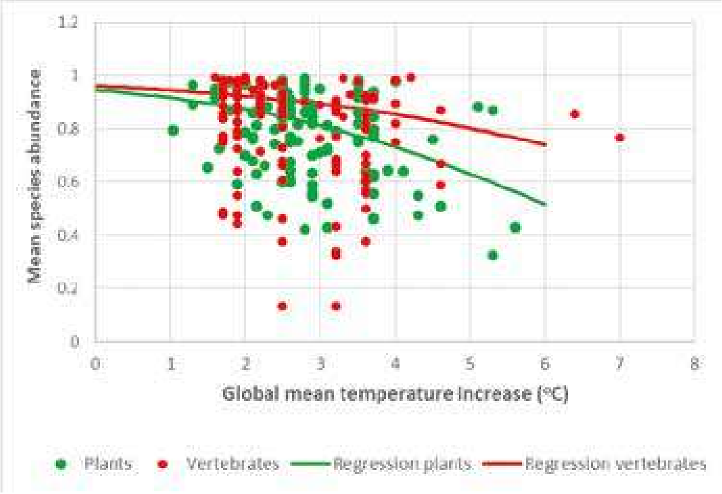
this means that fisheries near the equator are affected more negatively and may migrate to Northern latitudes that may gain. The impacts on EU Member States experience depends on the biophysical impact model and the degree of warming.

The results from GLOBIOM estimate all EU countries are projected to experience declines in marine productive capacity from climate change, with the most serious impacts in Denmark, Spain, France and the UK. It estimates a reduction of 3 to 9 million tonnes in annual catches by 2050. However, the MAgPIE model estimates an increase in marine fish catches in North-Western Europe due to climate change. It is noted that both models do not consider additional impacts from marine heat 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.



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

COACCH Economic Cost Estimates. COACCH is developing new analysis 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 – on the basis of a meta-analysis of a range of studies. The results of GLOBIO are shown in the Figure for the direct impacts of mean temperature increases under climate change on plants and vertebrates. The results show the negative impact of climate change on biodiversity. Plants are more sensitive than vertebrates (partly from a lower ability to adapt). The exact relationships are uncertain, but the analysis suggests a 25-30% decline in plant biodiversity for 4 degrees warming and a 10-20% decline in vertebrate biodiversity.

COACCH is also using the GLOBIOM model to identify and quantify the impacts on land use, fertiliser and greenhouse gases from adaptation in agriculture and forestry management, and potential impacts on biodiversity. This is driven by changes in cropland away from the South of Europe and an increase further North, and associated effects of biodiversity. Earlier results indicate that these effects are likely to be significant, particularly under the high emission scenarios.

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 is updating estimates of the impact of climate change on heat and cold-related mortality.

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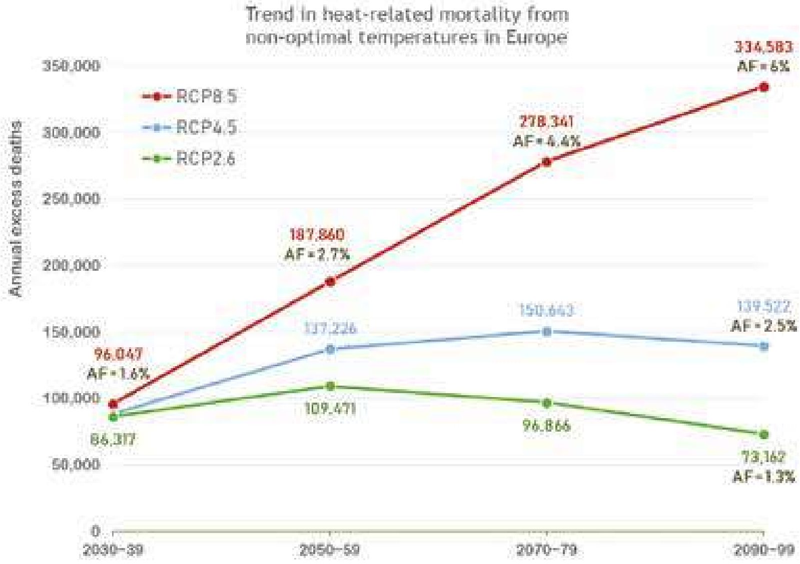

Trend in annual excess deaths attributable to heat (moderate and excessive) in Europe.

