Section 3

Governance of Earth system tipping points

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Section summary

Governance efforts to address the specific and severe threats of Earth system tipping points (ESTPs) are currently lacking and urgently needed. A future governance framework for ESTPs should prioritise efforts to prevent tipping events, while also minimising impact-related harms, fostering adaptation and resilience, and facilitating knowledge co-production. Failure to prevent tipping would likely impede the achievement of the Sustainable Development Goals (SDGs). These objectives can only be reached together, through systemic changes that address the root causes of Earth system change with transformations to sustainable and just societies.

In all domains of governance (prevention, impact governance, knowledge production), the diversity of tipping processes (their timing, drivers and impacts) need to be carefully considered and used to inform approaches tailored to distinct ESTPs.

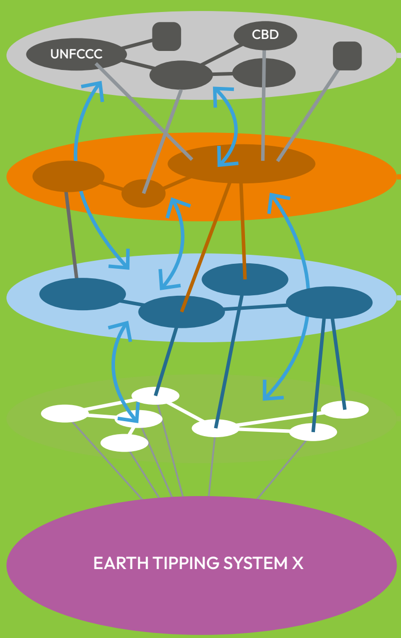
Governance of Earth system tipping points should be based on existing principles of global governance and international law, such as precaution, equity and justice, as well as care for future generations. The nature of threats presented by tipping dynamics in the Earth system challenges the common reactive and linear logics of decision making in global governance. Short-term decisions can have severe, even catastrophic, consequences over extremely long time horizons, potentially affecting life on Earth for several millennia, and future generations' chances for survival and wellbeing. These extremely high stakes place a major burden of responsibility on the present generations and – unlike other global challenges – dramatically elevate the logic of precaution. Scientific uncertainty (for example, about how close we might be to a tipping point) should be reason for action, not delay, with anticipatory approaches and systemic risk governance of particular importance in guiding decision making.

Section summary (continued)

Effective prevention strategies need to address the multiple, interacting drivers of ESTPs, which often operate at different scales. We distinguish primary (often global-scale) and secondary (often regional-scale) drivers to aid decision makers in devising multi-scale approaches and selecting appropriate governance venues. The primary driver in many cases is global temperature change, which makes accelerated mitigation of greenhouse gases the most important and effective prevention strategy. Rapid, near-term mitigation efforts should be combined with enhanced management of short-lived climate pollutants (SLCPs) and scaling efforts for sustainable carbon dioxide removal (CDR) to minimise the rapidly increasing risk of transgressing ESTPs. Solar geo-engineering approaches remain speculative and subject to concerns over side-effects and governance. For the time being, they are not available to support prevention efforts, although additional research is merited. Overall, effective prevention strategies need to address all drivers of diverse tipping processes with coordinated cross-scale approaches.

Global institutions across multiple domains, including climate change, development and international migration, need to consider the implications of tipping processes for their effective operation, adjusting existing frameworks, approaches and practices for governing the impacts of global environmental change.

A 'polycentric' architecture that would distribute responsibilities for prevention and impact governance across multiple sites and scales of action, and attend to linkages, coordination and effective information flows between different actors and institutions, is the appropriate model for governance. Important decisions concern the differentiation between global-scale tasks, especially mitigation of GHG to limit global temperature increase, and those at regional and national scales, such as addressing secondary drivers of specific tipping systems (for example, deforestation for Amazon dieback). Regional and national institutions with a direct geographic relationship to a tipping system could also have responsibility for impact management, such as resilience building, adaptation or managed retrea



SCALE	SCALE-SPECIFIC ESTP GOVERNANCE TASKS	ACTOR EXAMPLES
GLOBAL	-Frameworks and principles -Prevention 1 (GHG mitigation) -Funding and capacity building for adaptation. Loss and Damage -Knowledge co-production, systemic risk assessment	-UNFCCC -CBD -UNEP -IMO -Transnational civil society organizations
REGIONAL (CORRESPONDING TO ESTP SCALE)	-Prevention 2 (regional drivers) -Coordination of adaptation planning and measures -Monitoring and early warning systems -Tipping-system specific learning and experience sharing	-Arctic Council -ACTO -OECD -International NGOs -Missing for many ESTPs
NATIONAL	-Prevention 3 (national drivers) -Planning and preparedness for impacts (adaptation, disasters, loss and damage, migration,-) -Monitoring and early warning systems -Science funding, knowledge co-production	-National governments -Indigenous peoples governing bodies -National Industry associations -NGOS
LOCAL	-Implementation of prevention measures (national and regional drivers) -Adaptation planning and action -Knowledge co-production	-City and municipal governments -Community organisations -NGOs

Figure 3.0.1: Polycentric Governance of an Earth system tipping point

Stylised depiction of polycentric governance for a tipping system, i.e., distributing and sharing responsibility for various tasks across multiple scales and institutions with multiple, networked actors at each scale and linkages (e.g., membership, information flows, coordination) across scales. The table summarises how key governance tasks could be distributed across scales for a specific ESTP. Not all relevant scales of governance are included; e.g., bi- and multilateral levels are missing.

There are well-developed global and national sustainability governance institutions that can and should adopt responsibilities for the governance of ESTPs. At the global scale, this includes the UN Framework Convention on Climate Change (UNFCCC) and Convention on Biological Diversity (CBD). Existing governance expertise across scales is strongest regarding mitigation, and weaker regarding impact management.

Existing institutions and measures need significant adjustments and strengthening in light of ESTPs, and we illustrate this need for reform specifically for the Paris Agreement (e.g. NDCs and the Global Stocktake, loss and damage). But many other institutions will need to reassess their efforts with regard to the risks of ESTPs. Governance capacity at the scale of specific tipping systems is currently limited (as in the Arctic and Amazon) or lacking (as in the tropical coral reefs, major ocean currents and monsoons). This is where most innovation and work is needed, including the consideration of new institutions or initiatives.

