Climate change and economic impacts

Improved climate change cost assessments and socio-economic tipping points

Economic costs of climate change have long been studied and various methods exist to assess the costs of climate protection and adaptation measures. But how can these costs be estimated on a regional level? And how does climate change affect regional economic systems?

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Over the last four years, the COACCH project (CO-designing the Assessment of Climate CHange costs) has assessed the economic costs of climate change and climate actions. Its main objective has been to produce an improved downscaled assessment of the risks and costs of climate change in Europe that can be of direct usability and respond to the different needs of end users from the research, business, civil society, and policy making communities. To this end, the project assembled Europe's leading climate change impacts and economic modelling teams together with stakeholders to co-develop methods and analyses in an innovative research-practice-policy integration. This overall objective is substantiated in to five specific goals:

- To develop technically excellent and innovative research on complex climate change impact chains, using downscaled climate information and advancing integrated assessment methods and models developed under early RTD research calls.
- To develop a challenge-driven and solutions-oriented research and innovation approach, proactively involving business, civil society, public decision makers and research stakeholders in the co-design, co-production and co-dissemination of policy-driven research.
- To significantly advance the knowledge and the evidence base not only on climate tipping elements and tipping points but also on socio-economic tipping points.
- To advance the economic valuation of climate action in the EU at various scales (spatial grids, regions, countries, economic sectors) over short to longer-term timeframes to support a more informed policy process in the achievement of intended nationally determined contributions for the EU.
- To enhance innovation capacity and integration of this new knowledge using co-dissemination of results with stakeholders, maximising the use of innovative approaches in communication for dissemination, including direct elicitation of end-user needs.

An integral feature of the project has been its proactive engagement of a broad range of stakeholders in its co-design approach. This has included not only co-design of the research objectives, but also co-production and co-dissemination of the results, as well as regular and thorough evaluation of the process. Applying the co-design principles has helped the research to focus on and reflect the interests and needs of users, while considering cross-sectoral perspectives that can offer useful information and results for both the public and private sectors. This co-design centred approach represents a major development from previous European studies on the economic costs of climate change, which have generally been science-led.

State of knowledge and key research gaps

In an initial phase, the project assessed the current state of research and knowledge on economic costs of climate change in Europe across a range of sectors. This information helped frame the project, and especially the initial exchanges with stakeholders. There is comprehensive coverage of economic impacts and policy (including adaptation) for coastal zones and storms as well as river flooding. In both instances, adaptation policy studies include considerations for decision making under uncertainty. Good coverage of economic assessments exists also for agriculture, energy, health, and to a lesser extent transport and tourism. While there is emerging policy and adaptation analysis in the field of agriculture, the remaining fields have limited policy analysis available. There is a lower evidence base for other fields, including forests and fisheries, water management, business and industry, macro-economic analysis, and biodiversity. Finally, climate and socio-economic tipping points were identified as areas with notable gaps in economic analysis. The work on tipping points will be presented in further detail below.

Sectoral economic cost estimates

Building on the identified research gaps, the project produced new sector estimates of the economic costs of climate

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change. The modelling team made use of climate projections for Europe available from EUROCORDEX, and, through stakeholder discussions, selected a core set of RCP-SSP combinations for use in the project. A first criterion was to assess different effects of alternative climate scenarios relative to a common socio-economic scenario. SSP2 ("Middle of the Road") was selected by stakeholders as a key socio-economic pathway, with particular emphasis on the SSP2-RCP4.5 and SSP2-RCP2.6 combinations. As a second priority, the project aimed to assess the effects of different socio-economic effects on a single climate scenario. To this end, the project analysed the RCP4.5 scenario with SSP1, SSP2, SSP3, and SSP5.