It has also been updating these estimates to take into account the urban heat island effect. Early analysis finds that when the UHI effect is introduced, the spatial distribution of temperature projections in Europe changes, with rising risks for highly populated cities in Western Europe, even for low warming scenarios. Complementing this, COACCH is undertaking new heatwave hotspot vulnerability mapping for Europe. This looks at the additional potential vulnerability from heatwaves, taking into account three layers for defining risk to population, hazard, exposure and vulnerability.

COACCH is also updating the heat related mortality estimates, with detailed work in the Netherlands, as well as updated analysis at the European scale. The mortality projected at EU level is from exposure to temperatures above the minimum mortality temperature, which includes both moderate and excess heat. Heatwaves account for 40-50% of total heat-related mortality. While the study on Netherlands focuses just on heatwaves. this difference is not clear in the summary.

For Europe, the estimated 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. These estimates are higher than previous estimates (e.g. Watkiss and Hunt, 2012, Ciscar et al,. 2014), reflecting updated climate projections and also the inclusion of excess heat. The highest number of fatalities are in southern and central Europe.

The COACCH project is also derving new estimates for the value of statistical life, to improve the context specific valuation of changes in fatalities due to heat (above). This will use discrete choice stated preference surveys in Spain and the UK. Alongside this, COACCH is undertaking similar stated preference surveys for valuation of tick-borne diseases, a key risk for Europe, focusing on the welfare impacts of lyme borreliosis and tick-borne encephalitis. This will undertake survey work in the Czech Republic, Slovakia, and Austria.

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

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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 are being used to assess the macro-economic effects of climate change in Europe. This will also consider 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.

Climate Tipping Points

Introduction. Climate tipping points relate to critical thresholds at which a small perturbation 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 (feedbacks) and they can be potentially abrupt, non-linear and irreversible.

These 'bio-physical' climate tipping points provide a key justification for global mitigation policy, yet they are poorly represented in economic assessments of climate change. Lenton et. al. (2008) compiled a list of global tipping elements and Levermann et al. (2012) identified the most important for Europe. Several studies make indicative estimates of the warming levels (°C) that might trigger these events.

COACCH Analysis. The COACCH project has been analysing the potential tipping points of most concern in the short-term for Europe. These are focusing on two short-term tipping points and one long-term one.

Artic summer ice is projected to disappear at moderate levels of warming, i.e. 1–2°C, though winter sea ice is not projected to disappear below 5°C. This melting does not affect sea levels, but it will influence Artic ecosystems, navigation, and also potentially Atlantic storm tracks into Europe as well as extreme winter weather. There are existing studies that have considered the economic impacts at the global level from artic summer ice loss and increased warming (Hope et al., 2018). However, COACCH is focusing on the regional impacts, where summer Artic ice-loss affects extreme events (including storms as well as winter temperatures). The COACCH project has assessed projections of Arctic sea ice extent, based on CMIP5 models. An example is shown below, for two models and two RCPs. These indicate that under RCP8.5, summer ice sheet loss is projected by mid century (both models), but there is greater variation in RCP4.5. These assessments are being used to assess the potential changes in extreme cold conditions, and possible windstorms, with new COACCH analysis to investigate the potential in regional economic costs of these changes.

