CO-DESIGNING THE ASSESSMENT OF CLIMATE CHANGE COSTS

The Economic Cost of Climate Change in Europe

Climate and Socio-Economic Tipping Points

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

COACCH

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/

For further information on the project, contact Franceso Bosello (CMCC): francesco.bosello@cmcc.it

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Contributing authors and reviewers:
Paul Watkiss, Alistair Hunt, Michelle Watkiss, PWA. (Editors)
Jenny Troeltzsch, Katriona McGlade, Jack Tarpey, Ecologic Insitute
Daniel Lincke, Jochen Hinkel, Global Climate Forum.
Wouter Botzen, Onno Kuik, Predrag Ignjačević, Max Tesselaar, VU
Kees van Ginkel, Marjolijn Haasnoot, Ad Jeuken, Frederique de Groen, Ana Laura Costa, Deltares
Franceso Bosello, Shouro Dasgupta, Ramiro Parrado, Enrico Scoccimarro, Gabriele Standardi, CMCC
Karl Steininger, Gabriel Bachner, University of Graz
Esther Boere, IIASA

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Introduction

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

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

This document summarises the results from the COACCH project on the economic costs of climate change in Europe – it presents the results of the work on climate and socio-economic tipping points

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.

Socio-Economic Tipping Points

The COACCH project has developed a new concept of socio-economic tipping points (SETP) (Van Ginkel et al., 2020). 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, especially at a more local level. These changes may arise directly in Europe, but may also involve global events that subsequently spill-over into Europe.

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 socioeconomic 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.

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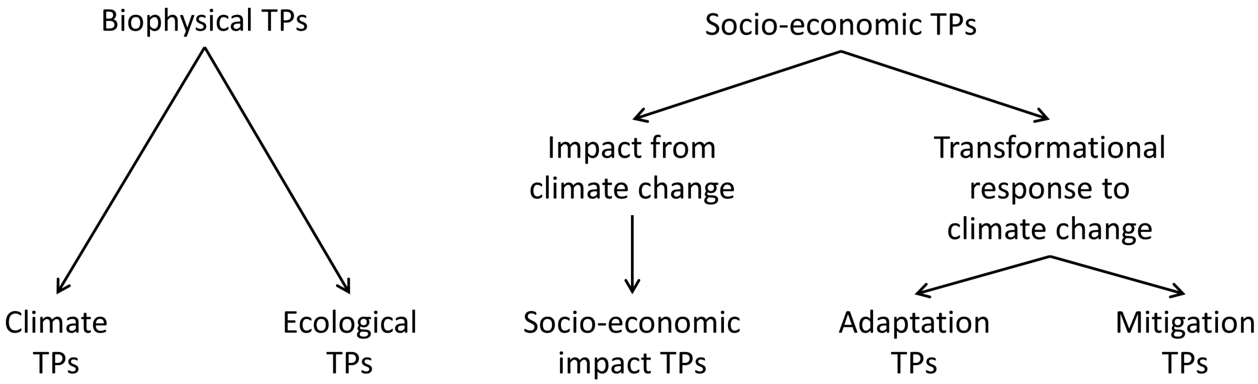

Typology of tipping point in different branches of literature.

Following a further prioritisation, a number of these are being assessed in detail in the project.

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

These are discussed in this policy brief.

Food Production Shocks

Climate change and extreme weather events can lead to short-term variability and shocks to agricultural supply. In turn, these can cascade along the entire food system, posing threats to food prices and even food security, and potentially spilling over to other systems. To assess these interdependencies requires analysis of demand and supply relationships, the effects of climate shocks on yields and prices, the impacts on food commodity markets. The different adaptation mechanisms that may act as market stabilization policies, such as storage or different trade mechanisms.

The COACCH project has investigated these issues, looking at the potential socio-economic tipping points associated with climate-induced yield shocks. The main tipping point explored is whether climate change may lead to such large crop losses that continued agricultural production is unviable, triggering rural abandonment and declines in the effective usage of land. This in turn leads to rural land-use change, changing trade patterns and potential macro-economic impacts.

The analysis has assessed the potential for yield shocks and price spikes, and the possible emergence of socio-economic tipping points. This involves a series of steps that involves General Circulation Models (GCMs) to assess future climate change, a process-based biophysical crop model to assess productivity, a bio-economic model and an international macro-economic model.

The analysis looked at extreme combinations of shocks on crop productivity, looking at the largest average yield losses (weighted by crop area) over a 30-year period around 2030 and 2050. Examples are shown over the page for a GCM output (for the RCP8.5 scenario for the two time periods). The largest yield shocks are in Southern and Eastern Europe.

The analysis then used an extended version of the GLOBIOM model, and combined the shocks above alongside yield changes (positive and negative) from gradual climate change, to look at potential tipping points. This also looked at different future socio-economic pathways (SSPs).

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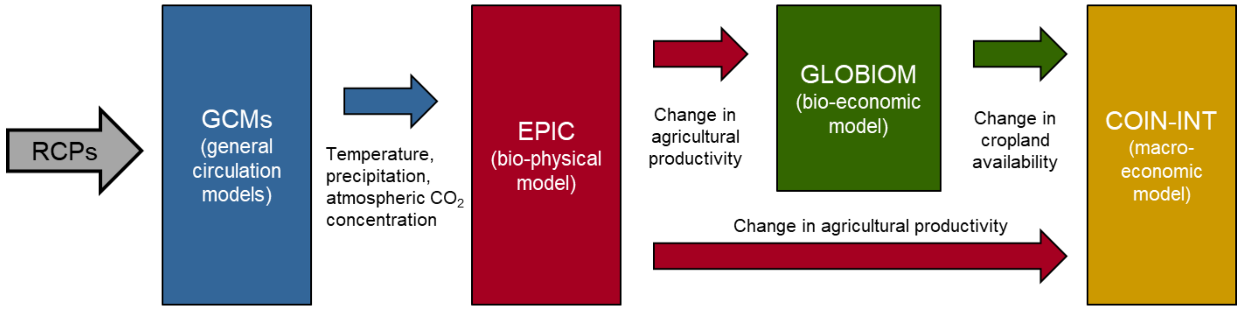
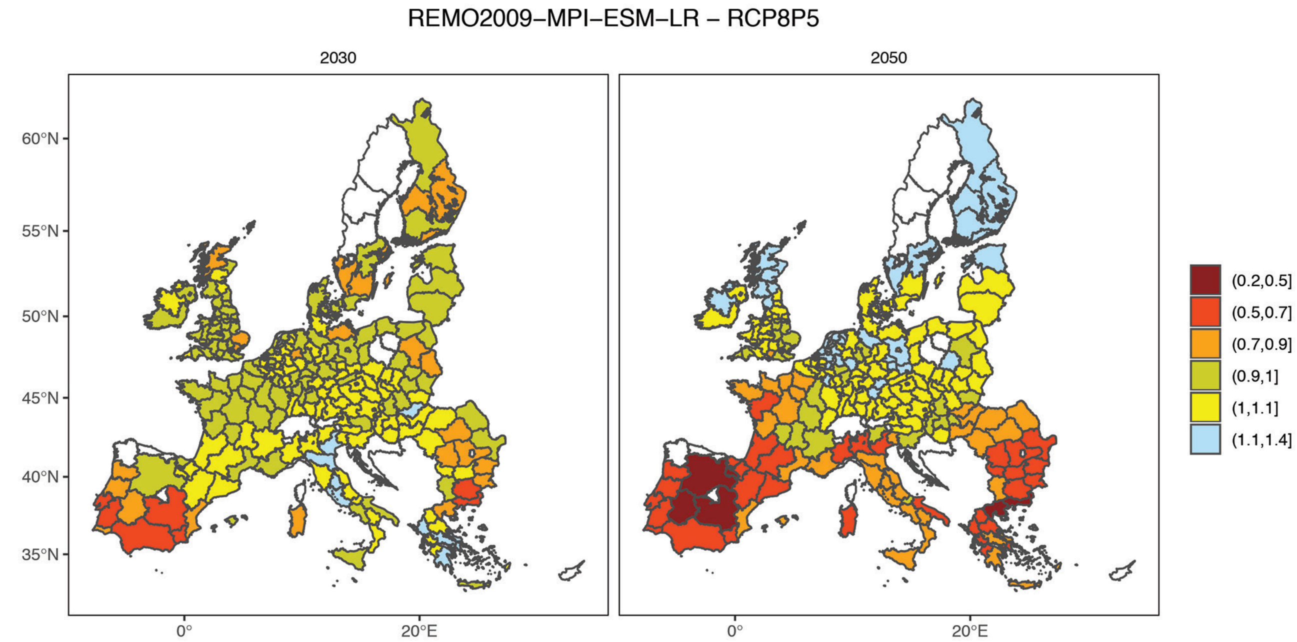
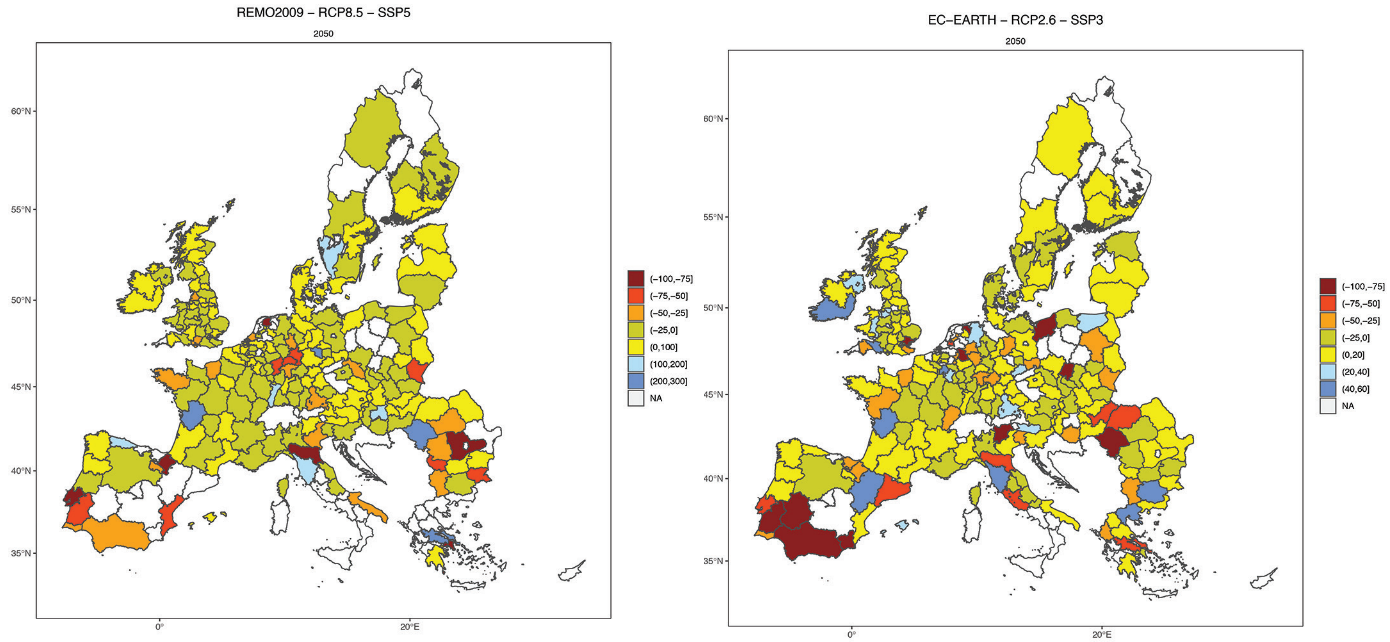




Average factor of yield changes across crops around the 2030 and 2050 time-slice for RCP8.5.