Key messages

- Governance of Earth system tipping points is lacking and existing global governance institutions do not address the specific risks they pose.
- Preventing the transgression of Earth system tipping points should become the core goal and logic of an urgently needed global governance framework. Such efforts need to pursue multiple objectives simultaneously, including risk minimisation, impact governance, justice and equity.
- Current climate mitigation efforts, including governance of short-lived climate pollutants and carbon dioxide removal need to be strengthened rapidly, and address non-climate drivers at regional and national scales.
- Governance of Earth system tipping points should be based on existing principles of global governance and international law, such as precaution, equity and justice, including care for future generations and deep cooperation, with decision making guided by anticipatory approaches and systemic risk governance.
- Governance of Earth system tipping points should be polycentric, distributing responsibility, authority and accountability across multiple scales and institutions, including at the regional scale of the tipping element.
- Earth system tipping processes challenge existing governance structures, e.g., for climate change impacts, because of the expanded scope of change, the increasing speed of change, the potential for regional trend reversals, and the novel distribution of vulnerability.
- Existing institutions for impact governance need to be adjusted to match the temporal patterns and spatial scales of different tipping systems to adequately anticipate, respond to, and mitigate their risks and impacts. In some cases, this might require new institutions or mechanisms.
- The transgression of Earth system tipping points would significantly increase the need to address irreversible losses. Loss and damage mechanisms within and beyond the UNFCCC would have to be expanded.
- Knowledge institutions need to be reformed to better support effective governance through solutions-oriented, context-specific, actor-relevant and anticipatory knowledge, while learning challenges must also be addressed.

Recommendations

- Now is the time for governance actors, including UN bodies, international organisations, national governments and non-state actors, to engage in the process of learning, interest formation/ positioning, coalition building, and agenda setting for the governance of Earth system tipping points.
- Given that Earth system tipping points risks are already moderate at current levels of warming, and increase substantially above 1.5°C above pre-industrial levels, countries need to reduce GHG emissions rapidly and dramatically in the near term and reach zero by mid-century to minimise the risk of transgressing tipping points.
- Parties to the Paris Agreement should include Earth system tipping points in future Global Stocktake processes, assessing collective progress towards their prevention and impact governance.
- Parties to the Paris Agreement should include a discussion of Earth system tipping points in future revisions of their NDCs and mid-century decarbonisation strategies, including an assessment of how the country contributes to tipping-points risks, how it will be affected by their impacts, and national measures and plans to prevent their transgression and to prepare for their impacts.
- Parties to the Paris Agreement should initiate an evaluation of the adequacy of current mechanisms for addressing climate change impacts (e.g. adaptation, loss and damage, finance) in light of the specific risks posed by Earth system tipping points.
- Countries within the geographic scope of a specific Earth system tipping element should consider the need for new initiatives for collective impact governance.
- International organisations, national governments and science funders should foster urgent international research collaboration, especially in the social sciences and humanities, by promoting open, trans and interdisciplinary, solutions-oriented, networked knowledge systems focusing on Earth system tipping points.
- Regional and national science and knowledge institutions and boundary organisations should foster anticipatory capacity building with participatory co-production processes involving policymakers, scientists, other knowledge holders, artists, and designers.

Chapter 3.1 Governing Earth system tipping points
Introduction

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Summary

Existing institutions of global sustainability governance do not address the specific risks and challenges posed by Earth system tipping points (ESTPs). State and non-state actors need to engage in agenda-setting for the development of a governance framework that can close this gap. This chapter seeks to inform emerging discussions, decisions and actions as tipping points move onto global and national policy agendas.

This chapter explores possible goals for the governance of ESTPs and relevant governance principles, actors and institutions, sites, and scales. Future governance efforts will have to simultaneously pursue and balance multiple objectives, prioritising the prevention of ESTPs. Several principles of international law and global environmental governance apply to this domain, including justice, precaution and adaptability. Focusing on the time-specific features of tipping processes and their implications for governance, we heavily emphasise the need for anticipatory governance with multiple time horizons, including some that exceed the scope and capacities of current global governance approaches.

A 'polycentric' governance approach is best suited for Earth system tipping processes, which play out at multiple scales. Principles for sharing responsibility, devising efficient information flows and learning at and across scales will be vitally important tasks for effective governance. Many existing institutions can adopt responsibilities related to tipping-point governance. At the global scale, the UNFCCC is key among these. A number of features of the Paris Agreement would need to be adjusted and revised to account for the specific challenges presented by ESTPs. Strong institutions at the regional (multilateral) scale of Earth system tipping elements are often missing, inviting consideration as to whether new initiatives are needed, for example, with a specific governance mandate for the tropical coral reefs or Atlantic Meridional Overturning Circulation (AMOC).

Key messages

- Governance of ESTPs is lacking. Existing governance institutions, e.g. for climate change, do not address the specific risks posed by ESTPs.
- Unavoidable tensions between the governance needs for ESTPs and other objectives – especially social and economic development and justice – need careful consideration. However, failing to prevent ESTPs would undermine and likely impede the achievement of the SDGs.
- Governance of ESTPs should be polycentric, distributing responsibility and authority across multiple scales and institutions. This includes the regional scale of specific tipping systems, where existing institutions are weakest or lacking.
- The diversity of Earth system tipping processes, e.g. in terms of their geography, timing and impacts, demands governance approaches that are to some extent tailored to a specific tipping point or class of tipping points.
- Tipping dynamics imply that short-term decisions (years) have consequences on short and very long time horizons (years to millennia). Once tipping points are transgressed, the unfolding of change processes can become unstoppable. These connections between the short and long-term dramatically elevate the imperative of near-term preventive action, requiring anticipatory governance and new risk-governance approaches.
- Public understanding of tipping processes is likely limited and hard to change with common forms of science communication. Public risk perceptions are unlikely to generate public pressure for climate action in the short term.

Recommendations

- Now is the time for governance actors, including UN bodies, international organisations, national governments and non-state actors, to engage in the process of learning, interest formation/positioning, coalition building and agenda setting for the governance of ESTPs.
- Existing sustainability governance institutions across multiple scales, especially those related to the international climate change regime complex, should consider including ESTPs in their mandates and action agendas. At the same time, coordination, transparency, and network development efforts between various governance sites need to ensure an effective division of labour, alignment and synergies between initiatives.
- Parties to the Paris Agreement should include a discussion of climate tipping points in future Global Stocktake processes, assessing collective progress towards their prevention and impact governance.
- Countries within the geographic scope of a specific tipping system (e.g. all countries with tropical coral reefs) should consider the need for launching new initiatives with the specific mandate to address this tipping process (prevention, impact governance, knowledge development).
- Governance actors and institutions in the public, private and civil society domains should strengthen their capacities for anticipatory governance and systemic risk governance, expanding and adjusting existing approaches to decision making with novel methods.