Alpine glaciers are already showing a general trend of retreat, and glacier melting is projected to accelerate with warmer temperatures, exacerbated by ice-albedo feedback. will affect water availability as glaciers shrink. In the short-term, flows may increase with melt water, but in the longer-term, the seasonal buffering will decline and summer river flows are projected to fall, affecting water availability, hydropower and stability (landslide risk). The COACCH project has analysed the climate models to build up scenarios of these risk. This finds that all of the

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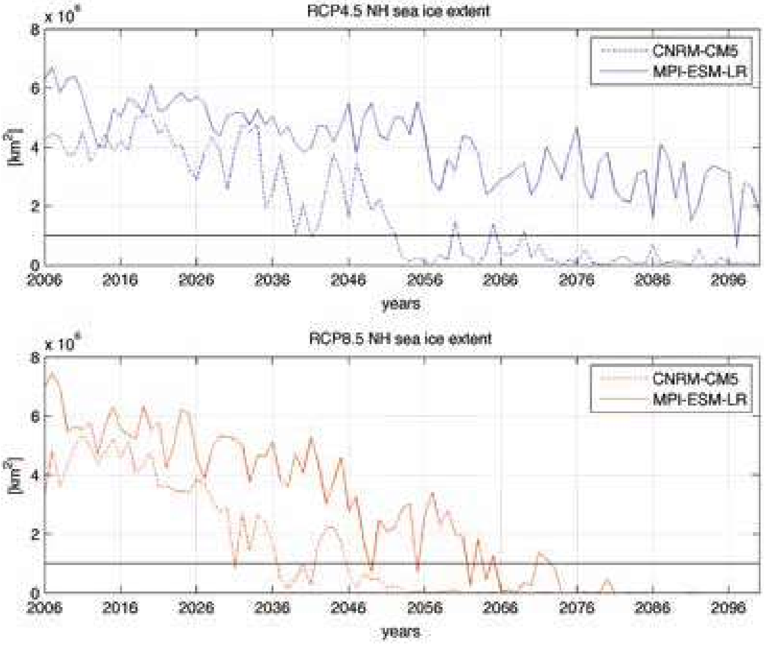
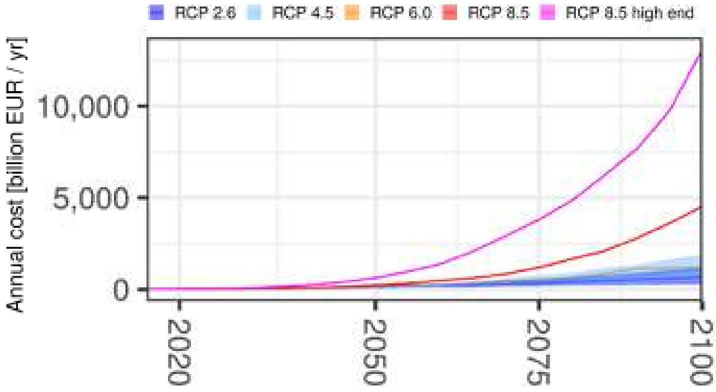


CMIP5 modeled September sea ice extent time series. Units are [10^6 Km^2].

The figure shows modelled projections of Arctic sea ice extent from two CMIP5 GCMs used to provide boundary conditions for EURO-CORDEX downscaling purposes.

RCPs indicate a reduction (compared to 2018) of about 50% (multi-model average) of the glacier volume over the Alps for 2050. Beyond this time, the results vary strongly with the scenario. Under the RCP2.6 and 4.5 scenarios, the average reduction is 60% and 80% (respectively) by the end of the century, but with almost complete loss under RCP8.5. Irrespective of the future scenario, these changes will have very large effects downstream, on hydro-power, irrigation for agriculture, river transportation and ecology. These may include increases in run-off (with higher melting) as well as changes in the timing of flows. COACCH is investigating these effects with hydrological models and economic analysis.



EU28 sea flood cost and protection cost over 21st century, showing also the effect of extreme SLR. Uncertainty ranges for lower RCPs show climate modal and socio-economic uncertainty.

Finally, the other major global climate tipping point risk for Europe in this century (and beyond) is from rapid sea level rise (SLR), notably from the accelerated melt of the Greenland Ice Sheet (GIS) and/or the accelerated melt / possible collapse of the (West) Antarctic Ice Sheet (AIS). The water stored in these would raise global sea levels by about 7 m (GIS) and 5 metres (WAIS), although such increases would take millennia. The tipping points for the onset of these events are uncertain, though they are more likely to be above 2°C. Recent modelling has shown that the mass loss of the AIS could be very sensitive to temperature rise and mitigation targets: under high (8.5) RCP scenarios and with certain instability processes, the AIS could contribute around one metre by 2100 and about 15 meters by 2500 to global-mean sea-level rise (DeConto and Pollard, 2016).