The sector estimates calculated in the project include both market and non-market impacts, assuming no adaptation. The results are presented as current prices, without adjustment or discounting. When possible, analysis of costs and benefits of adaptation was considered. Taking selected examples for sea-level rise (using the DIVA integrated assessment model), the costs are estimated at 135–145 billion euro per year, rising rapidly to 450–650 billion euro by 2080 (COACCH 2021; Lincke et al. 2018). These estimates include only direct costs, though further unquantified costs are expected as a result of ecosystem losses and knock-on effects in other sectors. Annual river flooding costs are estimated at 11–18 billion euro by 2050 to 18–42 billion euro by 2080. The estimates include the combined effects of climate and socio-economic change. In the health sector, a Value of Statistical Life approach was used to estimate the costs of heat wave related health impacts. By 2050, these costs will range from 102 billion euro (RCP2.6-SSP2) to 176 billion euro (RCP8.5-SSP5) annually. By 2080, these numbers are 68 billion euro (RCP2.6-SSP2) to 313 billion euro (RCP8.5-SSP5) annually (COACCH 2021; Scasny et al. 2020).

Climate and socio-economic tipping points

A key innovation of the project has been the development of the new concept of socio-economic tipping points (SETPs) (van Ginkel et al. 2020). Climate and ecological tipping points have been well established in the literature (Lenton et al. 2008; Kriegler et al. 2009; Russill & Nyssa 2009) and represent thresholds that, when passed, can change the state of the climate or ecological system – often irreversibly. Examples of these include the die-off of coral reefs (e. g., the Great Barrier Reef), sudden collapses of parts of the West-Antarctic ice sheet, thawing of permafrost, and large-scale reduction of the Amazon rainforest, among others. Though some research has been carried out on coupled socio-ecological systems (Milkoreit et al. 2018; Reyers et al. 2018), this work has remained focused on changes to ecological systems, rather than socio-economic systems. Recognizing this research gap, the project sought to expand the state of knowledge on tipping points in the socio-economic domain, which can be especially policy relevant for decision makers on climate adaptation and mitigation.

Within the framework of the COACCH project, a three-step approach was followed to build a sound basis for the development of the socio-economic tipping point concept. Firstly, a literature review was carried out to assess different approaches to tipping points and to develop a typology. Secondly, stakeholder consultation helped identify examples of SETPs that could be of particular relevance to European policy, and which would serve as areas of specific research for the project. Finally, these two elements were combined to offer suggestions for policy relevant future research on SETPs.

In addition to considering the type of systems where tipping point concepts are applied (e. g., physical, biological, socio-economic), the literature review examined a set of key criteria which were used to assess different aspects of tipping points. This includes the shift from one to another stable state of the system, the causal mechanisms leading to these state shifts and stabilisations, as well as the consideration of abruptness and nonlinearity. The analysis of the literature produced a typology of tipping points in the context of climate change (van Ginkel et al. 2020).

Climate tipping points represent abrupt changes of large elements of the climate system as a result of increasing greenhouse gas concentrations. *Ecological* tipping points denote state shifts in ecological systems, often resulting from climate change. Both are in the biophysical domain. Tipping points in the socio-economic area are less clearly defined since different pathways may occur. For example, climate change may trigger a large-scale socio-economic event or shock, such as rapid migration due to an extreme event. Alternatively, in anticipation of foreseen climate impacts, one may deliberately tip the socio-economic system into a new state, for example from a fossil-fuel based energy system into a system based on renewables. Within the socio-economic field, COACCH identified tipping points tied to climate change impacts, and tipping points tied to transformational responses. *Transformational* tipping points denote abrupt and fundamental changes in human response to climate change, which can be further separated into mitigation and adaptation tipping points. These encompass the fundamental policy changes that emerge due to climate change, which may occur at the level of the individual, policy maker, private business, or others. In recent literature, some of these are referred to as "social tipping points" (Otto et al. 2020). These transformational *response* tipping points, which primarily result from human action, are distinct from the final category, tipping points related to socio-economic *impact*, which primarily result from human inaction. The state shift in this last category is the result of a combination of climate change and inaction or inability to successfully adapt to the new conditions.