3.1.1 A new governance agenda for Earth system tipping points

While attention to the threats posed by ESTPs is growing, explicit governance efforts to address them do not yet exist. Governance refers to rules, regulations, norms and institutions that structure and guide collective behaviour and actions. This includes the processes that create governance, which often involve politics, policymaking and mechanisms for holding actors accountable for their actions and inactions. We consider not only governments and their intergovernmental initiatives as key actors, but also corporate and industry bodies, civil society organisations, cities and municipalities, as well as transnational networks.

The current landscape of global and regional (multilateral and non-state) environmental and sustainability governance efforts does not yet consider the specific challenges presented by ESTPs. For example, the constantly evolving regime complex for climate change centred on the UNFCCC is relevant and directly shapes tipping-point risks, especially through mitigation policies. But, even though tipping points have been given increasing attention in IPCC assessment reports (see Chapter 3.4), so far, the international climate change regime does not explicitly consider their risks in its goals and mechanisms. Similarly, the long-standing governance efforts for biodiversity, oceans, forests, the Arctic and Antarctic do not yet address ESTPs.

Given this status quo, the key task for the global community is the establishment of a governance agenda for ESTPs. To the extent possible, this requires adjusting existing institutions to account for ESTPs. But there might also be circumstances where such adjustments will not suffice, and novel frameworks, actors or institutions will be needed to anticipate, prevent the transgression of, and handle the adverse impacts of tipping processes. In some cases, such as climate change, the existing governance regimes are already complex, politically contested and cumbersome. Integrating a new set of challenges into their already-crowded agendas requires political attention, a set of committed actors, and (human, institutional and financial) resources, all of which are limited. Yet, this work is necessary and urgent and would re-frame and re-orient some of the existing governance efforts. Grounded in scientific knowledge, discussions about governing tipping points need to provide a clear and convincing logic for action. Strategic efforts are needed to build this agenda, helping various stakeholders develop an understanding of ESTPs and the risks they present, and fostering alliances of actors with shared perspectives.

Agenda-setting efforts need to consider several fundamental questions in this early stage of ESTP governance. These include:

Goals. What could and should be done about tipping points? What are the most important governance goals?

Actors. Who should be involved in tipping point governance? Who has responsibility, who is affected, who has relevant skills and capacities to address tipping points? How to ensure a voice for the most vulnerable or marginalised actors?

Scales. At what scales should tipping point governance take place? How can multi-actor and cross-scale interactions be coordinated?

Sites. What are suitable governance institutions to address ESTPs, and to what extent are new institutions needed?

Principles. What should be the governance logics and principles guiding the development of norms, processes and mechanisms?

Resources. Who finances governance efforts related to ESTPs?

Knowledge. What is the role of science, knowledge and predictive capacity in tipping point governance, and how should effective science-policy engagement be designed?

Below, we begin to address some of these questions with a specific focus on the specific tipping points identified in this report, including the questions related to governance goals and principles (3.1.2), actors, sites and scales (3.1.3). The chapter concludes with a brief discussion of some of the likely political challenges of ESTP governance (3.1.4). The following chapters address some of these topics in more depth. Chapter 3.2 explores prevention of ESTPs as a central governance objective. Chapter 3.3 is concerned with the governance of tipping-point impacts, including adaptation, loss and damage, and migration. Chapter 3.4 addresses questions of knowledge production and science-policy interactions related to ESTPs.

3.1.2 Governance goals and principles

Given this status quo of lacking specific governance responses to ESTPs (pre-governance), fundamental questions include what actors collectively want to achieve, and which principles should guide their collective decisions and actions. A central challenge in developing governance for tipping points is the scarcity of obvious procedural analogues or instructive case studies. However, governing ESTPs is still a question of governing political, economic and social systems where there are familiar repertoires involving goal setting, institutional design, regulation, financial incentives and behaviour change across multiple scales and sectors and communities.

3.1.2.1 Governance goals

Based on the significant risks posed by Earth system tipping processes – major self-sustaining reorganisations of natural systems with potentially significant, negative consequences for human wellbeing – there is a strong argument for prevention as the primary objective of governance in this domain. Climate tipping points present a variety of risks, but for many people, communities, ecosystems and even entire countries, they present an existential threat. Importantly, due to their specific causal dynamics (self-amplifying feedback mechanisms), the vast majority of tipping processes cannot be halted once they have started; after passing a critical threshold, systemic reorganisation is inevitable and often irreversible on human timescales.

That means that short-term decisions, actions and inaction (i.e., over the next 5-20 years) can have extremely long-term consequences and ripple effects over millennia. The here and now is causally connected to the deep future. Policymakers have to consider their responsibility for future impacts that only they are able to prevent.

