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European Commission

SCIENCE FOR POLICY BRIEF

Earth System Tipping Points are a threat to Europe

HIGHLIGHTS

- **With global warming rapidly approaching 1.5 °C, the risk of crossing several Earth System Tipping Points (ESTP) becomes an emerging security threat.**
- **International climate mitigation action needs to step up to avoid dangerous climate change leading to the possible crossing of ESTP.**
- **Europe needs anticipatory governance to prepare for widespread systemic risks resulting from crossing ESTP.**
- **Early warning monitoring systems, improved integration of ESTP in socio-economic modelling, and strategic foresight methods are needed to enhance anticipatory governance.**
- **Risk assessment of ESTP needs to inform the EU Climate Adaptation strategy, the EU Civil Protection Mechanism, and the forthcoming EU Preparedness Union Strategy.**

PREPARING FOR EARTH SYSTEM TIPPING POINTS

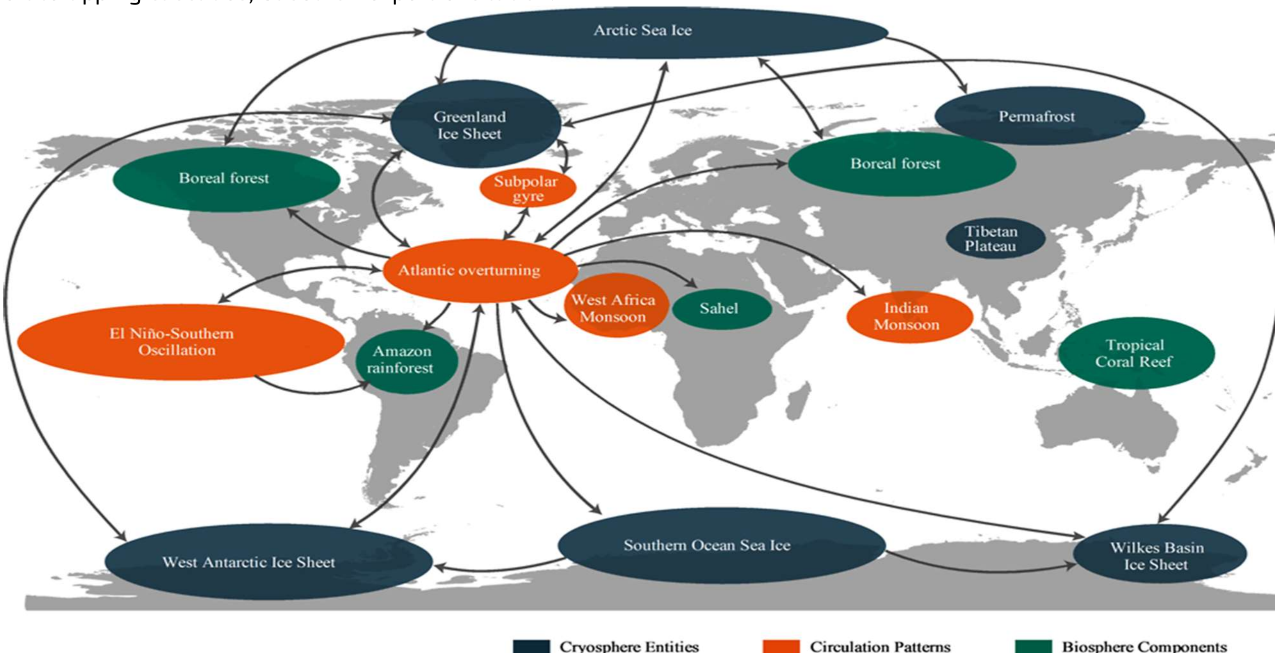
Climate change and nature loss can cause tipping points in the Earth System (Box 1, Fig. 1). With a five year average temperature already 1.3°C higher than pre-industrial[1], and 2024 the first year above 1.5°C[2], Europe stands out as the fastest warming continent. This calls for stepping up global climate mitigation action in line with the Paris Agreement objectives to significantly reduce the risks and impacts of climate change.

Current scientific understanding[3] highlights the increasing risk of crossing several ESTP beyond 1.5°C (Fig. 2), while others may regionally tip before (e.g. warm water coral reefs)[4].

Therefore, urgent anticipatory governance of the expected widespread impacts across the different regions in Europe is needed. Building resilience and preparedness through transformational adaptation pathways becomes imperative[5]. Due to their profound impacts on ecosystems, economy and society[4,6], ESTP related risks become increasingly relevant for the Preparedness Union Strategy[7], as outlined in the Niinistö Report[8]. Europe remains, however, unprepared for rapidly increasing climate risks[9], leaving a security blind spot[10] for the even more profound, complex cascading poly-crises expected by the possible crossing of ESTP.