In sum, the study produced a definition of socio-economic tipping points as "a climate change induced, abrupt change of a socio-economic system, into a new, fundamentally different state (beyond a certain threshold that stakeholders perceive as critical)" (van Ginkel et al. 2020). These exhibit three key characteristics: (1) Two stable states, which are distinct from one another on either side of a critical threshold, (2) a mechanism explaining nonlinear behaviour – that is, a causal pathway demonstrating why these states are stable and explaining what led to the shift from one to the other, and (3) rapid, abrupt change that is notably faster than other systemic changes.

Stakeholder consultation on SETPs in Europe

With a definition of socio-economic tipping points now established, the project team moved into the second phase of the research. An in-person workshop (May 2018) assembled over 40 stakeholders from the entire spectrum of target groups. From an initial set of 22 possible SETPs, stakeholders helped narrow down and prioritize those that were considered of most interest for further research within the project. These are:

- 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 SETPs, with analysis of wildfire related energy supply shocks, as well as multiple floods and transport disruption;
- Extreme sea-level rise, including transformational adaptation;
- Economic SETPs, including the potential for large macroeconomic impacts; and
- Financial SETPs, including the potential collapse of insurance markets from extreme weather risks, as well as major impacts on countries and financial markets.

A selection of these will be presented in further detail below, with full details available in the project documentation.

Food production shocks

Agriculture and food systems are heavily impacted by climate change. Extreme weather events can cause shocks to agricultural systems, leading to variability in yields, increases in food prices, and potential spill over effects in other sectors. The project investigated the relationships between climate shocks, crop yields and prices, and food commodity markets, as well as adaptation responses aiming to stabilize market conditions. The tipping point examined is whether climate impacts could cause to crop losses large enough that agricultural production becomes unviable, leading to rural abandonment.

The analysis involved a combination of General Circulation Models representing climate change, combined with biophysical and bio-economic models (EPIC and GLOBIOM, respectively), and finally an international macroeconomic model (COIN-INT). The results found that in certain RCP-SSP scenarios, significant agriculture losses would occur, potentially triggering abandonment of farmland, possibly as high as 7% at the European level. There is a strong variance in the results across the different regions of Europe, with Southern Europe (Spain, Italy, Greece) at most risk of passing the tipping point for rural abandonment (COACCH 2021).

Migration

There is evidence that climate extremes in the past have been a factor in both internal and external migration (within a country, or from one country to another). Climate change-induced migration can be considered a socio-economic tipping point, since at a certain point people decide or are forced to move elsewhere. Such migration has socio-economic impacts on both the place of origin (e.g., loss of labour force) and the destination (e.g., housing shortages). In the COACCH project, two aspects of migration were examined. Firstly, the project assessed migration from Africa to Europe, using historical climate data, current migration numbers, and projected drought increases to estimate future possible migration. The results show an increasing number of migrants to Europe over time, varying significantly according to the scenario combination. By 2050, the projections show 0.4–0.9 million migrants per year under an SSP2 scenario, with the low end representing 1.5 °C of warming, and the high end representing 3 °C of warming. Under an SSP3 scenario with 3 °C of warming, this number jumps to almost 1.2 million migrants per year by 2050, and quickly approaches two million by the end of the century.

The project also explored the relationship between sea-level rise and migration away from coastal zones. In many instances, adaptation through flood defences are not economically viable or even possible, meaning that sea-level rise will likely lead to tipping points in many vulnerable countries around the world. The results for a high-end sea-level rise scenario (170 cm by 2100) estimate that up to 100 million people could be forced to migrate in the 2050s, and an additional 100 million by 2100. Across all scenarios, adaptation dramatically reduces the amount of migration, even through the end of the century, to about five million people.

Energy systems and wildfires

Climate change will have a marked effect on energy and electricity systems as extreme events like heatwaves lead to increasing demand for air conditioning, and droughts cause a shortage in cooling water for thermal power generation plants. One such risk that has not yet been studied in depth is the potential impact of wildfires and the associatetd impacts on energy supply.