Relative change in cropland under selected scenarios compared to a no climate change scenario in 2050 for two model runs.

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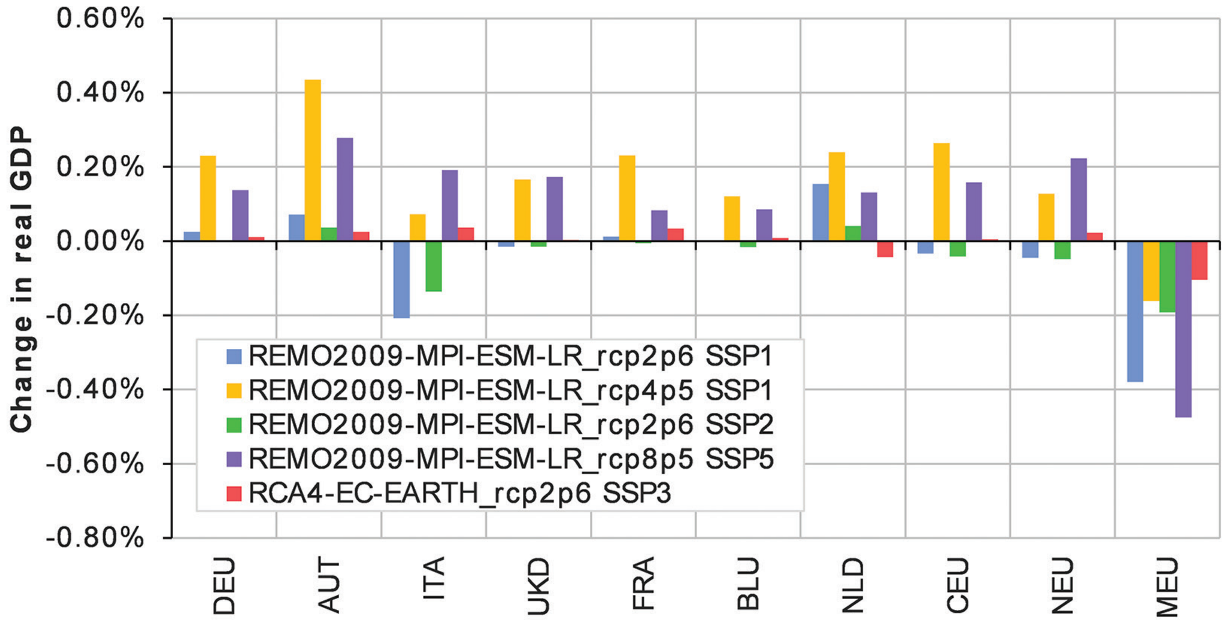

Changes in real GDP in 2050 due to the combined effect of changed cropland availability and yield changes, relative to a Baseline scenario without climate change. **(DEU: Germany; AUT: Austria; ITA: Italy; UKD: United Kingdom; FRA: France; BLU: Belgium and Luxemburg; NLD: Netherlands; CEU: Central Europe; NEU: Northern Europe; MEU: Mediterranean and South-Eastern Europe).**

The analysis found that under some future scenarios, large agricultural losses occur, which could trigger rural abandonment in some areas of Europe. In fact, cropland losses due to farmland abandonment could be as high as 7% at the European level. However, land abandonment patterns vary strongly across Europe – while there are potentially large impacts in the south, there may be positive economic effects for the rest of Europe. The middle and Southern parts of Europe, most notably in Southern Spain, Italy and Greece have the highest occurrence of the tipping point of rural abandonment (see figure below).

However, crop and food markets are highly globalized, and thus it is important to look at the macroeconomic effects of these changes. The final step was therefore to look at the macroeconomic implications of farmland abandonment, using the COIN-INT computable general equilibrium (CGE) model. The results from the analysis above for a selection of 'worst case scenarios' was fed into this model for the 2050s.

The analysis found that in the worst-case scenarios studied, food prices in Europe slightly increase. The combined effect of slow-onset yield changes and cropland losses leads to modest positive GDP effects in most European regions, except for the more vulnerable regions in the south, where there were negative effects of up to –0.5% lower GDP in 2050.

The macroeconomic analysis finds changes in cropland availability due to extreme events can offset the potential positive gains from higher yields, and in some cases, may dominate. This means positive effects might be strongly overestimated if only the slow-onset effects of climate change on agriculture are included.

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Migration

Migration can be voluntary or forced and can be internal, i.e. within a country, or external, i.e. from one country to another. There is some evidence that past climate extremes have been a stress multiplier for internal and external migration. Looking to the future, climate change could also be a potential contributory factor in migration, both as an adaptation strategy, but also leading to forced migration. The COACCH project has investigated potential socio-economic tipping points looking at two migration pathways.

Migration from Climate Extremes

There has been migration from Africa to Europe in recent decades due to a range of "push" and "pull" factors that contribute to the decision to move. There is also some evidence that climate extremes (e.g. droughts) are a threat multiplier (push factor) for migration, though actual causal pathways are complex. The academic literature provides a wide range on the potential number of migrants in response to increasing climate change, although these have been contentious.

Climate change-induced migration can be regarded as a tipping point, as at a certain point people make a decision, or are forced, to move to a different location. It can arise where it leads to a need to change livelihoods, as no other viable adaptation options exist. This migration, especially if large, can have potential impacts on the origin location (leaving higher dependency ratios, etc.) as well as impacts on the destination region (housing and service provision, etc.) although these can also be positive (labour skills).

COACCH has investigated potential effects using a migration relationship, based on climate data for the historical period, 1960–2000, for 39 African countries (from Marchiori et al. 2012). Major weather anomalies in agriculturally dependent countries are a factor in internal migration, and wages are affected by weather anomalies and incentivise populations to migrate internationally. This allows analysis of rural to urban migration, migration to other African countries, and migration to Europe.

The analysis in COACCH expands this and applies a gravity model to reflect the fact that migrants from North Africa are more likely to move to Europe (than other international regions). This is used to estimate current baseline numbers of migrants, and then look at future possible migration, based on the projected increase in drought events. This has been undertaken for different SSP-temperature pathway combinations.

The results find an increase in the annual number of migrants from Africa to Europe rising over time. However, the numbers increase significantly depending on the SSP-temperature pathway combination, in the 2050s and especially in the 2080s. This shows that climate and socio-economic change are both important.

The figure below shows the SSP2 socio-economic scenario for three different temperature pathways (1.5°C, 2°C, and 3°C) and SSP3 for the 3°C temperature pathway.

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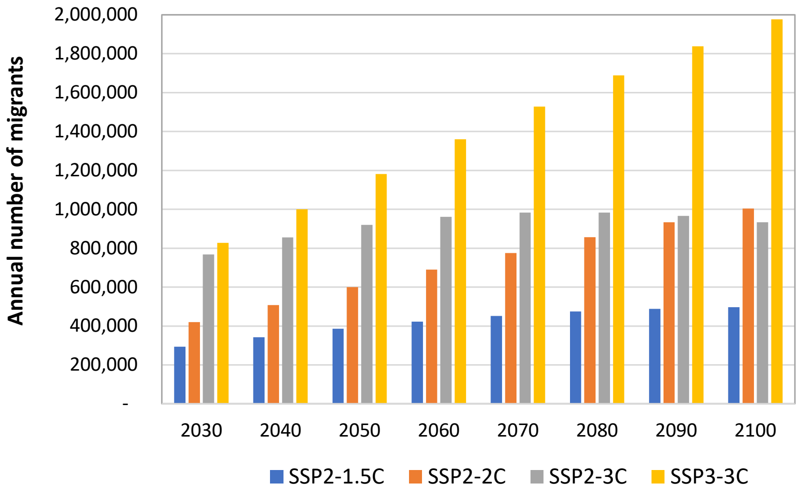

Africa to Europe Annual Migrant numbers associated with projected increases in major weather (drought) extremes

For the SSP2 scenario, the number of migrants increases markedly with warmer pathways, with an estimated 0.4 to 0.9 million migrants / year by the 2050s, for the 1.5 and 3°C pathways respectively. However, the SSP3 scenario leads to an estimated 1.1 million migrants / year for the same time period (for 3°C) due to the influence of high population growth in developing countries. These numbers continue to rise over the rest of century, and could reach 1 to 2 million/year, depending on the warming scenario.

It should be noted that these modelling results are based on historical data on migration flows, and will be affected by many other factors, notably on access restrictions. In practice, migration will be driven by complex and multi-faceted social, cultural and economic factors.

Overall, the analysis finds that the numbers of migrants moving from African regions to Europe could rise over the course of the 21st century, triggered by localised climate induced socio-economic tipping points. The increases are driven by a combination of population growth and climate change, although the analysis indicates that it is the climate change driver that is responsible for the majority of the rise.

Sea-level rise and migration

Sea-level rise (SLR) is a major threat for coastal zones globally. The potential of large and/or more frequent coastal floods may lead to increasing coastal threats, including retreat, which in turn may increase migration, within a country or internationally.

While flood defences can be upgraded to reduce damage, studies show this will not be economically efficient for all of the global coastline (Lincke and Hinkel 2018) or may involve adaptation costs that are beyond the resources of countries or communities affected. As a result, coastal protection for all inhabited coastline world-wide is unlikely, and this may involve major tipping points for countries or areas that are particularly vulnerable.

The COACCH project has used the DIVA model to investigate these potential risks. It has assessed extreme sea-level rise scenarios this century and the consequences in terms of the socio-economic tipping point of coastal migration.

For high-end sea-level rise, modelled as an average sea-level rise of 170 cm by 2100, coastal migration is projected to rise strongly if there is no further adaptation. This occurs when coastal areas are permanently inundated or if they are flooded very frequently by storm surges (i.e. they are affected by the 1-in-1-year event).