The COACCH project is running the DIVA model to estimate the potential economic costs for Europe from these extreme sea-level rise scenarios. This has considered a high end scenario with global coastal average sea-level

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rise of 170cm by 2100, to illustrate the effects of such high end sea-level rise. In this case, coastal floods have severe effects with an exected 30 million people flooded 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.

Socio-Economic Tipping Points

Introduction. The COACCH project has 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 socio-economic systems, which can lead to major economic costs. These changes may arise directly in Europe, but may also involve global events that subsequently spill-into into Europe.

The first activities in COACCH were to more clearly differentiate these events from the other types of tipping points in the literature. This is shown in the figure below.

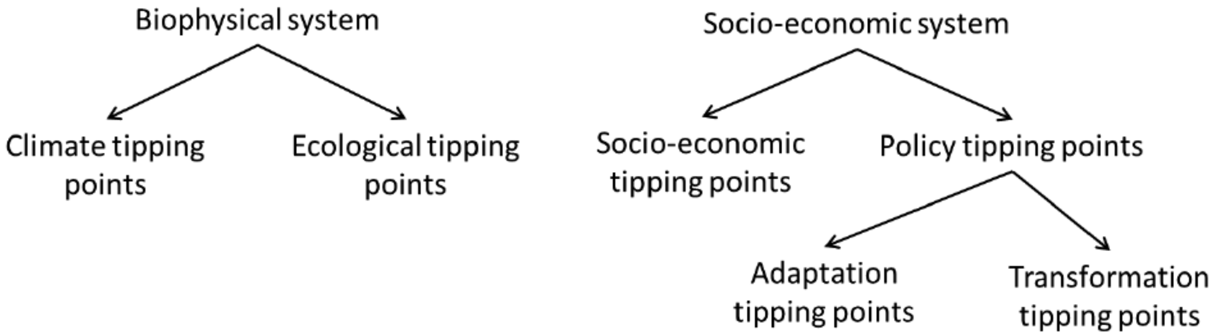
The next activity was to more specifically define these events. It is more difficult to translate the strict definition of tipping points into the socio-economic domain, because there are different types of pathways that may occur. These may involve a case where climate change triggers a large-scale socio-economic event (a major shock). It might also involve climate change (above a threshold) affecting the functioning of an established socio-economic system. They could therefore trigger a rapid increase in costs, e.g. as measured by a large drop in the GDP of a region, or they may require a fundamental new functioning of an existing system with high associated costs.

To progress this, the COACCH project identified common characteristics for SETPs. First, they should have the potential to switch from one stable state to another, at either side of some critical threshold. Second, there is the potential for non-linear behaviour, i.e. with the potential for a sudden transition. Finally, there is the potential for rapid and abrupt change (in the resulting socio-economic systems). Based on this analysis, the COACCH project defines socio-economic tipping points as *'a climate change induced, abrupt change of a socio-economic system, into a new state of fundamentally different quality, beyond a certain threshold that stakeholders perceive as critical'*.

The 1st COACCH workshop identified a set of 22 possible SETP of interest to stakeholders. Following a further prioritisation, a number of these are being assessed in detail in the project. These are:

- Collapse of insurance markets from extreme weather risks;
- Migration, including from coastal areas;
- Food/water shocks in Europe;
- Trade disruptions due to flooding of critical parts of the network;
- Climate induced economic shocks;
- Impacts on financial markets for high-risk countries;
- Energy supply system switches;
- Transformational adaptation to accelerating sea level rise.

A number of these have already provided early results, which are summarised below.



Typology of tipping point in different branches of literature.

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Flood insurance affordability in Europe

Introduction. Flood insurance coverage can enhance the financial resilience of households to flood risks. However, climate change is projected to lead to challenges for national insurance systems and global reinsurance, resulting in increasing premiums, decreased coverage or increased moral hazard.