Strategic foresight analyses[11,12] have long identified the crossing of ESTP as important future global trends that will require concerted, multifaceted, decisive leadership. ESTP will challenge the stability of environmental, technological, economic, social and political systems, within a framework of growing fragmentation, complexity and uncertainty. Europe needs preparedness to function under all circumstances[8], and to effectively anticipate, prevent, withstand or respond to any type of major shock or crisis

Figure 1: Global map of the main tipping systems: Green: biosphere systems. Orange: circulation-atmospheric systems. Blue: Cryosphere systems. Arrows show the potential interactions among the tipping systems that could generate tipping cascades, based on expert elicitation.



with cross-sectoral and cross-border impacts, and which can even threaten the EU as a whole[8]. Preventive mitigation action to avoid the crossing of ESTP lies at the core of social and intergenerational fairness. Decisions now will be a legacy to future generations. Moreover, as most ESTP have a global dimension, international cooperation will be required.

MODELLING ESTP AND THEIR IMPACTS

Biophysical modelling of ESTP is advancing but remains uncertain

The research community has linked the risks of crossing ESTP to global temperature change[3,14] based on multiple lines of evidence derived from paleo-climatic and Earth System observations, as well as models of the Earth System and its components. Earth Observations[15] are used to explore early-warning signals of approaching tipping points and the loss of systems resilience (Box 2), together with ground-based data[16].

Box 1: Tipping Points and Tipping Systems

The Intergovernmental Panel on Climate Change (IPCC)[13] defines a tipping point as "a critical threshold beyond which a system re-organizes, often abruptly and/or irreversibly" and a tipping system (Fig. 1) as "a component of the Earth System that is susceptible to a tipping point"[13]. ESTP pertain to the biophysical domain, excluding social and technological tipping points. Potential ESTP[4] have been identified for the cryosphere (e.g. mountain glaciers, large ice sheets, permafrost), biosphere (e.g. boreal forests, the Amazon) and coupled atmosphere-ocean systems (e.g. African Monsoon, the Atlantic Meridional Overturning Circulation-AMOC). Within ESTP, climate tipping points (CTP) refer to systems whose destabilization can result in self-perpetuating changes in parts of the Earth's climate system[4]. CTP may lead to re-organization of regional climatic conditions from one stable state to another — one that is potentially much less suitable for sustaining human and natural systems. Regional ESTP crossing can affect the livelihood of millions of people (e.g. coral reefs, alpine glaciers, dry ecosystems). ESTP involve non-linear, possibly irreversible change that can occur on timescales much shorter than the climate trend that is causing the change, and defying the capacity of society and ecosystems to adapt. As such, the impacts on economy and society of crossing ESTP can be severe and widespread[6].

Global temperature has already reached the lower end of the likelihood range of several Climate Tipping Points (Fig. 2), while other systems may pass a tipping point in the next decades. Once triggered, transition times from one state to another may range from less than a decade to millenia[4], which will determine the time to adapt to changed conditions.

Currently, the exact assessment of the occurrence of ESTP in biophysical model projections is limited by our understanding of ESTP interactions, feedbacks and cascading responses of Earth System processes. A continued development of these models, including finer spatial resolution, is needed for improved ESTP risk assessments, to identify hotspots of action, and to navigate governance. TIPMIP[17] aims to advance on these challenges by organising an intercomparison of ESTP modelling, and to provide a systematic evidence base for risk assessments.

Box 2: Early warning monitoring systems for ESTP

Early warning indicators may signal the loss of a system's resilience and the approaching of a tipping point. Ground data can be used to track the functioning of tipping systems and their destabilization responses (e.g. ocean circulation)[16]. Earth Observation and paleo-climatic reconstructions can also be used to understand the functioning of ESTP and their destabilisation responses, including the use of 'critical slow down' indicators, e.g. a sign of a system's weakening through increasing recovery times after disturbance[18,19].

In Europe, the Copernicus program provides dedicated climate change indicators[20] and datasets that could support tracking of ESTP and their impacts.

New satellite missions, relevant to the monitoring of early warning signals of ESTP, are planned[21] and several European initiatives (e.g. ARIA program[22]) connect the remote sensing and modelling communities to identify early warning signals of ESTP.

Operationalisation of ESTP monitoring activities could better inform the scientific community and policy makers on the state of Earth systems, the proximity of tipping points, and anticipatory responses.