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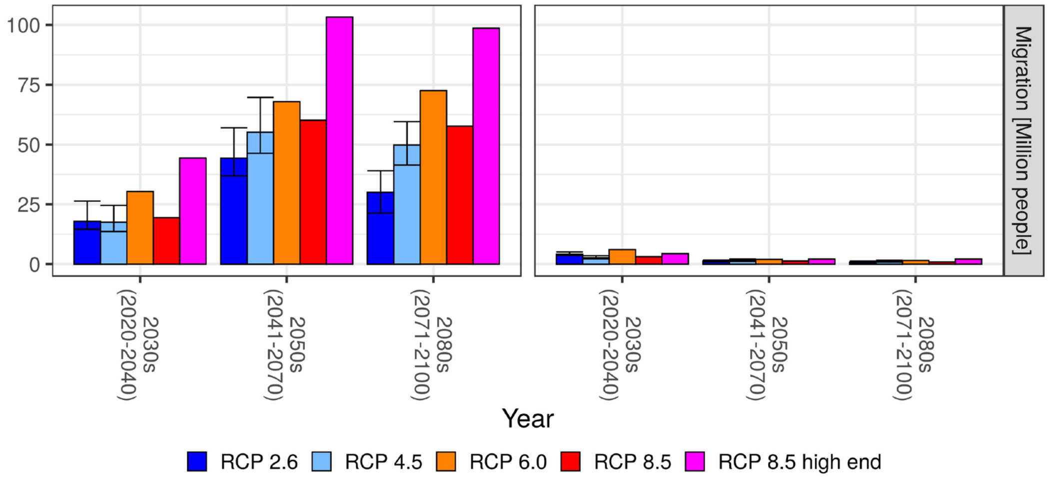

Estimated coastal migration, without (left) and with (right) adaptation.

The modelling in the COACCH project estimates that globally, up to 100 million people could be forced to migrate in the 2050s and an additional 100 million people in the 2080s, without adaptation, under these extreme scenarios. This migration could, in turn, trigger potential socio-economic tipping points in the countries of origin, if a certain percentage of the population leaves. However, with adaptation, these would be significantly reduced down to approximately 5 million people even in the 2080s. These estimates are shown above, with no adaptation (right) and with adaptation (left).

The COACCH analysis has estimated the proportion (%) of the population of a country at risk of migration from extreme sea-level rise. The results suggest that there are 50 countries worldwide, where sea-level rise induced migration could lead to more than 10% of the current population migrating (under a high-end sea-level rise without further adaptation).

There are also some countries that are particularly badly affected, such as small island states. Indeed, in many of these countries, a much higher proportion of the population is likely to migrate. For example, there are seven highly vulnerable Pacific islands where 50% or more of the population might be forced to migrate, and globally, there are estimated to be over twenty countries where 25% or more of the population might be forced to migrate (in the absence of adaptation).

In Europe, Denmark is potentially the most affected country, because of its high coastal population. While the potential risks could be large for the Netherlands, it is not as affected because the protection standards are so high – even under high-end sea-level rise, the existing protection would still be sufficient this century, although overtopping would occur more frequently (see also the adaptation to SLR tipping point).

However, migration from one country to another could also trigger a tipping point if the absolute number of migrants is very high. The COACCH analysis estimates that there are 33 countries for which the accumulated sea-level rise induced migration is more than one million people (for high-end sea-level rise without further adaptation). While most of these coastal migration hot spots are located in South- and South-East Asia, the big European coastal countries (UK, France, Germany, Italy) also have significant coastal migration under these assumptions. Interestingly, there are not very high coastal migration flows from the Middle-East and Africa, with a few exceptions (the two main ones being Egypt, because of the Nile delta, and Nigeria, because of the Niger delta).

The COACCH project has also looked at the macro-economic effects of migration, using Computable General Equilibrium Models. This has looked at two issues. First, the costs of leaving assets behind due to coastal retreat, and second, the costs of moving (mobile) capital inland. These were considered alongside other macro-economic impacts of sea level rise, e.g. from the loss of capital and changes in productive capital. Results are given in the macro-economic section of the policy brief.

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Energy supply systems and wildfires

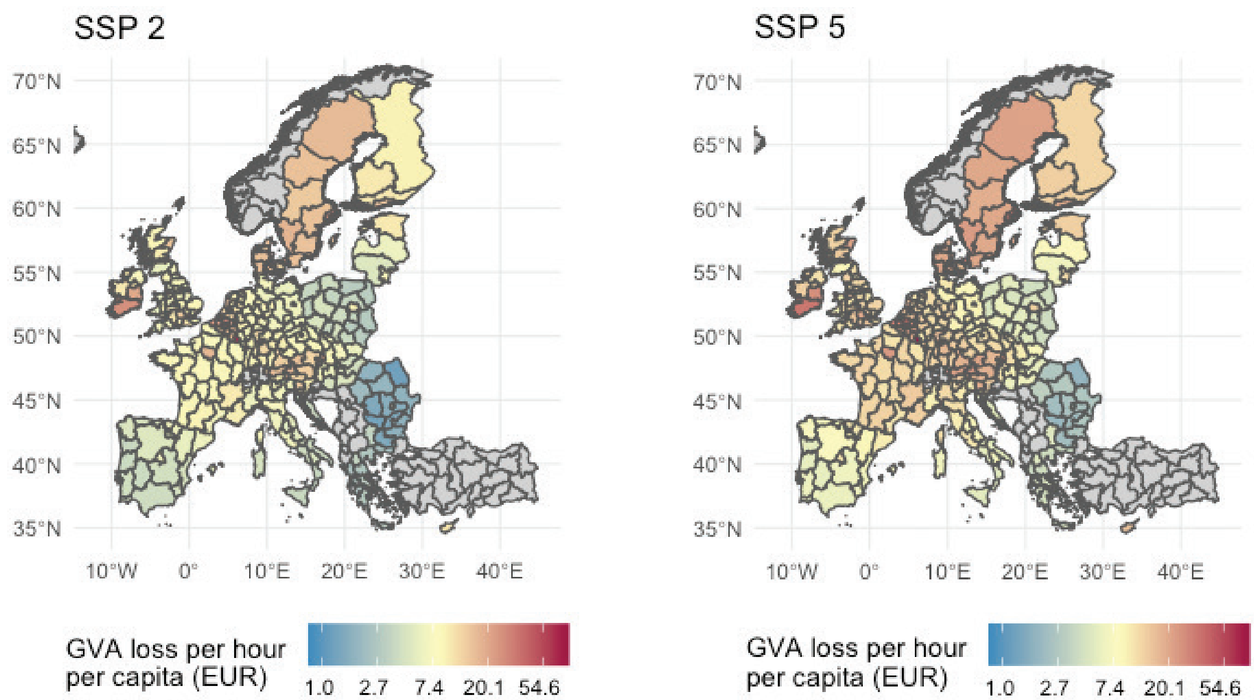
Climate change is likely to be an important risk for the electricity system. A number of potential impacts have been identified in the past, which include the potential impacts of extreme events. These include the effects of heat-waves and the lack of cooling water in thermal generation plants, as well as increasing air conditioning and electricity demand peaks during very hot summers.

However, there is a further extreme risk that has not been well studied: the effect of wildfires on electricity outages. These represent a new type of electricity system effect, i.e. a socio-economic tipping point where wildfires could lead to major electricity black-outs from impacts on electricity transmission and distribution networks.

The evidence of these risks has emerged following two large-scale events in 2019. The incidence of wildfires in Australia and California resulted in several major, lengthy blackouts and demonstrated the potential for this hazard to disrupt electricity supply. Even in the absence of an active fire, lessons from California demonstrate that risk aversion can lead to actions which interrupt electricity supply due to planned fire-prevention power outages (Johnson 2019).

The COACCH project has investigated these potential events using a risk-based approach to assess the possible future impacts of wildfire-caused blackouts in EU countries. This builds on other work in the COACCH project (Scoccimarro et al. (2020)) which found that much of Europe could experience a major increase in wildfire probability by the end of the century, including areas which until now have not experienced such threats. The cause of these increases is due to an exponential increase in the dryness of wood with higher temperatures and rising drought stress, increasing fuel loads for wildland fires.

The project has estimated the changes in extreme drought and the increase in Forest Drought Stress Index (Williams et al., 2013) for the rest of the century for different future scenarios (RCP2.6, 4.5 and 8.5) to estimate the potential wildfire risk. It has then estimated the potential exposure of the electricity system in terms of value added at risk (VAaR), taking account of future socio-economic change (using the SSPs).



Potential GVA loss per hour due to electricity blackouts for 2050 economies under SSP2 (middle of the road) and SSP5 (fossil fueled development), for the 'current' electrification scenario.

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The project has looked at the Gross Value Added (GVA) lost for a blackout event, based on the current and future socio-economic projections. An example is shown on the previous page for SSP1 and SSP2 (for RCP8.5). This shows that the GVA for a blackout event varies with the country and the region, but that it also varies with the socio-economic development pathways. The study has then used macroeconomic modelling to quantify VAaR in terms of the lost GVA per hour of blackout per capita.

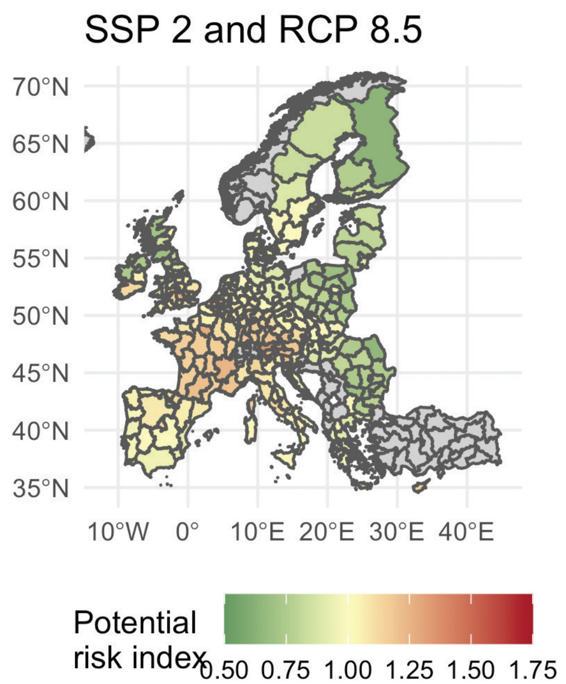
The results (shown in the figure) indicate that across Europe, electricity system VAaR is projected to increase strongly under three of four SSP projections (the exception being SSP3), due to a marked increase in manufacturing sector activity. The mean values in GVA loss per hour are between 6 and 13 EUR / capita, but there is a high variance (with maximum values ranging between 45 and 96 EUR / capita).