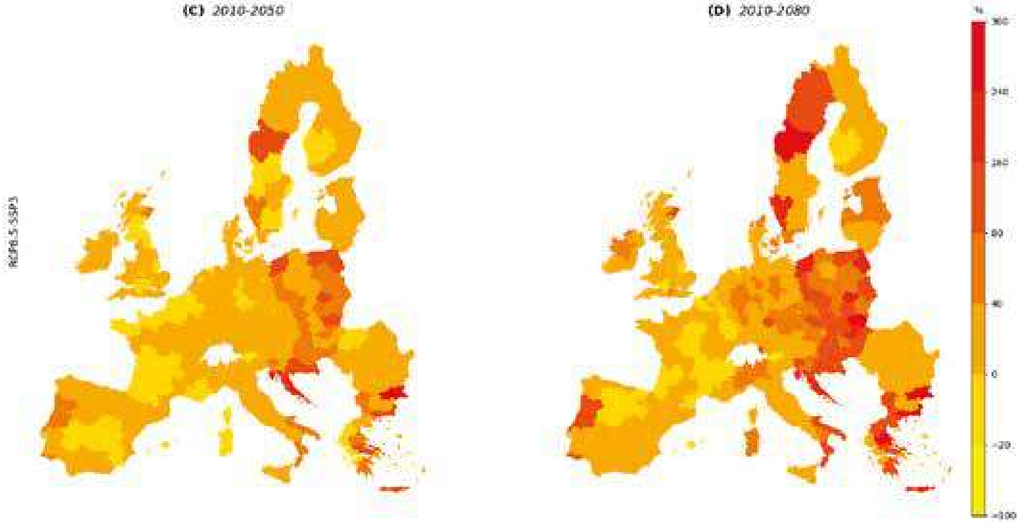
These effects of climate change will vary across the Member States, because they use different flood insurance models. One particular issue may arise for voluntary insurance markets. The increase in flood risk under climate change may cause substantially higher risk-based insurance premiums, which makes it less attractive to purchase flood insurance, and this exacerbate inequality problems with the affordability of insurance for low-income households. Importantly, a socio-economic tipping-point could occur when formal flood insurance systems disappear due to unaffordability and low demand.

Method. COACCH has examined whether such an insurance tipping-point could occur in Europe (for current flood insurance systems) due to the future flood risk caused by climate and socio-economic change. This uses an adapted version of the "Dynamic Integrated Flood and Insurance" (DIFI) model, which integrates flood risk simulations with an insurance sector and a consumer behavior model.

COACCH Results. The results show major potential impacts on flood insurance, with tipping point exceedances increasing over the 21st century. They show rising unaffordability and declining demand for flood insurance especially towards 2080. This happens under all climate scenarios, but it is especially high under a high climate change scenario, which leads to socio-economic tipping-points of signficant impact in several regions of Europe, as insurance uptake almost disappears.

The patterns of unaffordability are shown below – defined as the percentage of the population in high-risk areas that cannot afford the premium. High increases in unaffordability are found in Eastern European countries, as well as regions in Sweden, Portugal and Italy. These are driven by higher increases in flood risk, but also in some cases, below average projected income growth.

The effects also depend on the baseline insurance market. For example, countries that maintain risk-based flood insurance premiums show a higher growth of unaffordability compared to countries with a solidarity-based insurance market where premiums are cross-subsidized, because premiums can rise rapidly when they reflect risks in flood-prone regions.



The percentage change of unaffordability under status-quo insurance arrangements for households in high risk areas under the RCP8.5-SSP3 scenarios of climate- and socio-economic change for the periods 2010–2050 (left) and 2010–2080 (right).

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This could lead to important impacts, notably that governments or households themselves may bear the responsibility of covering the damage after events have happened. On the other hand, cross-subsidizing premiums lead to rising costs of insurance that are transferred to households in low-risk regions, which may be considered unfair for these households.