Biophysical modelling is a fundamental first step to characterize ESTP related risks, understood as the combined effects of hazards, exposure, vulnerability and capacity to respond. However, both biophysical and socioeconomic data are needed for risk assessments, which aim to identify, analyse, and evaluate potential risks, including their impacts and adaptation options.

ECONOMIC MODELLING NEEDS TO CONSIDER ESTP

Assessing the risks and impacts of ESTP is challenged by the insufficient integration of biophysical and socioeconomic modelling frameworks[9,23,24]. Biophysical model outputs rarely align with policy-relevant socio-economic modelling requirements (e.g sectoral data at higher resolution, lower uncertainty, connection with social exposure and vulnerability, etc). Insufficient integration has traditionally jeopardised governance for anticipatory action[4,23].

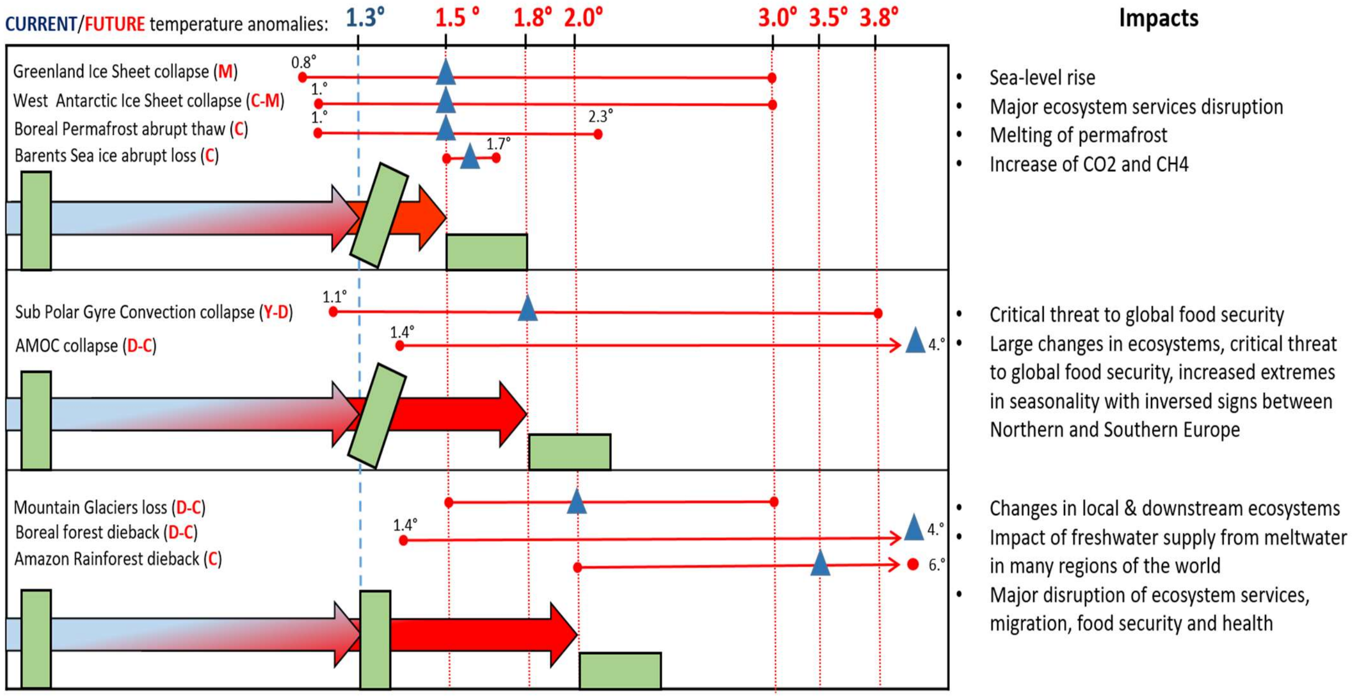
EU funded projects aim to improve the understanding of impacts (e.g. TipESM[25]; ClimTIP[26]) and complex Earth-social system dynamics (e.g. RECEIPT[27], DominoES[28]), by developing new methods and conceptual frameworks, such as the "Anthropocene evolutionary trap" or the "Polycrisis" concept. The conclusions obtained from applying these conceptual analytical frameworks are used to retrofit computer modelling and promote a more comprehensive exploration of the interactions between human and Earth Systems, aiming at more strategic mitigation, preparedness and adaptation strategies[28].