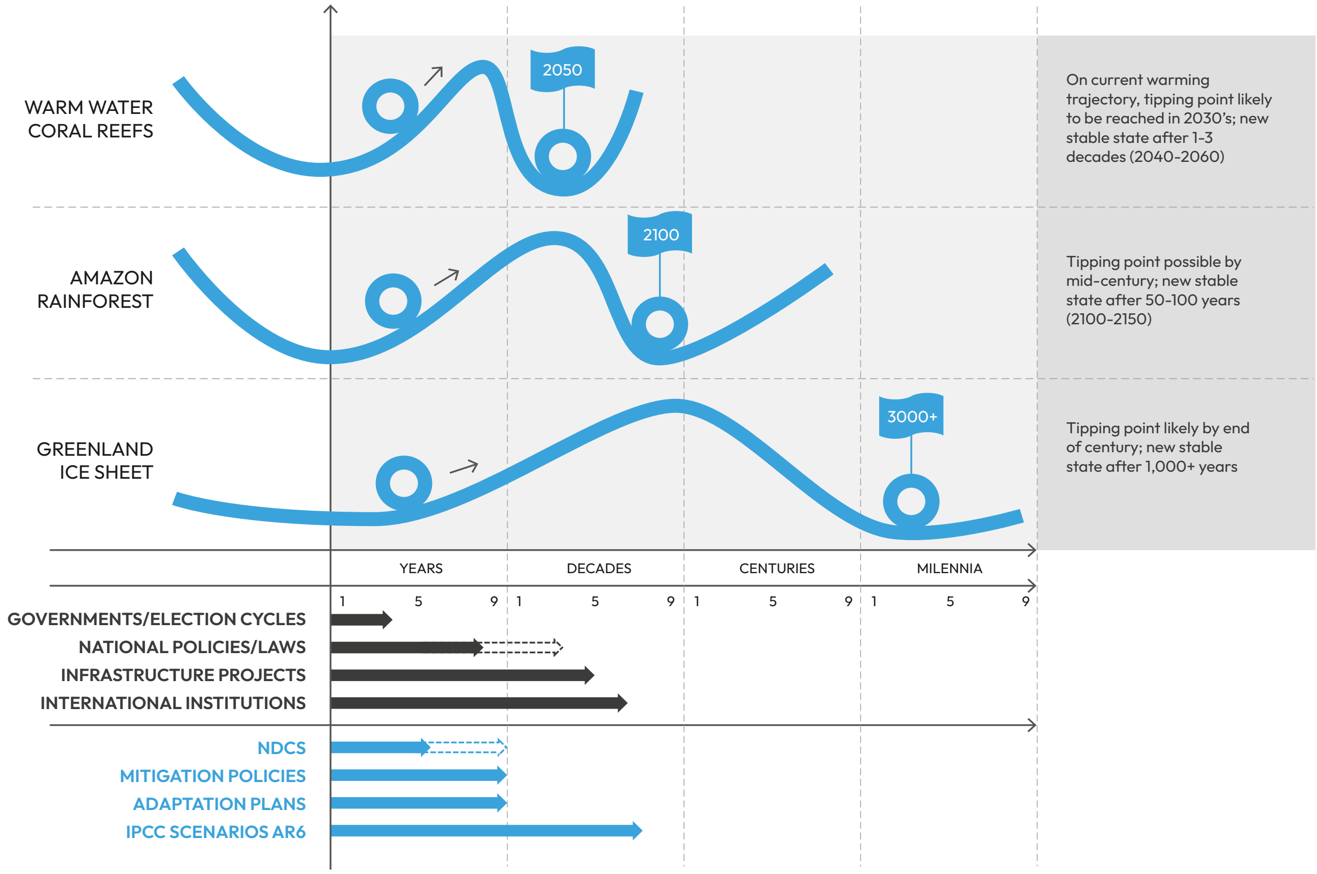

Figure 3.1.1: Temporal diversity of Earth system tipping processes. Stylized representation of the time-related characteristics of some tipping systems, especially differences in 'time until tipping' and differences in the length of the reorganisation process, and the comparative time horizons of political institutions and decision making. The figure does not represent system dynamics. There are significant uncertainties regarding these temporal characteristics. Assumptions about global temperature changes in the course of the century are based on Climate Action Tracker 2023, i.e., 1.5°C in the 2030s, 2.7°C by 2100.

While a focus on prevention is essential while it is still possible, governance actors have to consider additional objectives, especially the anticipation of adverse impacts of tipping processes. Some Earth system tipping processes, including the disintegration of the West Antarctic and Greenland ice sheets (see Chapter 1.2.2), might no longer be preventable, and some tipping points might be passed despite collective prevention efforts, making early impact governance imperative. Actors will need to balance their efforts between these multiple governance domains and objectives, and they will have to adjust their priorities to changes in the state of tipping processes over time – e.g. prioritising impact governance once scientific evidence for the transgression has become sufficient.

Figure 3.1.2 depicts how different governance objectives and corresponding activities would be distributed across the timespan of a tipping process. For this purpose, we outline three phases of a tipping process: pre-tipping, reorganisation after the transgression of the tipping point and stabilisation in the new system state. Based on current evidence and understanding, all ESTPs are in the pre-tipping phase. Given the existence of multiple potential ESTPs, future tipping-point governance would likely be in different phases regarding different tipping systems at any point in time. For example, there might be ongoing prevention efforts regarding the Amazon rainforest dieback (pre-tipping) while efforts regarding warm-water coral reefs might be focusing on impact governance (reorganisation).