The project has identified this as another socio-economic tipping point, as wildfires could affect electricity infrastructure and networks, leading to significant power outages. The project estimated the Gross Value Added (GVA) lost as a result of black out events, based on potential wildfire risks and electricity system exposure, across a range of RCP-SSP combinations. Furthermore, the project developed a new indicator to denote the potential risk for blackouts due to wildfire by combining drought hazard and GVA loss. The results show that in addition to regions traditionally at risk due to fires (e.g. the Mediterranean), parts of central and northern Europe will experience increased wildfire and blackout risks in the future.

Macro-economic tipping points

The project also employed the ICES macroeconomic model to further assess climate-induced shocks, combining the sectoral results from the rest of the project into a macroeconomic framework. Using the ICES model allowed for outputs at the NUTS2 level, while also considering trade, and spill over effects between sectors. To identify *large* economic shocks and thus a socio-economic tipping point, a threshold was set at a loss of 5% of Gross Regional Product (GRP).

The results show that until 2050, no European regions experience a loss above the threshold of 5% of GRP. In the 2050s, high warming scenarios could cause this level to be passed in some regions. Moving towards the 2070s, low and medium scenarios still cause few regions to exceed the tipping point, while high warming scenarios cause this socio-economic tipping point to be passed in about 20% of European regions.

Flood insurance affordability in Europe

The project investigated effects of climate change on flood insurance coverage. Increasing flood risks could lead to rising insurance premiums, potentially making insurance coverage unaffordable for low-income households. The analysis 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 rising unaffordability and declining demand for flood insurance in Europe, especially towards the year 2080. High increases in unaffordability occur in Eastern European countries, as well as regions in Sweden, Portugal and Italy. Furthermore, the functioning of flood insurance systems varies because different current insurance systems are better at coping with increasing flood risk. 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.

A stepwise approach to research on tipping points

Beyond the tipping point research within the project, COACCH delivered a framework to guide future research on climate change induced socio-economic tipping points (van Ginkel et al. 2021, preprint). Tipping points may happen on various scales, and in more sectors than described above. Decision makers, spatial planners and capital investors want to know how the conditions under which they might occur can be identified, and how this could support the design of adaptation and mitigation policy. To facilitate this, a stepwise methodological approach was developed to identify tipping points under many uncertain possible futures and accounting for adaptive policy change.

An example of a tipping point studied outside COACCH is the financial collapse of ski resorts in the Swiss Alps (Vaghefi et al. 2021). The gradual retreat of the snowline due to climate change poses a large threat to winter tourism in the Alps, notably to low-altitude resorts, some of which have already collapsed. The study showed that ski resorts with elevations below 1800 meters will not survive after 2050 unless they find income from activities other than winter snow tourism. This highlights the urgency of developing new adaptation strategies that aim at income diversification from other activities such as summer tourism, to secure the profitability and survival of the resorts.

Conclusion

The project has produced an extensive amount of new and innovative research on the risks and economic costs of climate change in Europe. Through a carefully structured co-design methodology involving stakeholders and end users throughout the entire project, the consortium has developed an innovative collaboration approach that has produced outcomes of direct relevance to policymakers, researchers, business, investment, and the public at large.

The project team has identified important gaps in sectoral and macroeconomic cost estimates for climate change and has addressed a number of these through new modelling work and case studies. Of specific note include further advancement modelling approaches for global land systems (Dietrich et al. 2019), studies on best practices for extreme weather insurance (Hudson et al. 2019) and flood insurance (Tesselaar et al. 2020), and extensive new research on sea-level rise and coastal flooding (Hinkel et al. 2019; Abadie et al. 2019; Schinko et al. 2020; Abadie et al. 2020; Nicholls et al. 2021).

Finally, the project has produced innovative research in the field of tipping points, specifically through a review on the concept of socio-economic tipping points and stakeholder consultation on important SETPs in Europe (van Ginkel et al. 2020). Additionally, this work led to the development of a framework for the identifying and preparing for SETPs, of particular relevance to decision makers operating in highly uncertain climate and socio-economic conditions (van Ginkel et al. 2021, preprint).

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