Economic impacts of ESTP are underestimated

EU economic and financial stability are powerful drivers of EU policy making. The cost of climate impacts could become very large if not staying within the 1.5°C objective of the Paris Agreement. By 2090, with a global warming level of around 3.6°C, the EU economy could face costs of about 7% of GDP[29]. However, these values do not consider the consequences of crossing ESTP, their non-linear cascading impacts and plausible abrupt changes[6,23,30]. By capturing a more comprehensive set of climate variables and the inclusion of persistence effects, the latest climate scenarios under the Network for Greening the Financial System[31] estimate that the GDP losses from physical risks could reach up to 15% at a global level and 10% in Europe by 2050, without further policy efforts, and compared to a scenario without climate change.

A new meta-analytical integrated assessment model[30] is now employed to evaluate the costs of crossing ESTP. Estimates including ESTP suggest an increase in global economic damages by at least

Figure 2: Tipping systems (green vertical rectangles) that would impact Europe, listed in relation to global temperature anomalies. Tilted rectangles represent the start of a tipping process by global warming until the transition to the new equilibrium (horizontal green rectangle). Blue triangles show the central estimate of tipping temperature anomaly and the horizontal red line the temperature anomaly range of the likelihood of tipping occurrence. In brackets, the transition timescale in years (Y), decades (D), centuries (C) and millennia (M), and intervals (e.g., year to decades, Y-D). The right column shows some of the expected biological and physical impacts.



Data source:[3][6]

25%. In worst-case scenarios, costs may double. Improved calibration and modelling of more complete damages may even increase these estimates[30].

The large cost of inaction justifies stepping up mitigation efforts but also calls for enhancing EU financial mechanisms to support both public and private sectors in climate adaptation and preparedness efforts, which already are components of Europe's focus on competitiveness (2024-2029), and the Draghi Report[32].

The insurance sector is currently important in buffering economic shocks but, as of today, only 25% of the losses due to natural catastrophes are insured in the EU, leaving a protection gap[33] covered by households, companies, and the public sector. A discussion is needed on the role for national and EU financial support mechanisms to deal with ESTP economic impacts. The recent Council Directive (2024/1265) introduces new requirements for Member States on reporting macro-fiscal risks for budgetary frameworks, to address the disaster and climate-related contingent liabilities and fiscal costs associated with the projected rise of the costs of climate change.

Moreover, integrating a wide variety of ESTP risks into forward looking climate stress testing would enhance the capacity of financial institutions to manage compound financial stability risks. Scenario analysis could also demonstrate the economic benefits of mitigation and anticipatory impacts governance.

NEED FOR ANTICIPATORY GOVERNANCE OF ESTP

Governance addresses both prevention of crossing ESTP and anticipatory action on their impacts through preparedness and resilience building[4,34]. Europe has a package of prevention policies in place, targeting the multiple drivers that destabilize tipping systems. These include among others: greenhouse gas mitigation commitments under EU Climate Law[35], enhancement of carbon removals under the Carbon Removal Certification Framework[36], biodiversity protection under the Nature Restoration Law, and the EU Deforestation Free Trade Regulation[37]. The risks of crossing ESTP warrant enhanced focus on international mitigation efforts.

In contrast, anticipatory governance of the impacts and responses of crossing ESTP remain unaddressed.

Actions to consider include the reinforcement of early warning monitoring systems (Box 2), ESTP-tailored climate risk assessments (Box 3), short-term disaster preparedness and long-term adaptation and resilience planning.

Box 3: Risk assessment of ESTP in Europe

Emerging qualitative methods are used to address Climate Risk Assessments in Europe. They aim to bypass unmanageable uncertainties of projected climate impacts or expected futures. As examples:

EUCRA report[9]: "Storylines" and "wild cards" are used to explore future climate risks and uncertainties. Storylines help envision plausible scenarios, allowing for robust planning across sectors, while wild cards introduce low-probability, high-impact events that could drastically alter outcomes. Together, these methods help to better understand potential ESTP crossing and their cascading effects, and foster resilience and adaptation strategies.

The Security Blind Spot report[10]: "what-if" scenarios are used to assess the potential impacts of the collapse of AMOC and the Subpolar Gyre on the UK's food and financial stability. Scenarios explore extreme but plausible outcomes, such as the drastic reduction of the UK's growing season by up to 60 days, highlighting the cascading impacts on food and financial securities as a blind spot in national security planning.

Moreover, anticipatory governance needs to consider the possibility of a broader spectrum of future climates[38], including ESTP-driven reversals in regional climate trends, away from current configurations under global warming. For example, in the Northern regions of Europe, cooling and drying would be expected under ESTP, while warming and wetter conditions would be expected under linear climate change. Regionally, ESTP can lead to more extreme climate gradients between Northern and Southern Europe, as associated with the crossing of the Subpolar Gyre and AMOC[38,39]. ESTP are expected to result in long-term, continental-scale, cascading and compound multi-hazard impacts, and require a focus on region-based resilience and adaptation planning in Europe[9,39].