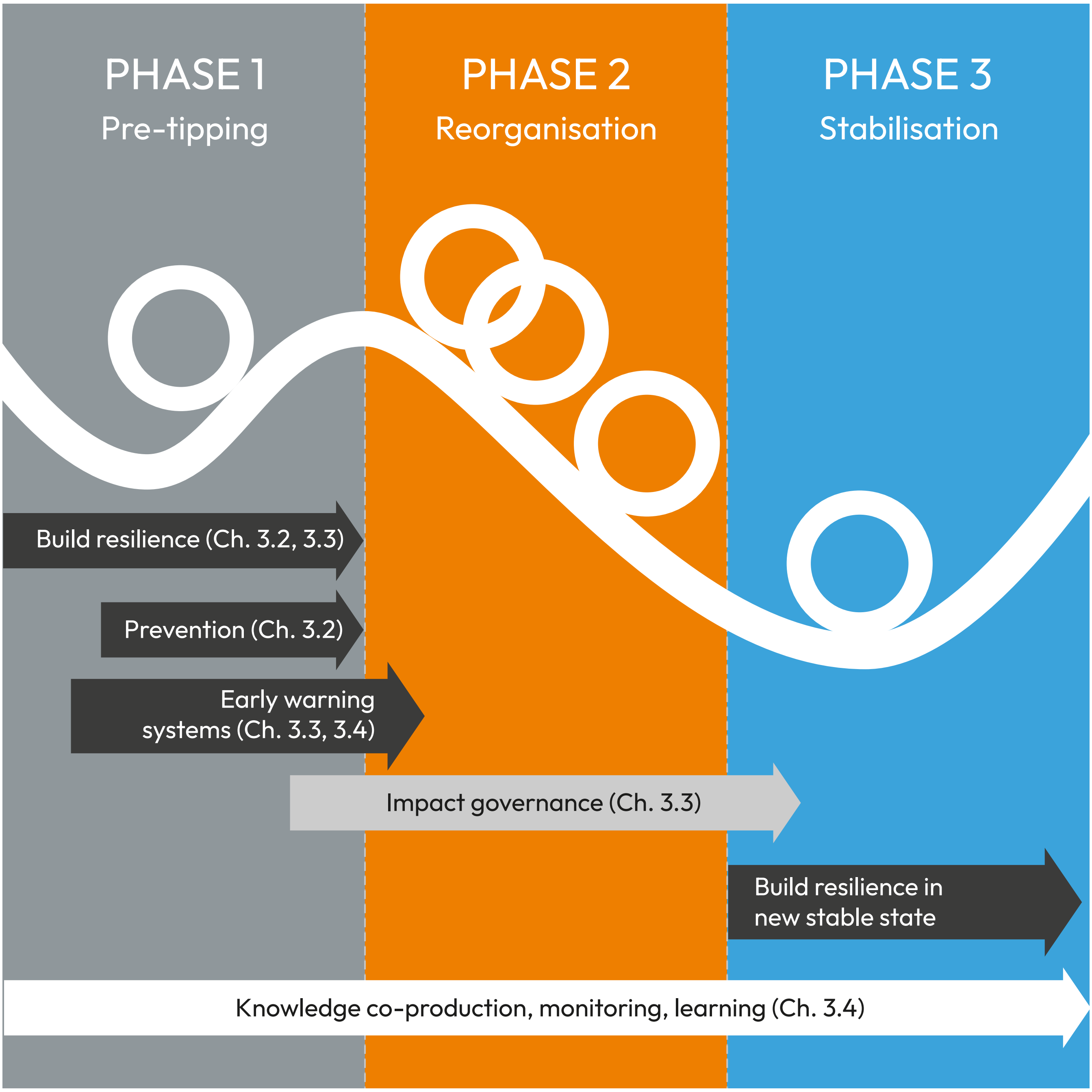

Figure 3.1.2: Governance tasks across different phases of tipping processes. The temporal distribution of governance objectives and activities across the timespan of a tipping process. Three phases can be distinguished: (1) pre-tipping, (2) reorganisation after a tipping point has been passed, and (3) stabilisation of the new system state. Each phase is associated with distinct objectives and corresponding governance activities. In Phase 1, the focus of governance should be on preventing the transgression of the tipping point and fostering resilience of the tipping system in question as well as potentially affected communities. Impact governance has to start in this phase (anticipation, preparation, planning), and becomes the single focus of governance efforts in phase 2. Once the tipping process (system reorganisation) has started, prevention efforts are no longer effective with regard to this tipping system, but continue to be needed for other ESTPs. In phase 3, governance needs to focus on stabilising new conditions and rebuilding resilience. Knowledge production and learning are necessary across all phases.

Addressing the expected impacts of ESTPs is strongly linked to the existing governance frameworks for climate change adaptation, vulnerability, resilience-building, and loss and damage. In light of tipping points, the goals, approaches and institutional frameworks in this domain will require adjustments and rethinking. Some tipping processes can unfold over decades, centuries and millennia, presenting decision makers and affected communities with the prospect of continuous change over long time periods until the tipping system in question reaches a new stable state (i.e., the loss of stable climatic conditions for decades/foreseeable future). The type and scale of their impacts will change over the entire period of the state shift. What's more, tipping processes display changing time-related characteristics while they unfold (e.g. increasing rates of change in certain time periods). Impact governance, especially adaptation planning, needs to take these characteristics into account.

Further, tipping processes in major Earth systems imply that the current, familiar state of these systems will be irrecoverably lost (e.g. coral reef state vs. algae-dominated state), and not merely temporarily altered with the option to re-establish current conditions. Affected communities will experience this disappearance of current Earth system characteristics as losses – the removal of the climatic foundations of current social structures. These losses of current economic, social and cultural conditions can occur on relatively short time horizons after the transgression of tipping points. Therefore, loss and damage institutions will have increased importance in the governance of ESTPs. At the same time, tipping point impacts could undermine institutional governance capacities, either directly or via political disruption or conflict (Howard and Livermore, 2019; Laybourn, Evans, and Dyke, 2023).

In some cases, tipping processes could challenge or render meaningless current governance logics and approaches due to their unexpected impacts. For example, the potential slowing or shutting down of convection in the North Atlantic Subpolar Gyre (see Chapter 1.4.2.1) could lead to regional cooling in Northern Europe and along the North American East coast, as opposed to currently expected warming trends in these regions. Existing adaptation plans will have to take these insights into account and be prepared for the fundamental changes in logics and approaches that might be needed.

Importantly, the set of ESTPs that have been identified to date are highly diverse in terms of the affected systems, the timing and length of the tipping process, and the kinds of interacting impacts they will have on societies and ecosystems. The design of risk assessments, prevention approaches, adaptation strategies, and loss and damage institutions will have to be specific for and targeted to each affected region and climate tipping point. At the same time, impact governance needs to consider potential interactions between multiple tipping dynamics (see Chapter 1.5) and their impacts (double or multiple exposure).

Prevention efforts serve as important 'brakes' on the drivers of climate change and tipping points; impact management is necessary to the extent prevention might be ineffective or fail. A more holistic – and systemic – approach to the governance of ESTPs would seek levers that could simultaneously reduce pressures on tipping systems and contribute to resilience to impacts. Scholarship on transformation and climate justice points out that ingrained societal, economic and geo-political structures drive resource extractivism as well as inequality and vulnerability (Gupta et al., 2023; Whyte, 2020; Ghosh, 2021). Transformations towards sustainable and just societies (Patterson et al., 2017; O'Brien, 2018; Bennett et al., 2019; Scoones et al., 2020) would simultaneously reduce emissions, foster social-ecological resilience, increase justice and equality, and create the conditions of trust (between individuals, communities, countries and generations) that are needed for the effective, cooperative governance of ESTPs (see also Section 4). For example, increasing access to renewable energy in communities without electricity could increase adaptive capacity, reduce vulnerability and contribute to mitigation at the same time. Depending on the way new energy infrastructure is developed and ownership rights are designed, these changes could also increase justice and social cohesion.

3.1.2.2 Governance principles

Many existing principles of international law and global environmental governance – shared beliefs of a fundamental nature that guide collective decision making and behaviour – are relevant for the governance of ESTPs. Below, we briefly discuss some of the principles we consider most important in the specific context of rapid state shifts in large Earth system components, recognising that others also matter. For instance, accountability and transparency are general governance principles we do not discuss here, as is the no-harm principle. Further, recent debates in international environmental law address the human right to a clean, healthy and sustainable environment and the legal rights of nature, which we only mention in passing. We also observe an emerging debate about shifts from international law and governance to Earth system law and governance (Patterson et al., 2018; Kotzé and Kim, 2019; Kotze et al., 2022).