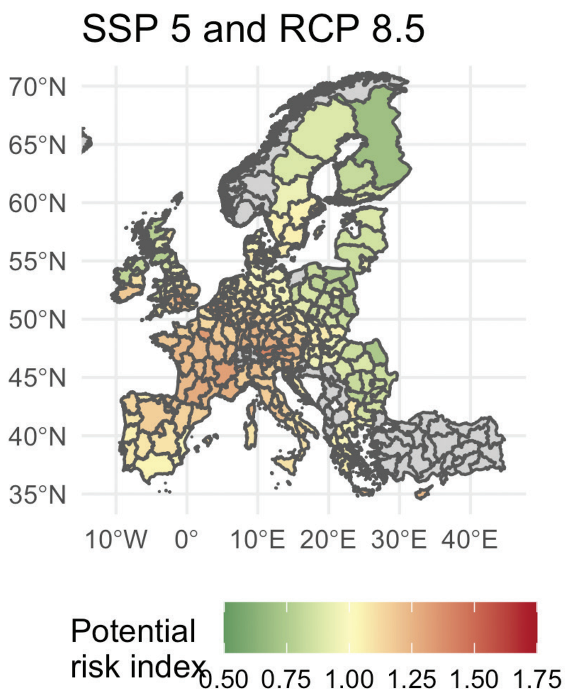
The project has also developed a new index of potential risk for wildfire risks from blackouts, to help identify areas most at risk. This combines drought hazard and GVA loss into an indicator. Normalizing and combining these two indicators produces an index which identifies areas likely to have high future exposure and increasing risk. These are shown below.

This identifies high risks in areas of the EU typically known to be vulnerable to fires, e.g. the Iberian Peninsula and Mediterranean region. However, it also identifies areas that may see increased risk in the future, notably in central Europe and northern latitudes. At the same time, other areas of Europe, notably Eastern Europe, are identified as having lower potential risk.

Looking forward, the vulnerability of the electricity sector to wildfire shocks will depend on electricity sector development. This includes the future structure and composition of the supply and transmission network – in terms of grid size, complexity and interconnections – as well as the generation plants. The latter will be particularly affected depending on future investment and energy policy, and the major shifts that may occur from the transition to net zero. Interestingly, some of the threat of major wildfires in Europe in the electricity sector might be avoided by investing in renewable energy.

Overall, the findings of the work highlight that for electricity system decision-makers in Europe, the new threat of major wildfires in Europe is an important risk to consider.





Potential future risk index (derived from hazard + exposure indicators) for RCP 8.5 model runs, for SSPs 2 and 5. Higher values indicate higher risk.

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Transport network disruptions due to river flooding

The risks of climate change for the transport sector primarily arise from extreme events, such as flooding. As well as direct damage costs, these lead to economic costs from passenger and freight transport disruption (travel time) and accidents, and can also have indirect effects due to impacts on the supply of goods and services.

The COACCH project has investigated the potential tipping points associated with these events, looking at system-wide flood extremes. The socio-economic tipping point is associated with a large loss of road network functionality due to combinations of river flood events. The analysis has looked at three different scales.

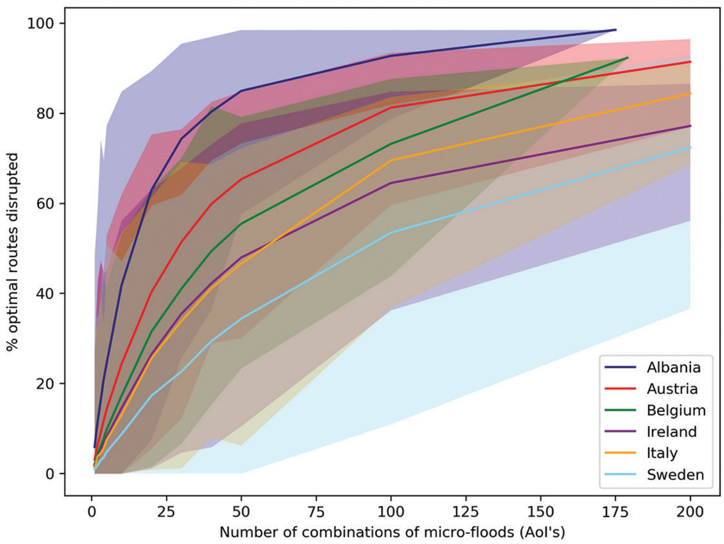
First, the study has assessed the sensitivity (robustness) of national road networks in Europe to major river floods. The results for a number of countries are shown in the figure, which plots the number of routes disrupted from combinations of floods.

This finds some countries – such as Albania and Austria – have much greater risk profiles, i.e. a large number of routes can be disrupted from a relatively small number of flood combinations. This indicates that countries like Albania and Austria are more likely to see SETPs than countries like Sweden and Ireland.

Another finding is the identification of flood hotspots in national road networks. These are shown by the shaded areas in the figure: sometimes only a few unfavorable micro-floods can disrupt a large area of the network. Such points in the road network may need flood-proofing by the national road operator.

Second, the COACCH project has focused down on a national case study, looking at the potential economic costs of flood hotspot events in Austria. This has looked at combinations of minor flood events, each with a return period of a 1:100 year event. This found that climate change may increase the impact of the combinations of these minor floods – indeed, the economic costs of the most disruptive scenario was estimated at 100 million euro. The impacts are dominated by travel time losses and cancelled trips for passenger cars (90%) with the remainder for freight.

Finally, the study looked at an individual (real) company – a vehicle manufacturer – and assessed if major river floods could significantly disrupt the supply of just-in-time input products to the factory. The analysis found that local



Sensitivity of road network performance to river flooding. Bold line = average degree of disruption from a combination of micro-floods. Shaded area = bandwidth of disruption from randomly sampled micro-floods – the outliers indicate hotspot events.

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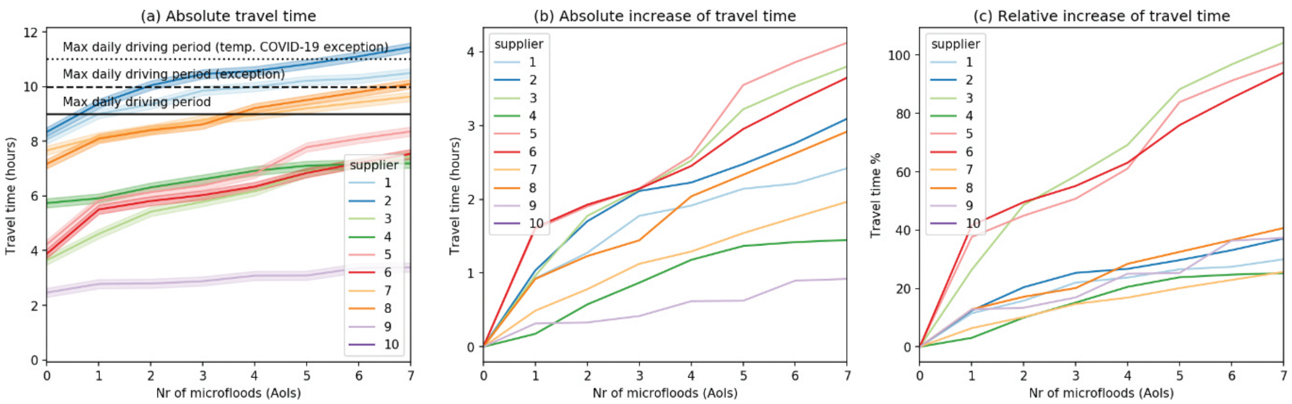
tipping points are more likely to be caused by a flood at the manufacturing factory itself, or a flood at one of the suppliers to the factory, rather than a flood to the road network.

This is because travel time delays from floods tend to increase in a rather linear fashion, even for combinations of floods (see figure below), indicating that in this case, the road network has a high degree of resilience. However, there were two exceptions. The first concerns the legal thresholds limiting the time that a truck driver can drive: if this is exceeded, the delay times increase sharply. The second is the time window at the factory and staff availability. If the time window is missed, this can tip over into a full day delay of stock deliveries. This creates problems because of the very small stocks that are kept, and is further multiplied as problems feedback to the supplier for timely return-transport of containers. This highlights that just-in-time production is very sensitive to cascading effects.



Increase in travel times for the worst-case flood disruptions for 10 suppliers providing inputs to a vehicle manufacturer, excluding congestion. Panel a: black lines indicate max daily travel times according to Regulation (EC) No 561/2006, and exceptions.

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Adaptation to extreme sea level rise

Following on from the case study above, COACCH has explored potential socio-economic tipping points and possible adaptation responses to extreme SLR. This has looked at a stylized model of a coastal city with a highly engineered coastal defense, loosely corresponding (but **not equal**) to the City of Rotterdam.

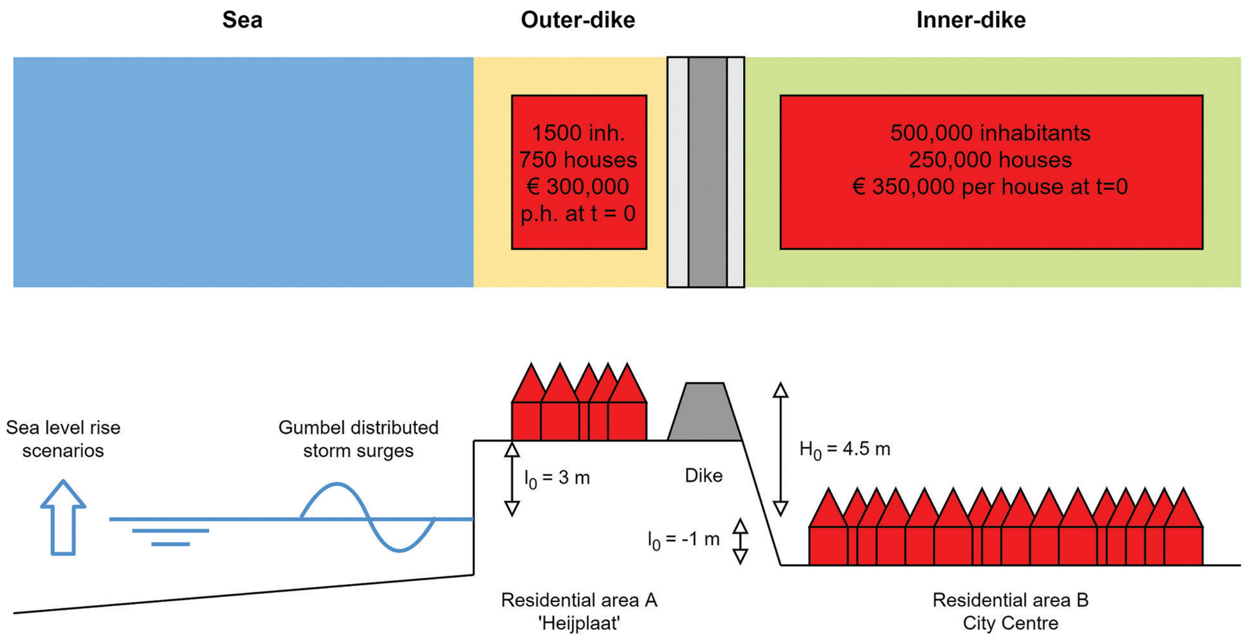
COACCH has run multiple simulations (> 300,000) to explore if a major socio-economic tipping point could occur from rapidly accelerating sea level rise. The SETP is defined as a sudden devaluation of the real estate price in the city before 2200. The figure below shows a possible future where the outer dike area is affected by such SETPs.