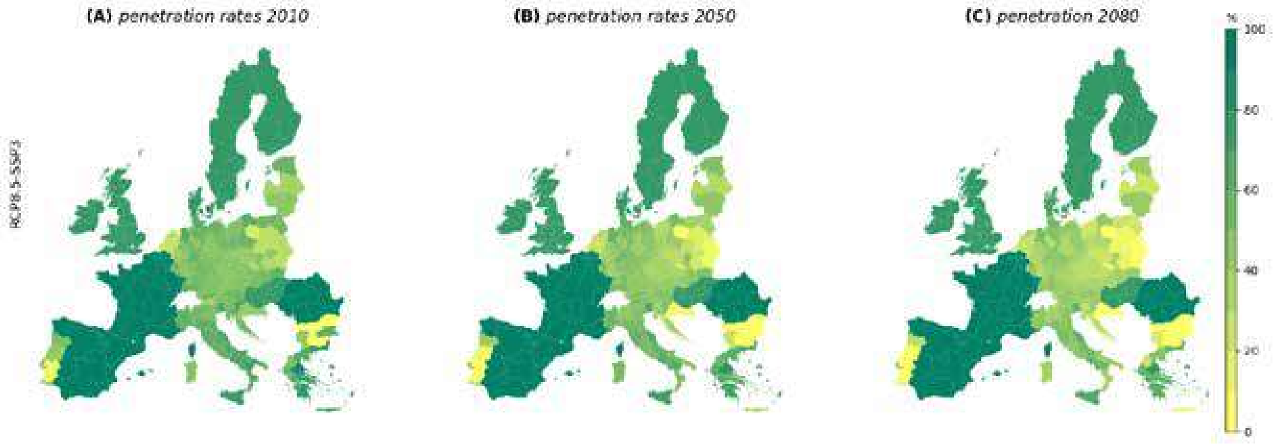
The figure below shows the projected development of flood insurance demand for three time-steps under current insurance systems. Countries where insurance is mandatory, or where uptake is a mortgage requirement or included in standard homeowner insurance, are shown to have fixed penetration rates that do not change over time. For most regions with a voluntary insurance system the demand for insurance decreases over time as a result of increasing unaffordability, or premiums rising faster than household risk perceptions. The most problematic development can be expected in many Eastern European regions as well as Portugal, where projected demand for insurance dwindles to almost nothing towards 2080.

The economic consequences of these failures could be very large. Unlike annual flood damages, the failure of insurance could damage asset values (property prices) and slow down the recovery speed in communities affected by flooding, which may have to rely on insufficient and uncertain compensation by governments or charity organizations, or have to deplete private savings in order to rebuild damaged property. The results have major consequences for insurance markets (reducing the effectiveness of risk pooling), as well as the European solidarity fund, which may be required to provide disaster relief more often in the future. The analysis shows that some SETP effects could be mitigated by introducing reforms of flood insurance arrangements.

Sea-level rise and coastal migration

Introduction. Sea-level rise (SLR) is a major threat for coastal zones in Europe and globally. As well as the damage costs presented earlier, the potential of large and/or more frequent floods, may lead to increasing coastal retreat (migration). Flood defences can be upgraded to reduce damage, but studies show this will not be economically efficient for most of the global coastline (Lincke and Hinkel 2018) or will involve adaptation costs that are beyond the resources of those countries or communities affected.

Method. COACCH has used the DIVA model to look at major SLR in terms of the socio-tipping effects that it might have on coastal migration. This is a particular issue under high-end sea-level rise, and coastal migration is projected to rise strongly during 21st century, in the absence of adaptation. New modelling in the COACCH project estimates that globally, up to 100 million



Insurance penetration rates under status-quo insurance arrangements under RCP8.5-SSP3. Countries that maintain mandatory or semi-voluntary (e.g. uptake required for mortage) systems can be seen to have high fixed penetration rates.