More generally, the governance of complex and complex-adaptive systems like the climate, which are characterised by non-linear dynamics, threshold effects, cascades and limited predictability, demands an approach that is distinct from presently dominant patterns of governing that usually assume linearity and simple causality (Duit and Galaz, 2008). Core principles of complex systems governance include multi-scale and multi-network approaches attending to cross-scale interactions (Galaz et al., 2016), anticipatory governance addressing unusual temporalities (Muidermann et al., 2020; Boyd et al., 2015), diversity in response capacity (Galaz et al., 2016), and adaptive governance, i.e., the ability to adjust to the changing conditions of the system that is being governed (Duit and Galaz, 2008). The latter requires managing tensions between "the dual needs of institutional stability and change" (Duit and Galaz, 2008, p. 320) – i.e., the ability to work in stable patterns of cooperative rules and processes and the need to search for, explore, and experiment with novel patterns.

Across all principles, here we emphasise the need for a significantly strengthened **anticipatory approach** in the context of Earth system tipping. The potential for irreversible yet delayed harms calls for foresight and anticipatory actions despite incomplete knowledge. Delayed action can make managing tipping points in the future much more costly or even impossible due to their self-perpetuating and irreversible nature. At the same time, uncertainties, delayed impacts, distant planning horizons, and the more immediate demands of present challenges, undermine the motivation or perceived need to act now.

Anticipatory governance is a "flexible decision framework that uses a wide range of possible futures to prepare for change and to guide current decisions to ensure a range of future alternatives and to minimise future risks" (Quay, 2010). It differs from conventional policymaking and planning, which tends to rely on expert-driven forecasting and quantitative modelling. Anticipation often involves collaborative and participatory processes; systems for experimenting, exploring, or envisioning future scenarios qualitatively and identifying pathways of change; strategic investments that increase the resilience or robustness of a system; and the capacity to adapt quickly to changing and dynamic conditions. The incorporation of Earth systems tipping dynamics in simulations, scenario development and public communications may help make the impacts of these processes more tangible, and thus easier to respond to. It is important to note that anticipatory processes can open up but also close down possibilities for action, depending on their design (e.g. who participates). Avoiding the mere reproduction and reinforcement of existing and dominant paradigms requires designing processes that can expand possibility thinking (Muiderman et al., 2023) by carefully managing the role of power in anticipatory processes.

Governance actors, including international institutions, can increasingly rely on anticipatory processes and tools to develop shared understandings of possible futures and pathways towards them, including participatory scenario development and serious gaming (Flood et al., 2018; van Beek et al., 2022; Vervoort et al., 2022). Strengthening long-term governance capacities and deliberate approaches to dealing with uncertainty is time consuming, more resource intensive than conventional science-policy interactions, and requires openness to non-conventional ways of collective learning.

Uncertainty and precaution: Like many other environmental issues, the governance of ESTPs relies on evolving scientific knowledge and must grapple with a range of uncertainties related to scientific evidence at a given point in time. Key uncertainties concern which Earth system elements exhibit tipping dynamics, the specific conditions and timing of the passing of tipping points, and the types, location and timing of various impacts of tipping processes on the natural world (e.g. changes in storm and precipitation patterns) and even more so societies (see Section 2). Given these uncertainties, the precautionary principle is relevant for the governance of ESTPs. It has been defined in different ways, including in the 1992 Rio Declaration (UNCED 1992): “Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.” Yet, beyond this definition, the nature and contents of the precautionary principle has been debated (O’Riordan and Jordan, 1995; Stirling, 2007; Brunnée and Streck, 2013; Read and O’Riordan, 2017).

Developing practical approaches to implementing the precautionary principle is a key part of the tipping point governance agenda.

Justice and equity: Justice and equity must be key considerations of environmental governance. The concept of environmental justice has national roots in US politics (Bullard, 2021), requiring the fair treatment and meaningful involvement of all people, regardless of their race, gender, colour, nationality, religion or other characteristics, in the development and implementation of public laws and policies. But the fundamental principles of distributional, recognitional and procedural justice also apply between countries in the international system (Vanderheiden, 2008; Bennett et al., 2019), especially in a North-South context (Najam, 2005). Recently, scholars have attempted to integrate concepts of justice with that of Earth system boundaries (Rockström et al., 2023) to propose Earth system justice as a guiding framework for global governance (Gupta et al., 2023). This framework emphasises just ends, ensuring that we remain within planetary boundaries, and just means, which calls for an equitable distribution of resources, responsibilities and harms, both within and across generations.

A specific expression of the principle of justice in international environmental law and governance is Common-but Differentiated Responsibilities and Respective Capabilities (CBDR-RC). This principle has been fundamental to the climate change regime. In a general sense, it concerns the fair distribution of a shared responsibility to act on climate change, including emission reductions and the provision of international assistance (e.g. in terms of finance, technology, capacity building), taking into account national circumstances and historical contributions to emissions. Significant differences exist in interpretation of the principle, reflecting deep, unresolved disputes in international climate politics. Given the central role of atmospheric warming as a driver of all Earth system tipping processes, a future discussion about the shared but differentiated responsibility for Earth system tipping will likely mirror existing debates between the Global North and South, more and less-developed nations, fossil fuel producers and consumers, and more and less-vulnerable nations. This will include questions of historical responsibility and corresponding expectations for the provision of financial support for climate action (Colenbrander et al., 2022). At the same time, new questions will arise about specific tipping systems – e.g. whether and to what extent individual governments, industries, companies or other actors have responsibility for so-called ‘co-drivers’ of tipping, such as deforestation in the world’s major forest biomes or ocean pollution near coral reefs.

Future care and intergenerational justice: While we may be nearing certain critical thresholds today and may experience the impacts of tipping points in the coming years and decades, many tipping processes and their largest impacts will unfold over hundreds and even thousands of years. This poses a long-term and intergenerational social dilemma, elevating the importance of intergenerational justice (Barry, 1997; Gardiner, 2011; Meyer, 2017) and long-term i.e., - future care. Intergenerational justice concerns the relationship between generations, more specifically the rights of future people and how they should be recognised and safeguarded in the present. A broader socio-ecological perspective of long-term care for planet Earth must also consider ethical obligations towards future non-human life, which also depends on the decisions and actions of present generations.

There are different perspectives on principles of future care, and to what extent it could and should shape decision-making processes. For example, in asserting the equal importance of inter- and intra-generational equity, the Earth system justice framework (Gupta et al., 2023) promotes equality and inclusion today to minimise harms from inherited inequality in the future. It also asserts the right of all future people to enjoy a standard of living comparable to the one of present generations and argues that current people bear responsibility for future harms and inequalities arising from our actions. This mirrors the Iroquois principle of thinking for the seventh generation, which entails both providing for the interests of descendants and making reparations for past harms inflicted by our ancestors.