Five factors influence whether a SETP will occur, and when it occurs, but these are uncertain. First, what will be the rate and magnitude of sea level rise till 2300? Second, how will the real estate market respond to the changes in flood risk: will it mainly respond to the rational flood risk management or will it be dominated by public sentiment and flood risk perception? Third, how will the city adapt the dike heights to possible sea level rise (for the study, four choices are considered based on i) reactive ii) public perception of risks iii) economic rationality and iv) maintenance of a 1 in 10,000 year protection level. Fourth, how fast can dike heightening measures be implemented? Finally, how will the 'random' sequence of yearly storm surge events unfold?

Nine possible SLR scenarios (1-9) have been considered, three of which (1-3) only occur if there is major and rapid ice sheet contribution (see over the page).

The risk of tipping points is shown below. Different sea level scenarios and possible real estate market responses are captured on the Y-axis. The uncertainty on the city response and the implementation time is captured on the X-axis. The uncertainty over storm surge events is captured in the colour of each grid cell: by giving the likelihood of SETPs over 500 possible storm surge scenarios.

The results over the page show a socio-economic tipping point (yellow areas) could occur in more extreme SLR scenarios (1-3) but this is influenced by the adaptation decision framework. Even in extreme SLR scenarios, SETPs can be avoided (but this would also be expensive) by proactive flood risk management, in which very high levels



The stylized model with an outer dike area A and an inner dike area B.

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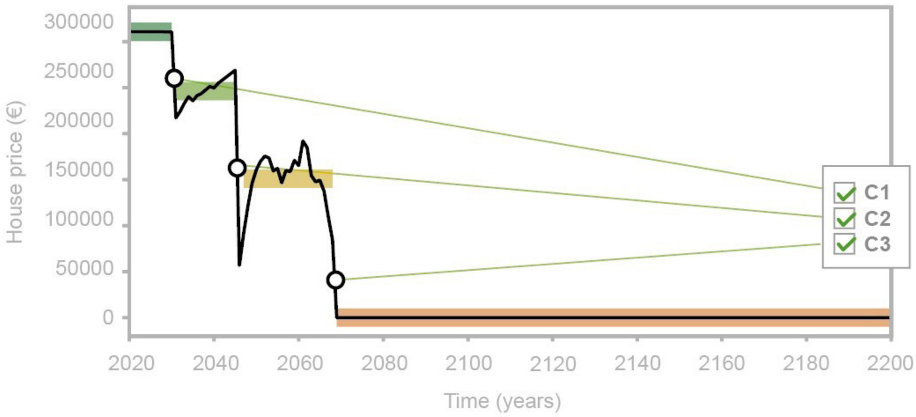
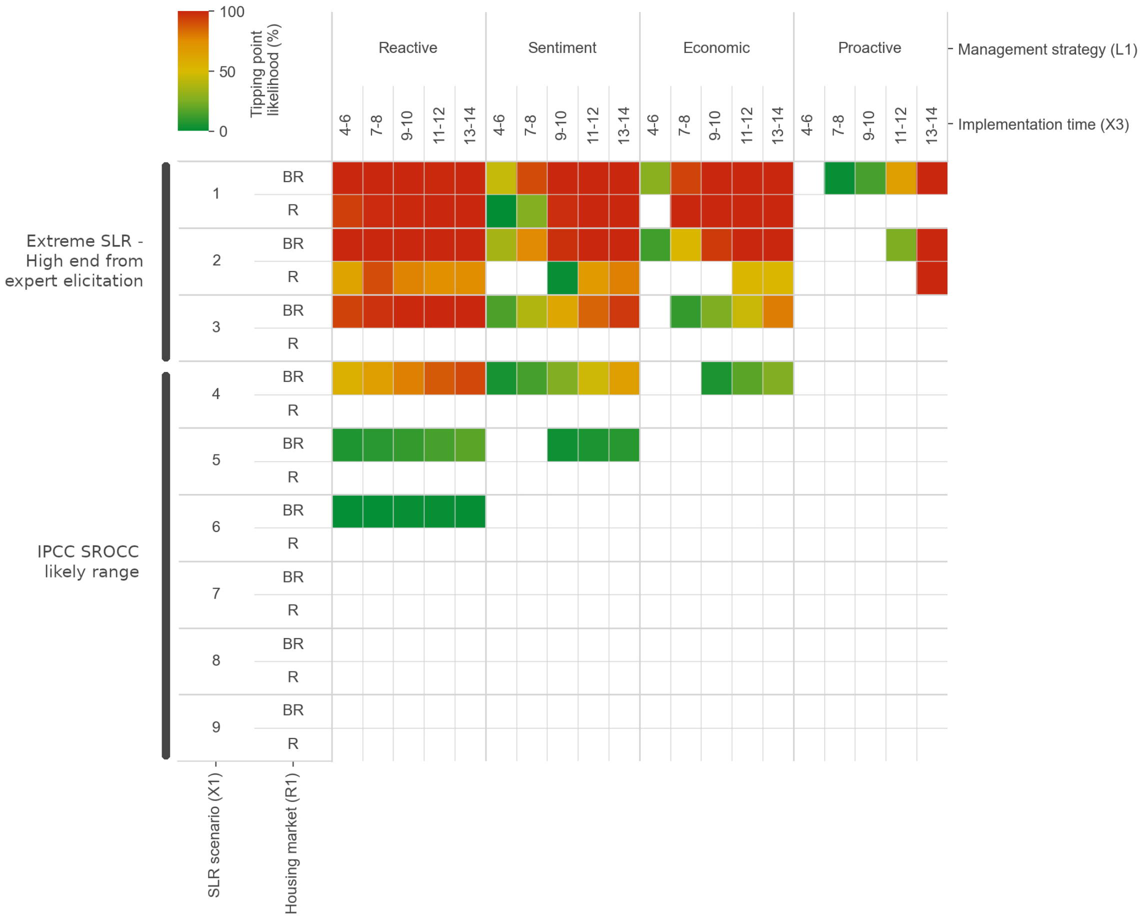
of risk protection are maintained and dikes are heightened with very short implementation times.

With a reactive approach and extreme sea level rise, SETPs are very likely to occur. In the most likely sea level rise scenarios (IPCC ‘likely range’), indicated by SLR 4-9, SETPs only occur when sentiment (perceived rather than actual flood risk) dominates prices on the housing market. In these likely sea level rise scenarios SETPs can be completely avoided with proactive flood risk management.



A possible future of the city, with two SETPs (house price collapses) in the outerdike area A.



Likelihood of SETPs (abrupt devaluation of real estate) before 2200 in the embanked city center (Residential Area B) under multiple possible futures

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Flood insurance affordability in Europe

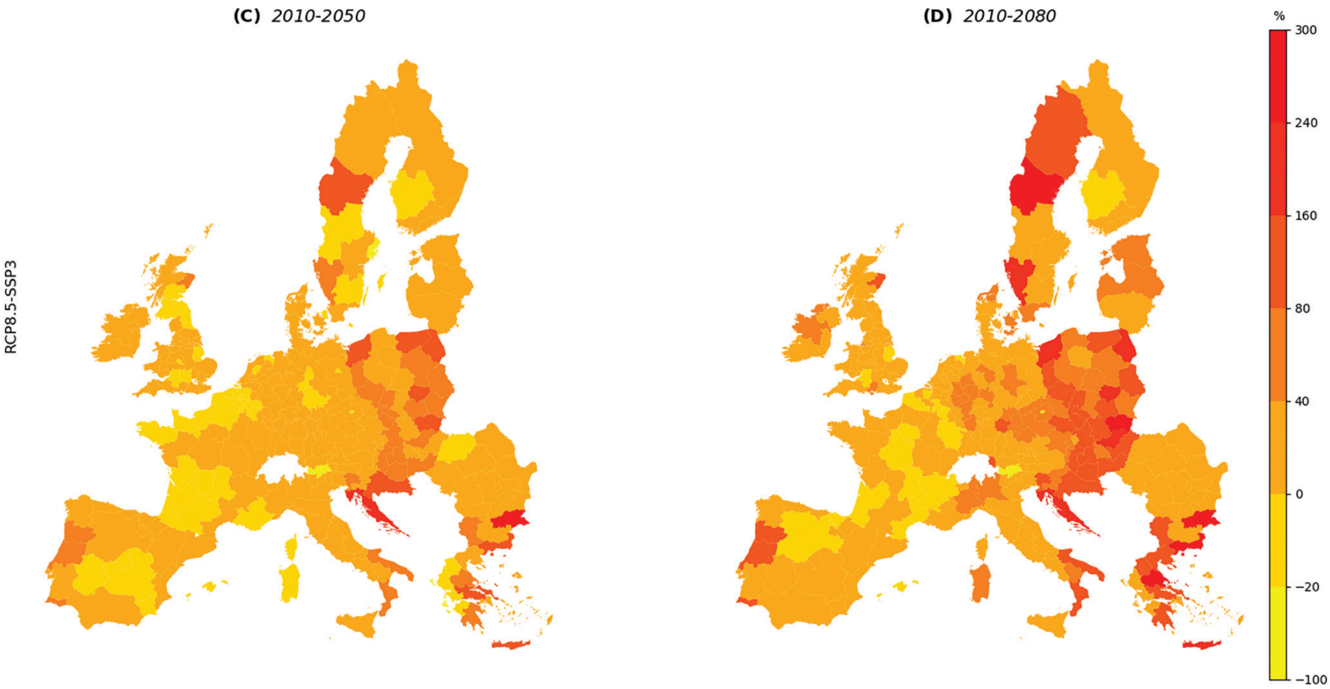
Flood insurance coverage can enhance the financial resilience of households to flood risks. However, climate change is projected to complicate the functioning of national insurance systems. This is because increasing flood risks could lead to rising insurance premiums, potentially making insurance coverage unaffordable for low-income households. These higher premiums could reduce the demand for insurance coverage, and decrease the ability of insurance to provide financial protection against destructive floods.

The COACCH project has investigated these issues. It has examined whether a tipping-point could occur in Europe for flood insurance systems, due to the impact of rising future flood risks from climate change and socio-economic change. This uses an adapted version of the "Dynamic Integrated Flood Insurance" (DIFI) model (Tesselaar et al., 2020), which integrates flood risk simulations with an insurance sector and a consumer behaviour model.