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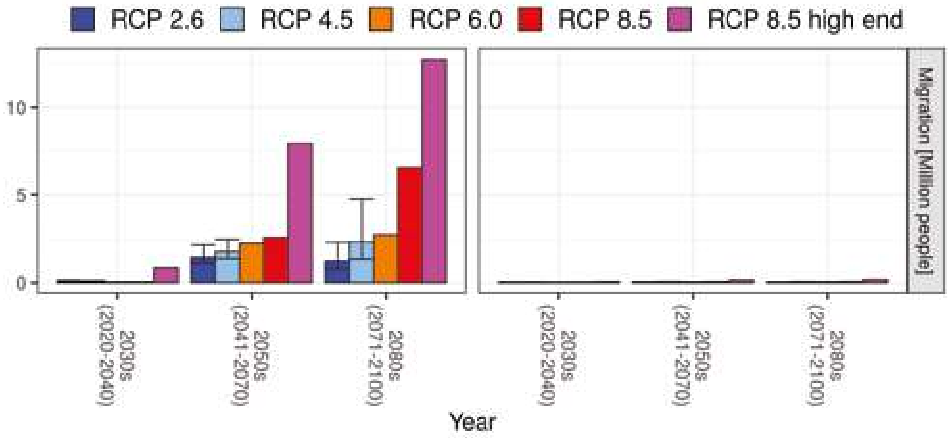

Estimated coastal migration, without (left) and with (right) adaptation.

people could be forced to migrate in the 2050s and up to another 100 million people in the 2080s, without adaptation. However, with adaptation, these would be significantly reduced, albeit still very large, with large migration from unprotected areas. The estimates are shown below, with no adaptation (left) and with adaptation (right).

This migration could trigger potential tipping points in the countries of origin if a certain percentage of the population leaves. There are 50 countries for which the total 21st century sea-level rise induced migration could be more than 10% of the current population under high-end sea-level rise (without further adaptation), though most of them are small island states. In Europe, Denmark is potentially most affected because of its high coastal population (note the Netherlands is not affected because protection standards are so high).

For the rest of the world, migration from one country could trigger a tipping point if the absolute number of migrants is very high. There are 33 countries for which the accumulated sea-level rise induced migration under high-end sea-level rise without further adaptation is more than one million people. While most of the coastal migration hot spots are located in south-eastAsia, the big European coastal countries (UK, France, Germany, Italy) also have significant coastal migration under these assumptions. It is noted that there are no high coastal migration flows from the Middle-East or Africa, with a few exceptions (Egypt because of the Nile delta, Nigeria because of the Niger delta).

Food Production Shocks

Introduction. Climate change and extreme weather events can lead to short-term variability and shocks to agricultural supply, impacting the entire food system, and posing threats to food security. This instability in the food system may spill over to other systems such as energy and water. Studies into the interdependent demand and supply relationships for these events requires a framework that can take stock of both the climate-induced deviations between expected and observed prices and yields, the impacts on the food commodity market, and different adaptation mechanisms that may serve as market stabilization policies, such as storage and different trade-liberalization mechanisms.

Method. As part of the work on socio-economic tipping points, COACCH has developed a non-stationary model for market stabilization policy design, called GLOBIOM-X. This aims to analyse the impact of climate-induced yield shocks on market stability and to assess whether market instability can be contained through the adaptation mechanisms of stockholding and trade liberalization. The model is based on the bio-economic land use model GLOBIOM. The new model runs in annual time steps and can address agricultural land use from the producers’ perspective based on expected prices. Stockholding is incorporated in the model by allowing producers to temporarily stock their products and consumers to take-up products from storage facilities.