Humans have the ability to plan for posterity and to take actions that will resonate hundreds of years into the future, yet this ability is not reflected in mainstream institutions, decision-making logics and governance approaches (Krznaric 2020).

Many of our existing institutions have short time horizons relative to the temporal scale of some of the Earth System tipping elements and do not value the interests of future generations. (Gardiner, 2006; Krznaric, 2020).

Recent efforts to better protect the interests of future generations include fostering representation of present-day children and youth in policymaking (e.g. lowering the voting age, establishing youth and climate councils) and increasing climate litigation on the grounds of intergenerational equity. Creating dedicated institutions with the central aim to safeguard the interests of future generations may be another promising pathway to increasing intergenerational justice (Slobodian, 2019). Examples include the Welsh Well-being of Future Generations Act, which requires public bodies to consider projects’ impacts on future generations and created the position of the Future Generations Commissioner. Further, some countries already recognise the rights of nature with legal – including constitutional – means. For example, Ecuador and Bolivia have adopted constitutional rights of ‘Mother Earth’, while other jurisdictions have recognised the legal personhood of specific ecosystems like rivers (New Zealand, India). These could offer blueprints for the protection of future non-human life.

Adaptive governance, agility and continuous learning: The Earth system consists of coupled natural and human systems and can be described as a complex-adaptive system. Tipping points are features of complex-adaptive systems. The inherent limits to control and planning in complex (as opposed to mechanistic) systems have consequences for the design of governance institutions. One of these is the need for continuous system monitoring and learning about the system’s responses to decisions, policies and governance efforts. Building ongoing learning, responsiveness to observed changes, and flexibility to adjust policies into the design of institutions is called adaptive governance – actors adapt their approach in response to the feedback they receive from the system (Young, 2012; Armitage, Marschke, and Plummer, 2008; Folke et al., 2005). More broadly, recognising that knowledge about the dynamic processes of Earth and social systems is always evolving and never complete, governance has to take place in a close relationship with science and other ways of knowing, with frequent learning loops, monitoring and early warning mechanisms at the science-policy interface.

Systemic risk governance: ESTPs present significant – possibly irresolvable – challenges for conventional risk management approaches in organisational decision making due to the nonlinearity of the change process, the long time horizons, and the potential severity and irreversibility of impacts. Tensions in integrating tipping points into risk management frameworks may arise around commodification or monetisation of nature, mirroring tensions around natural capital accounting (Smessaert, Missemer, and Levrel, 2020). Tipping processes and the threats they present are better characterised as deep uncertainties, existing in a problem context where neither the probability of an event nor its impacts (i.e., harm) can be adequately expressed in terms of economic costs or other quantitative measures. Hence, the suitability of cost-benefit analysis and the standard practice of discounting - translating the financial value of future assets, resources or costs and damages into 'present value' by applying a specific rate smaller than 1 resulting in a reduction or devaluation - is severely limited in this decision context, even raising ethical concerns with regard to intra- and intergenerational justice (Weitzman, 2009; Gollier and Weitzman, 2010; Stoddard et al., 2021; Roemer, 2011).

More generally, this type of risk cannot be managed in the common sense of risk management (e.g. quantitative assessment, mitigation and hedging), but demands novel risk governance approaches (Galaz et al., 2017). Existing discussions about global systemic risk (Homer-Dixon et al., 2015; Centeno et al., 2015; Schweizer, Goble, and Renn, 2022; Juhola et al., 2022), telecoupling (Liu et al., 2015), polycrises (Homer-Dixon et al., 2021), risk-transfer analysis (Graham and Wiener, 1997), and 'integrated catastrophe assessment' (Kemp et al., 2022) offer important starting points. These approaches share a set of concerns that should form the foundation of risk assessment and decision making related to ESTPs. First, they consider a broad spectrum of risks (socio-political, material, technological, environmental) that also include risks stemming from human and governance responses to problems, such as abatement measures, maladaptation or authoritarianism. Correspondingly, they stress the need to assess risk trade-offs and balances. They also encourage risk assessment that captures a broader set of possible outcomes, especially catastrophic risks – e.g. related to high-end climate scenarios (Kemp et al., 2022). Second, systemic risk assessments take into account multiple possible interactions between determinants, drivers and types of risk, rather than assessing single risks in isolation (Simpson et al., 2021). This includes the possibility of compound risk at one scale but also scale-crossing dynamics (risk propagation) (Homer-Dixon et al., 2015; Centeno, Miguel A., Manish Nag, Thayer S. Patterson, Andrew Shaver, and A. Jason Windawi. 2015. "The Emergence of Global Systemic Risk." Annual Review of Sociology 41 (August): 65–85). Third, they consider how these interactions can create cascading dynamics across different systems (e.g. industries, countries, ecosystems), including tipping point cascades. This third dimension highlights the need to consider cascading risks in decision making and the development of governance approaches to cascade dynamics in complex systems.

Systemic risk governance should be informed by an in-depth analysis of feedback mechanisms and cascading effects between systems and subsystems, and it needs to be adaptive toward rapidly shifting societal contexts and demands. Containing systemic risks requires adaptive governance approaches at multiple institutional levels that are able to assess and respond to the underlying complex systems mechanisms. Governance needs time-sensitive monitoring of social-ecological systems and the implementation of early warning systems to manage cascading effects and tipping points.

Engaging with stakeholders, the affected public, and establishing regulatory frameworks and networks of institutions and actors is essential. (Juhola et al., 2022).

Response diversity: Diversity in governance responses and capacities is particularly important for governing complex systems (Walker et al., 2023). "Response diversity is a system's variety of responses to disruptions of all kinds. (...). It suggests keeping options open for unexpected situations (...)", including through creation of generic capabilities that can be adjusted as new information comes in and that have ideally positive externalities and co-benefits (Frank et al., 2014). Response diversity can be realised spatially, temporally, and between actors and institutions. For example, international trade provides spatial response diversity against disruptions at national or local scale, which can be further strengthened through trading with multiple sources and using various transport routes or modes. Temporal response diversity refers to variation in resource use over time and requires storage infrastructure; examples include storage in granaries and reservoirs, or banks and insurances. It is also important to account for possible cross-scale interactions, as building response diversity at smaller scales can erode response diversity at larger scales if local initiatives copy each other. Cross-scale interactions that erode the overall resilience can also occur between social and ecological systems. This facilitates complementarity and backup responsiveness, i.e., if one response fails, a higher level one can be activated.