The results find these insurance tipping points increase over the 21st century, with rising unaffordability and declining demand for flood insurance, especially towards 2080. This happens under all climate scenarios, but it is especially important under a high-warming scenario. This in turn leads to socioeconomic tipping-points in several regions of Europe, where insurance uptake almost disappears.

The patterns of unaffordability – the percentage of the population in high-risk areas that cannot afford the flood insurance premium – from increasing floods are shown below. High increases in unaffordability are found in Eastern European countries, as well as regions in Sweden, Portugal and Italy.

However, while flood risks are a key driver, an important finding is that the impact of climate change on the functioning of flood insurance systems varies because insurance arrangements currently differ between countries. Certain insurance systems are better at coping with increasing flood risk, e.g. the issue of declining demand for coverage is limited to countries where insurance uptake is optional.



The percentage change in unaffordability under status-quo insurance arrangements for households in high-risk areas under RCP8.5-SSP5, for the periods 2010–2050 (left) and 2010–2080 (right).

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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-subsidised. This is because premiums can rise rapidly in flood-prone regions when they are risk-reflective.

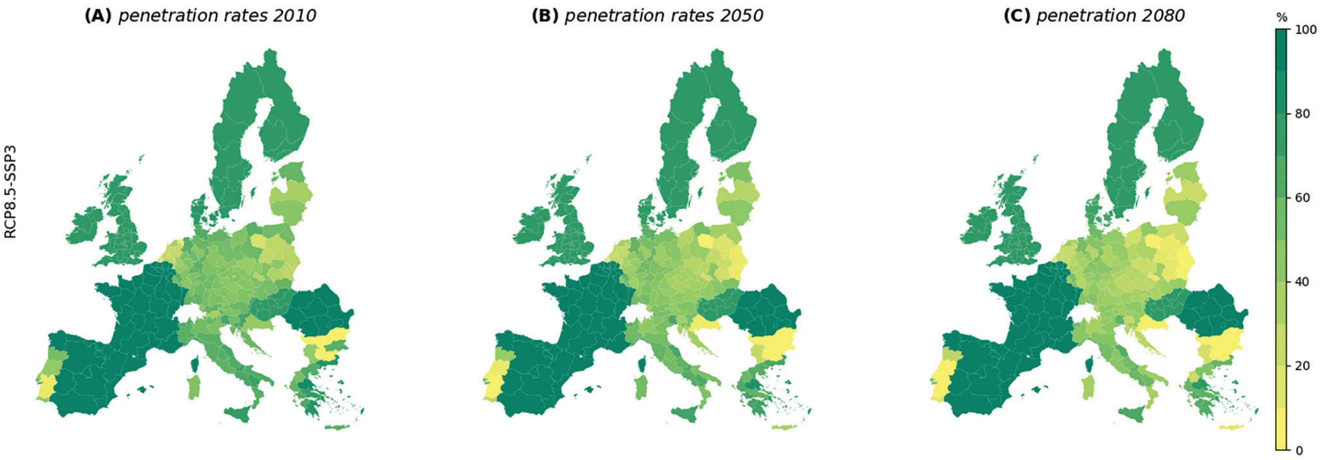
The figure below shows the projected development of flood insurance demand for three time-steps assuming current insurance systems. Countries where insurance purchase requirements are maintained have fixed penetration rates that do not change over time. In contrast, for countries where insurance is voluntary, the demand for insurance decreases over time as a result of increasing unaffordability, or premiums exceeding the risk perception of individuals. The largest decline in insurance penetration is expected in Eastern European regions as well as Portugal. In some regions, insurance uptake is projected to decline almost completely by the 2080s.

When these affordability tipping points occur, insurance uptake diminishes, and the formal insurance system is likely to be replaced by informal insurance, where households either rely on private savings (though these may be insufficient) or from ad hoc government disaster relief (with implications for the public finances).

The economic consequences of these failures (tipping points) could be very large. Unlike annual flood damages, the failure of insurance would damage asset values (i.e. property prices) and slow down the recovery speed of communities affected by flooding. The results have major implications 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.

Further analysis shows that some of these effects could be mitigated by introducing reforms of flood insurance arrangements. For example, declining insurance demand can be mitigated by implementing policy reforms such as insurance purchase requirements or introducing a degree of risk-sharing amongst risk groups. However, a drawback of mandatory insurance is that it limits consumer freedom, whereas a higher degree of risk-sharing may reduce the incentive for policyholders to mitigate flood risk.

Overall, this analysis shows that increased flood risk unaffordability could be a major socio-economic tipping point for Europe and warrants further policy consideration. The work has now been published (Tesselaar et al., 2020).



Flood insurance penetration rates under current insurance arrangements for households in high-risk areas under RCP8.5-SSP5 for 2010 (left) 2050 (middle) and 2080 (right).

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Macro-economic tipping points

A further analysis of climate-induced shocks has been conducted with the ICES macroeconomic model, a computable general equilibrium model which can provide output at the NUTS2 level. This has assessed the potential for large economic shocks from climate change (socio-economic tipping points), using the threshold level of a loss of 5% of regional Gross Regional Product (GRP).

The model has taken the sector results from COACCH (on the effects of climate change on energy supply, energy demand, labour productivity, agriculture, forestry, fisheries, transport, sea-level rise, and riverine floods) and input these into a macro-economic framework. This allows consideration of market adjustments, as well as effects on the quantity and quality of production factors. Further details on the modelling analysis are presented in the separate COACCH macroeconomic policy brief.

This analysis has looked at different RCPs to capture various warming scenarios, but also considered future socio-economic scenarios (SSPs). It also considered climate model uncertainty through the use of a low, medium and high sensitivity analysis.

The results are summarised in the table and figure below. The results find that before 2050, all losses in European regions are smaller than 5% of regional GDP. In the 2050s, however, it is possible that high warming scenarios (RCP6.0 and RCP8.5) could lead to such tipping point shocks in a handful of regions.

The pattern in the 2070s varies with the scenario. For the high warming runs (RCP6.0 and RCP8.5), major economic tipping points (losses > 5% of gross regional product) are common with around 20% of regions projected to experience such impacts. The socio-economic scenario also has an influence (the SSP) because higher growth leads to a higher exposure of capital stock and assets to climate change. In contrast, for low and medium climate-change scenarios (RCP2.6 and 4.5) the majority of regions do not exceed the tipping point in the 2070s. This highlights the importance of global mitigation in reducing localised economic tipping points and high losses.

The analysis also finds that greater economic "flexibility", i.e. larger substitutability across energy and non-energy inputs, or between domestic and imported commodities, tends to reduce the number of regions reaching the tipping point. This occurs even though more assets could be at risk, and compared with lower climate scenarios that have more "economically rigid" scenarios. This indicates that economic adaptive capacity and flexibility will be important to help reduce the risks of climate shocks.

Number of EU regions with a GRP loss larger or equal to 5%

	2050						**2070**					
	Low Impact		Medium Impact		High Impact		low Impact		Medium Impact		High Impact	
Inter-regional invest. Mobility	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
Scenario												
SSP1-RCP2.6	-	-	-	2	2	26	1	3	1	7	4	105
SSP1-RCP4.5	-	-	-	4	1	23	1	8	2	13	4	105
SSP2-RCP2.6	-	-	-	1	2	16	1	4	1	7	4	98
SSP2-RCP4.5	-	-	-	2	1	16	1	9	3	20	5	114
SSP2-RCP6.0	-	3	-	6	2	15	3	34	5	71	8	120
SSP3-RCP2.6	-	-	-	-	2	12	1	5	2	13	5	104
SSP3-RCP4.5	-	-	-	-	1	13	2	12	3	36	14	130
SSP5-RCP4.5	-	1	-	5	1	33	1	8	1	24	5	111
SSP5-RCP8.5	-	5	-	9	3	55	3	20	4	36	14	125

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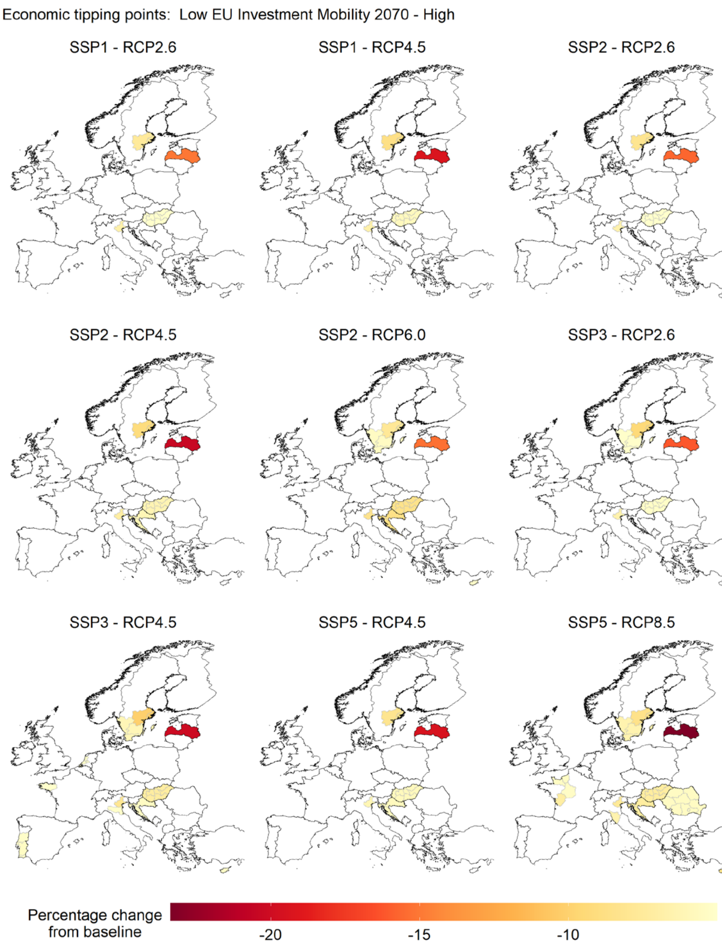