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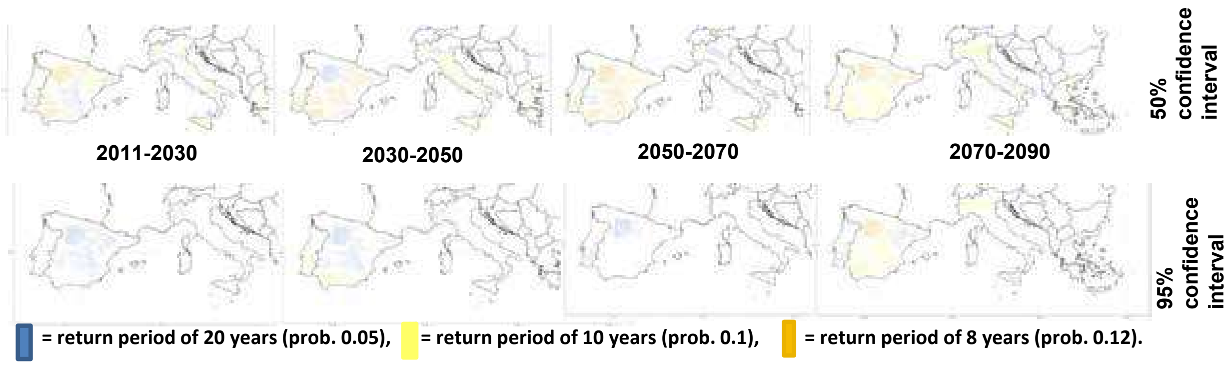
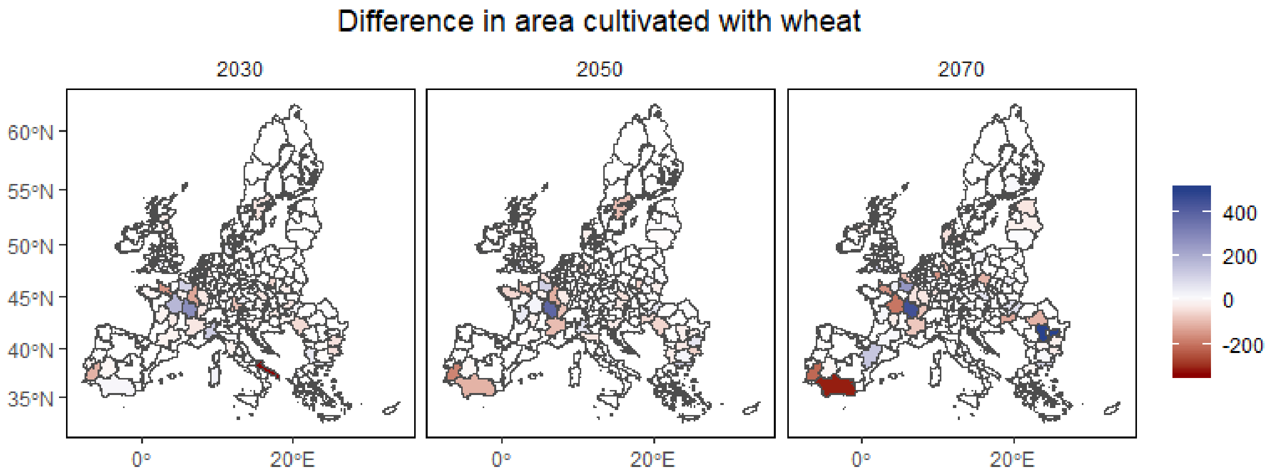


Climate models in combination with crop models show increased magnitude and frequency of climate-related yield shocks.



Area loss of cereals especially climaxes in Southern Spain

The tipping point nature of the analysis is described through a two-step procedure. The first step identifies the occurrence of extreme production lost due to yield shocks in Mediterranean Europe under different SSP/RCP combinations. The second step assesses how much land abandonment is triggered through an increased frequency and magnitude of change in yield losses.

Both the forecasted land abandonment and yield losses assessed by GLOBIOM-X are inputs to the macro-economic analysis. Through the macro-economic analysis, the CGE model COIN can produce impact on agricultural commodity prices.

Emerging findings

The early work on the COACCH project has identified that there are potentially important socio-economic tipping points, from subcontinental to local scale, that could affect Europe. These are more difficult to characterise than climate tipping points, and are often the result of complex socio-economic and climate drivers, as well as policy responses, but they could be significant in economic terms.

The early COACCH results have found 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 include very large-scale events, that would have major policy consequences at the European scale. Importantly, these events are currently omitted in policy discussions and further consideration of them is considered a priority.

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