The EU's anticipatory governance would benefit from dedicated ESTP research priorities. Further fundamental research on modelling and monitoring of the dynamics and interactions of ESTP would better inform risk assessments.

In addition to fundamental ESTP research, qualitative strategic foresight approaches offer a way forward to promote anticipatory governance discussions (Box 3). While far from perfect, these approaches can help to bypass inaction associated with high uncertainties, help to assess the potential impacts of widespread and disruptive crossing of ESTP, and prioritize adaptation and other preparatory governance needs[40].

Climate adaptation, preparedness and solidarity feature prominently in the EC 2024-2029 political guidelines[7], Europe remains insufficiently prepared for rapidly growing climate risks[9] and anticipatory governance of the impacts of crossing ESTP is absent from the policy agenda. Preparedness must ensure that the EU and its Member States are able to face increasingly complex, cross-border and multifaceted crises[12,41], so that they can continue functioning under all circumstances[8].

RECOMMENDATIONS AND NEXT STEPS

Raise awareness of the risks of crossing ESTP and promote anticipatory governance

- Prepare Europe for rapidly increasing climate risks, and address the security blind spot for the even more profound, complex cascading poly-crises caused by ESTP impacts.
- Inform the forthcoming Preparedness Union Strategy on the long-term environmental and societal risks associated with crossing ESTP, as well as the resulting governance challenges.

Prioritise proactive preparedness

- Identify and operationalize indicators for early warning monitoring systems, advanced data analysis and data curation, and modelling capacity to provide up-to-date biophysical and socio-economic information to policy makers, business and society.
- Advance risk assessments of individual, cascading and concurrent ESTP. Develop continental scale methodologies in support of ongoing integrated approaches developed by some Member States, other European countries participating in Copernicus and EU Civil Protection Mechanism.
- Assess the vulnerability, resilience and adaptation planning for macro-sectors (e.g. food, energy, infra-

structure, and supply chains) with systemic analyses of the impacts of ESTP at European, national and regional scales.

- Produce ESTP risk assessment to inform and improve synergies between existing European governance frameworks: the EU Civil Protection Mechanism[42], the EU Adaptation Strategy[43] with its forthcoming European Climate Adaptation Plan, and the forthcoming EU Preparedness Strategy. This recommendation would be a next step priority.

Integrate ESTP into economic, financial and policy planning

- Strengthen the connection of quantitative socio-economic and biophysical models, include ESTP in scenarios, refine highly uncertain non-linear damage functions, and develop the capacity to simulate poly-crisis, caused by cascading ESTP.
- Enhance the capacity to manage financial stability risks using advanced stress testing based on compound risks and tipping point scenarios through emerging methodologies.
- Evaluate the need for national and EU financial support mechanisms to deal with ESTP impacts.

Foster research, science communication and public engagement

- Strengthen underlying research on Earth System tipping processes, dynamics, and impacts.
- Communicate the need of anticipatory action, despite uncertainty in ESTP timing and impacts.
- Include ESTP risks in regular climate-science updates to policymakers to align governance efforts with scientific advancements and ensure that policies remain adaptive. Using available climate-science dissemination channels (e.g. the Disaster Risk Management Knowledge Centre and the Copernicus climate change service) would be a next step priority.
- Promote public engagement and behavioural changes to strengthen broader societal buy-in for ambitious climate policies.

Enhance EU cross-border and international cooperation

- Establish shared risk ownership of ESTP, as climate tipping points transcend national borders.
- Strengthen coordination and resource-sharing mechanisms at EU, Member State and international level, to tackle climate risks collectively.
- Promote coordinated unified frameworks for preparedness action, including early-warning systems, risk assessment and long-term resilience and adaptation planning.
- Foster collaboration among international organisations and programs to enhance the effectiveness of these policies.

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BACKGROUND

This policy brief is based on the workshop "Raising Awareness of Earth System Tipping Points: Implications for EU Governance", hosted on the 5-6 November 2024 in Brussels. The workshop brought together policy makers, scientists from the Earth System and socio-economic modelling domains, the Earth Observation community, insurance and finance experts, and several international organisations, to discuss the needs for anticipatory governance of ESTP. The workshop was co-organized by the European Commission's Joint Research Centre, DGs RTD, CLIMA, ECHO, ENV and ECFIN, the Potsdam Institute for Climate Impact Research, and the University of Oslo. A workshop report is in preparation. Follow-up workshops and outreach events are foreseen.

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