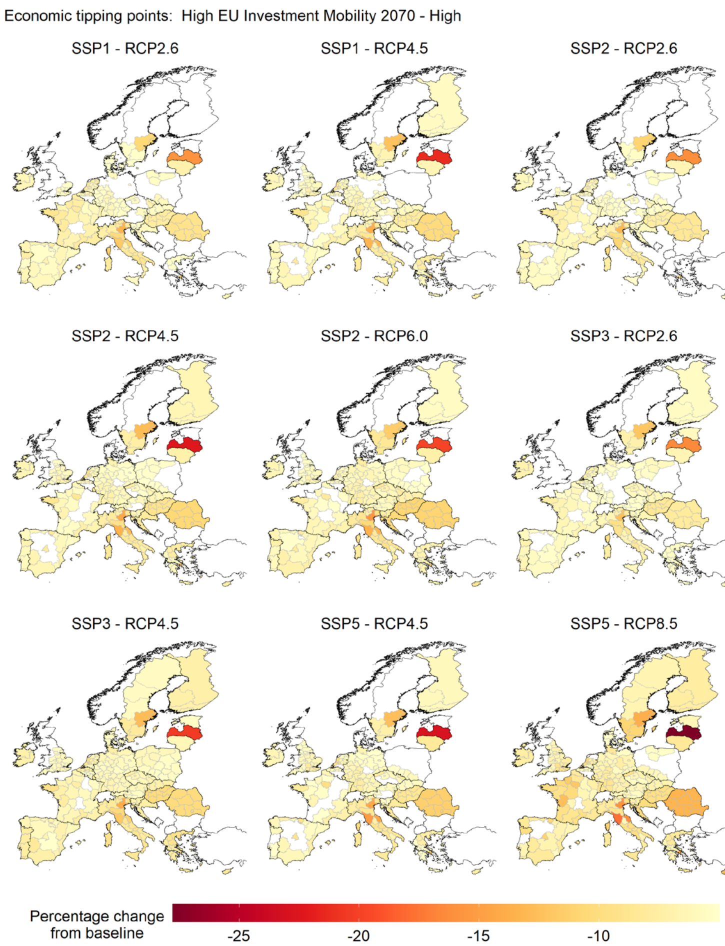

EU regions highlighting a loss larger than 5% of regional GDP under the different combination of SSP-RCPs, high impact case, year 2070 (low capital mobility top, high capital mobility bottom).

Key: scenarios for figures above (by position) are shown in table below.

SSP1 RCP2.6	SSP1 RCP4.5	SSP2 RCP2.6
SSP2 RCP4.5	SSP2 RCP6.	SSP3 RCP2.6
SSP3 RCP4.5	SSP5 RCP4.	SSP5 RCP8.5

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Time of Emergence of Impacts (ToEI)

Future climate change will lead to large economic impacts, but it can often be difficult to convey to decision-makers how important these future impacts could be. The COACCH project has developed a novel measure to do this. The time of emergence of impacts (ToEI) is a measure of the severity of climate change (Ignjačević et al., 2020). Unlike the use of monetary metrics (Euro) or % GDP equivalence, the ToEI estimates the future year in which climate impacts exceed a set threshold of past economic shocks.

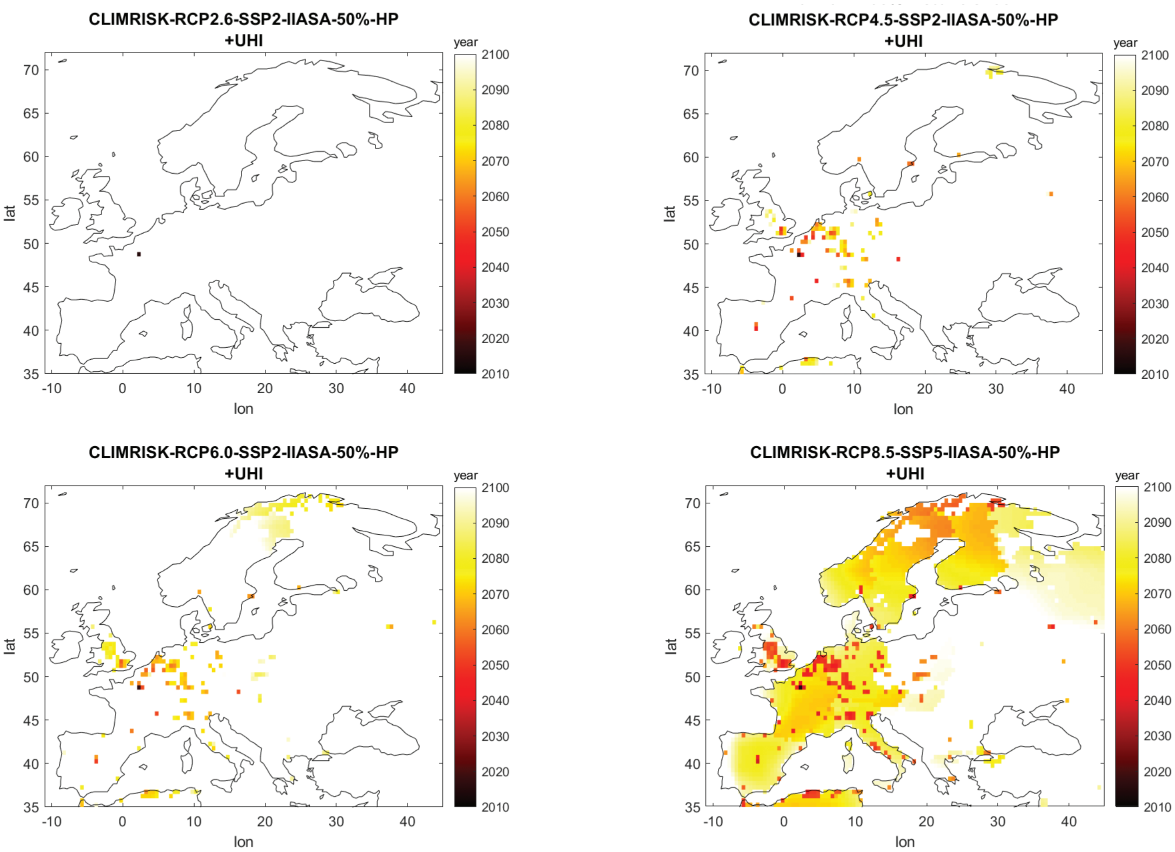
This has the advantage of putting future risks in context against a country's economic history, providing a useful measure of its likely coping capacity to climate shocks. The ToEI can therefore be considered a socio-economic tipping point, i.e. the future time period when a country moves into an unprecedented new state.

To explore the TOEI, the COACCH project has used the CLIMRISK model, an integrated assessment model with reduced-form damage functions, that allows downscaled (local level) analysis of the economic impacts of climate change (Ignjačević et al., 2020).

The results of the analysis of the ToEI are shown in the figure below. This analysis includes a consideration of the urban heat island (UHI) effect, which is important due to the impact it has on urban areas (which account for a large proportion of the population and GDP).

The figure shows the ToEI – the year – when the historic economic shock is exeeded. The darker the colour (towards red), the sooner the year that this occurs. In general a bright red signal indicates the ToEI occuring in the period 2040 to 2050.

The first important point to highlight is that under the RCP2.6 scenario, there is almost no exceedance of the ToEI anywhere in Europe this century. In contrast, under the RCP8.5 scenario, there is widespread excedence of the TOEI



Time of emergence of impacts (ToEI) of climate change in Europe under various RCP – SSP scenario combinations.

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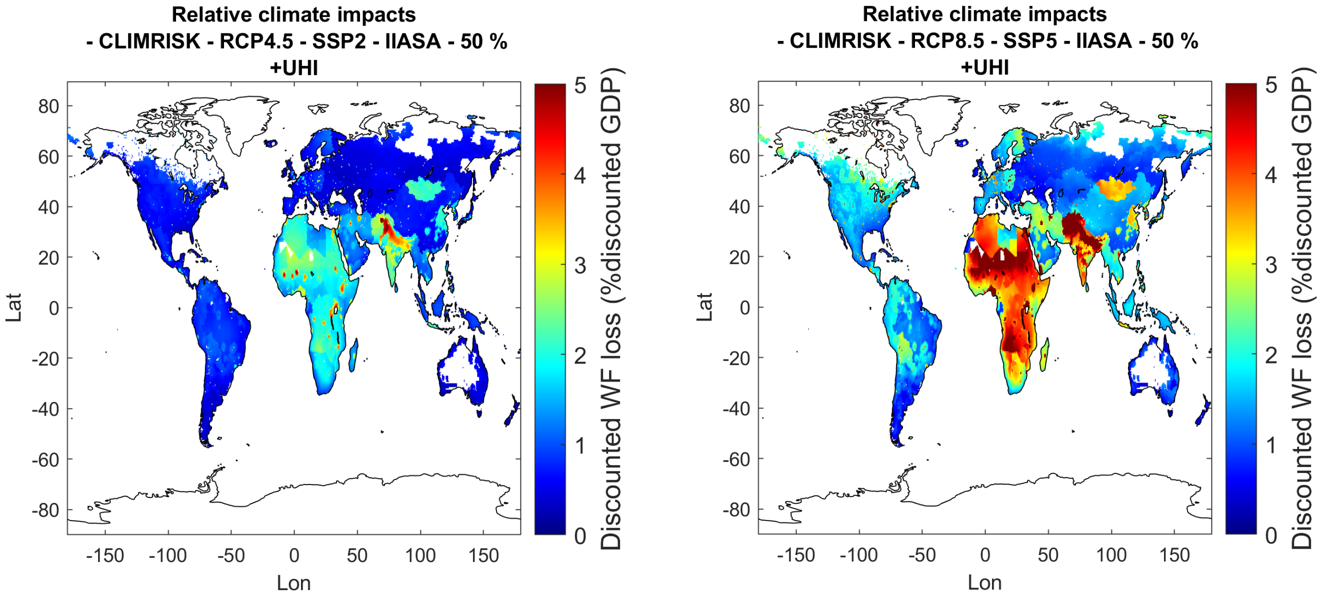
across much of Europe, and for major urban areas, possible exceedence by mid century.

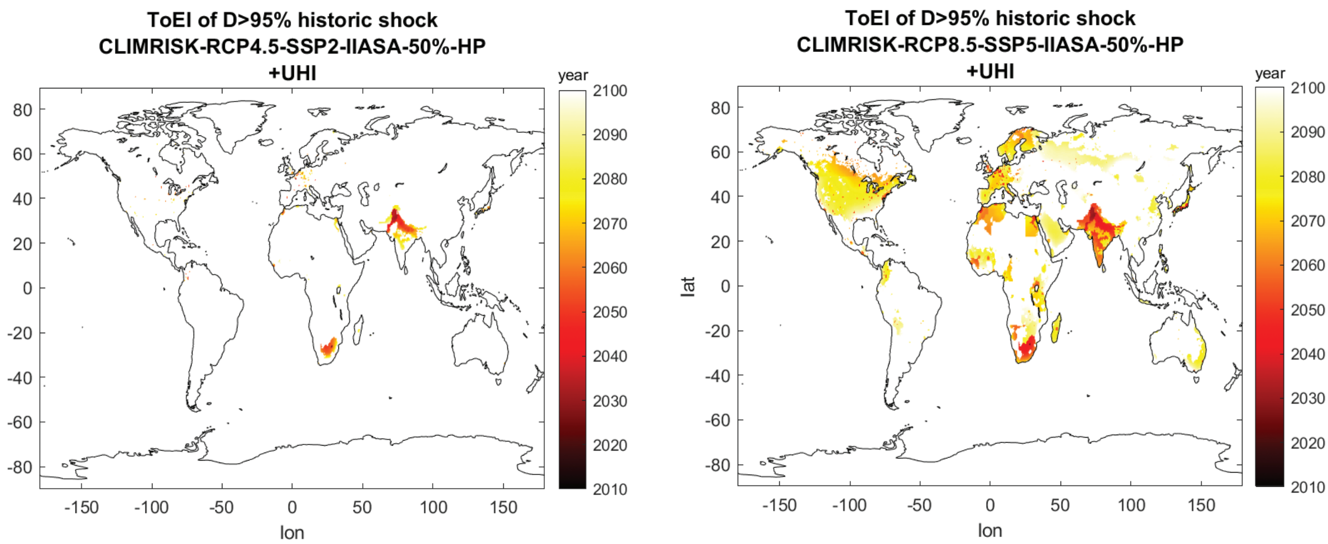
The second finding is that the ToEI results indicate that Western and Northern Europe are expected to experience the ToEI sooner than many Eastern-European countries. This reflects the fact that Eastern European countries probably have experienced larger economic shocks in recent history than the EU15.

The COACCH project has also looked at the economic costs of climate change and the ToEI at the global level, using the CLIMRISK model.

The results of climate change impacts – expressed as percentage losses of GDP – are shown first below for the RCP4.5 (SSP2) and RCP8.5 (SSP5) scenarios. This shows very large impacts in Africa and India, as compared to the US and Europe.



Relative climate impacts in the CLIMRISK model, expressed as percentage losses of GDP for RCP 4.5 – SSP2 and RCP 8.5 – SSP5 scenario combinations.



Time of emergence of impacts (ToEI) for the CLIMRISK model under the RCP 4.5 and RCP 8.5 scenarios.

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However, when the global map of ToEl is compared, shown below, a different pattern emerges. While some regions in Africa and Asia experience the ToEI more rapidly this century, Europe is also projected to experience severe climate impacts, with future shocks exceeding previous values.

A key conclusion of the analysis is that unprecedented impacts of climate change could be experienced in the 21st century, even across Europe. However, increasing levels of mitigation, e.g. moving from RCP6.0 down to RCP4.5, delay these risks by several decades, and they are almost completely removed under RCP2.6, i.e. under scenarios broadly consistent with the Paris Agreement goal of limiting warming to 2°C.

Financial Tipping Points

There is an increasing recognition that climate change has large economic costs which could affect financial markets. This has led to the concept of climate change as a financial risk. Awareness of these risks is being promoted through the Task Force on Climate-related Financial Disclosure (TCFD, 2019) and the Network for Greening the Financial System (NGFS, 2019) and includes:

- the physical risks of climate change impacts (as captured in COACCH impact analysis) including the impacts from slow onset climate change and increasing extreme events on assets, production, supply chains, etc.;
- transition risks, i.e. the risk from policy, legal, technology, and market changes associated with the transition to a low-carbon economy and financial and reputational risk to organizations.

The COACCH project has investigated the first of these, around physical climate risks, by developing a qualitative analysis of possible tipping points. This identifies a number of possible pathways that arise from the impacts described in other COACH SETPs, including insurance markets, time of emergence of impacts, and large macro-economic shocks.

The first possible tipping point concerns countries and the potential impacts of climate change on sovereign credit ratings. Climate related disasters (storms, major floods) can have a large negative impact on government finances and economic growth, and they are a major cause of contingent liabilities (notably for emerging markets). Major climate extremes already affect sovereign credit ratings today, and in turn the cost of debt and cost of capital. In a few cases, climate-related extreme events have been a direct cause of sovereign defaults.

Future climate change will affect the underlying economic and financial factors that the rating agencies use for assessing risk, both directly or indirectly, and could therefore lead to downgrades. Indeed, the major credit rating agencies have identified climate change as a global mega-trend that will impact sovereign creditworthiness. In an extreme case, this could lead to tipping points where major downgrades occur from unprecedented levels of climate impacts.

There is some existing literature that has assessed the potential impact of future climate change on country credit ratings, and in turn how this might affect the cost of debt, the public finances, and the cost of capital, but these use qualitative country rankings. The COACCH project provides new data that allows an analysis of sovereign risks based on the future economic costs of climate change.

The initial COACCH analysis finds that such risks are unlikely to be an issue for European countries up to at least 2050 (see the COACCH SETP on macro-economic costs, also in this policy brief), though, localised shocks could still be important. However, the analysis has identified large potential risks on sovereign creditworthiness for other countries globally, notably for small island states and some LDCs. This is due to the level of climate impacts, but also because they have less diversified economies and geographies, lower incomes, and lower fiscal flexibility.

Another financial SETP is the potential impact of climate change on insurance markets (see the COACCH SETP on insurance affordability also in this policy brief), and thus on investment levels in high risk regions. There is also further

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potential transmission pathways from climate change through to the financial markets. Climate change is a risk for the stock of manageable assets and investment returns, and potentially financial market stability. However, while climate effects could be very large (in financial terms) after 2050, it is difficult to foresee system-wide tipping points, and impacts are more likely to emerge as specific tipping points for investments in particular geographical areas or asset classes.

Finally, awareness of these financial risks will increase because of greater climate related disclosure (in the private sector and in financial institutions). This will have many benefits and will help investors and companies to identify and in turn address these risks.

However, greater disclosure could be detrimental for high risk countries or regions, as higher risk levels will be reflected in investment return thresholds. Importantly, disclosure could bring forward potential socio-economic tipping points, due to the financial market anticipation of future risks. This would mean that the financial impact of climate change could actually occur before the physical risks materialise. These issues are highlighted for further policy consideration, in order to ensure that greater disclosure does not lead to unanticipated impacts on highly vulnerable regions or countries.

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 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

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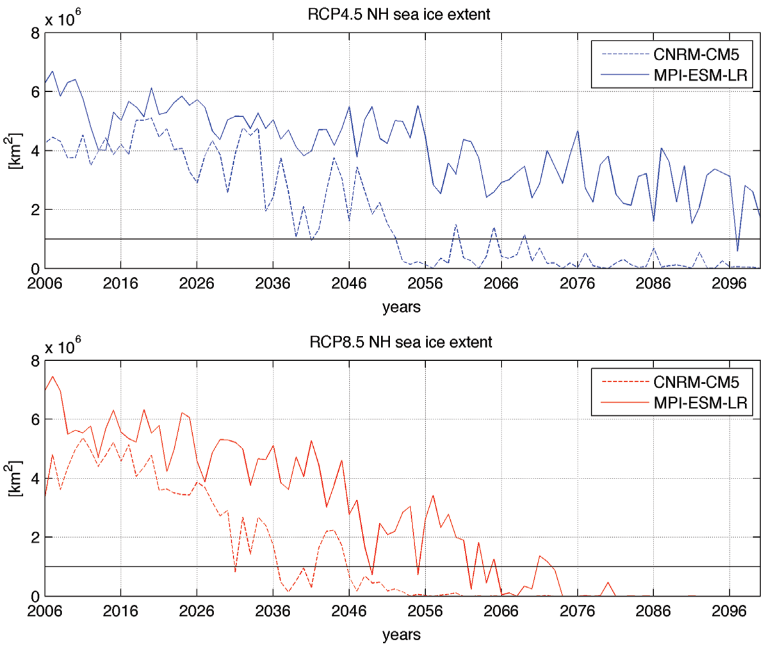

CMIP5 modeled September sea ice extent time series. Units are [10^6 Km^2].

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

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.

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 has run 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 rise of 170cm by 2100, to illustrate the effects of such high end sea-level rise. Under this scenario, coastal SLR and floods have severe effects with an expected 30 million people flooded each year, and EU expected annual damages of 13 trillion EUR. This is driven by the combination of higher climate change and the SSP5 scenario. It is noted, however, that adaptation could reduce these costs down significantly, to €44 billion per year – but under such high SLR there could be technological and economic limits to adaptation that prevent adaptation at some locations (not considered in COACCH).

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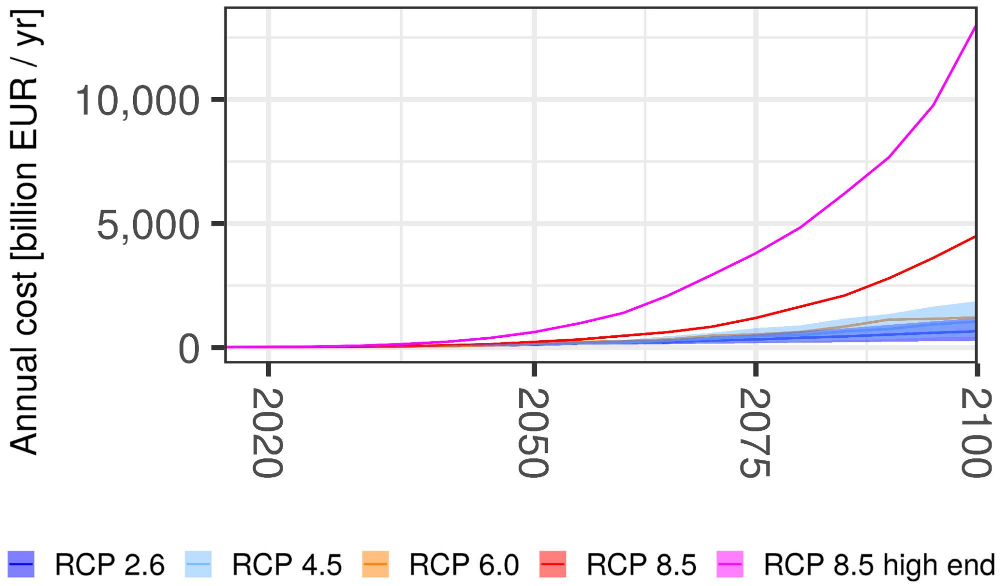

EU28 sea flood cost and protection cost over 21st century, showing also the effect of extreme SLR. Uncertainty ranges for lower RCPs show climate model and socio-economic uncertainty.

Key findings

The 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, as well as important economic costs from physical climate tipping points.

The socio-economic tipping point 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 are considered significant in economic terms and potentially pervasive.

The 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 socio-economic tipping point events are currently omitted in policy discussions and further consideration of them is considered a priority, alongside climate tipping points.

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WHO WE ARE

Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici
Italy

PBL Netherlands Environmental Assessment Agency,
Netherlands

Paul Watkiss Associates Ltd
United Kingdom

Basque Centre for Climate Change – Klima Aldaketa Ikergai,
Spain

Internationales Institut fuer Angewandte Systemanalyse
Austria

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