Diversity in response capacity comes at high costs because it requires redundancies. The design of such a governance infrastructure needs to balance response diversity and efficiency. While fostering diversity and functional redundancy runs counter to standard policy making logics that prioritise efficiency, it will be key for building impact management governance of tipping points. Response diversity can also lead to fragmentation, conflict, and overlapping mandates; hence, smart a principled coordination is needed (Galaz et al., 2016).

Deep cooperation: By their nature, ESTPs require cooperative solutions of all kinds – international, multisectoral, regional, even intergenerational – in addition to existing cooperative efforts related to climate change. But while more cooperation is needed, it will also become more challenging to develop cooperative solutions because of tipping points. They could easily trigger short-sighted responses such as resource grabbing, elevating nationalism and fronting security concerns with competitive logics that could undermine effective governance or even worsen the problem. The changes created by tipping dynamics could add their own, quickly growing, pressures on governance actors, threatening to overwhelm longer-term governance agendas with increasingly frequent crisis management and new international tensions related to migration and geopolitical changes (Howard and Livermore, 2019). The more effort needed to deal with the immediate, the less that will be available for the longer-term global governance required (Homer-Dixon et al., 2015; Laybourn, Evans, and Dyke, 2023). Despite the significant challenges of devising cooperative and effective global governance solutions, the logic of deep cooperation – across scales, borders and sectors – must supersede other more competitive, nationalistic or profit-seeking ones when dealing with Earth system tipping processes.

3.1.3 Actors, institutions, and scales of action

At this early stage of governance efforts related to ESTPs, there is not yet an established set of governance actors and institutions with explicit mandates or roles.

Given that many ESTPs are a consequence of climate change, it might seem obvious to address this set of challenges in the existing governance institutions for climate change. In line with this rationale, most of the scholarship on climate tipping points so far treats them as a single, global-scale issue that should be added to the agenda of the UNFCCC. However, a more nuanced perspective is needed that accounts for the complex existing climate change governance institutions at multiple scales, (the diversity of ESTPs with different drivers and impacts at multiple scales, and the corresponding need for a multi-scale, polycentric governance approach. The international regime for the governance of climate change is not the only one with a mandate that is relevant for ESTPs; other multilateral institutions could play an important role, including the Convention on Biological Diversity (CBD), the Arctic Council, the Antarctic Treaty, the recent High Seas Treaty, and the UN Environment Programme. More generally, different kinds of multilateral and international institutions can be distinguished:

- General bodies and specialised agencies of the United Nations (UN) system (global scale).
- International organisations based on treaties like the UNFCCC or the CBD.
- Regional bodies that can be treaty-based (e.g. Amazon Cooperation Treaty Organization, ACTO) or serve the purpose of political cooperation (e.g. Arctic Council).

Each kind has different characteristics and corresponding strengths. For example, treaty-based organisations have relatively rigid mandates formulated in an international treaty, while political cooperation platforms have more flexibility in adjusting their scope and agendas.

Here, we focus on the climate change regime before briefly discussing other institutional settings where tipping points could be addressed. This discussion seeks to open a debate about the need for novel governance institutions (and actors) that operate at the scale of a specific tipping element.

3.1.3.1 The multiple scales of tipping point governance

When considering what institutions of governance would be the most appropriate to address the risks posed by ESTPs, three non-mutually exclusive logics can be employed. First, ESTPs are arguably of **global concern** that requires global-scale governance, especially with a view to the possibility of tipping point cascades. While some tipping systems have a more regional character or focal point than others, they can have global-scale – or at least globally distributed – drivers. Additionally, most tipping processes have impacts and impact chains that would reach far beyond the regional scope of the tipping element. Given that Earth system tipping processes are a result of climate change, the international climate change regime centred on the UNFCCC might be the most suitable place to address tipping points, supported by the global-scale scientific knowledge production in the IPCC. Other global institutions could include the CBD and IPBES or UNEP (particularly for biosphere tipping systems).

Second, **governance might correspond to the geographical scale of the tipping system**. All tipping systems have a large geographical extent or distribution, crossing multiple national boundaries and affecting people in specific but often disconnected and widely dispersed regions. For instance, the world's warm water coral reefs can be found in multiple countries around the Pacific, Indian and Atlantic Oceans, while the Amazon rainforest stretches across eight countries. A number of tipping systems are close to the Arctic. Given this sub-continental/regional character (a scale below the global but above the national) governance institutions that operate at the scale of the tipping element might be most suitable to address the challenges specific to each tipping process. In some cases, like the Arctic, regional bodies already exist that could consider including tipping points in their mandate (Aakre et al., 2018) and changing their current character from coordination platforms to governance institutions. For example, a recent Amazon summit has given momentum to the idea of pan-Amazon governance, e.g. to tackle deforestation, potentially via the Amazon Cooperation Treaty Organization (ACTO). In other regions, existing governance fora might be weak and not willing to expand their scope and mandate. In cases where institutions at the scale of the tipping system do not exist (e.g. coral reefs, mountain glaciers, or the AMOC), the creation of new ones with a tipping point-specific mandate could be considered to match this scale and the corresponding problem structure (Galaz et al., 2008; Lebel et al., 2013).

Box 3.1.1: Regional institutions and tipping point governance

The **Arctic Council** operates at a scale that corresponds to a number of Earth system tipping elements, including the Greenland Ice Sheet (GrIS), the Arctic winter sea ice, and permafrost thaw. Based on this geographical scope, the council could be considered as a potential site for addressing tipping systems in the Arctic region.

An intergovernmental political forum among the eight Arctic states, with the involvement of Indigenous peoples, the council's main purpose is to promote cooperation in the Arctic – a mandate that does not yet encompass governance in the sense of collective rule-making. Although it does not develop binding frameworks, it has a strong science-policy interface and scientific capacity, including the Arctic Monitoring and Assessment Program (AMAP), and, in the past, it has been effective in setting policy agenda on novel issues of environmental concern.

The Arctic Council's work is organised in working groups, task forces and projects, with multi-annual priorities set by a rotating chairship. Despite its weaknesses, the existing model of involving Indigenous peoples in the Arctic as permanent representatives is a good foundation for engaging affected communities in governance related to Arctic tipping points. The council's limited membership could benefit effective decision making, but might also create challenges when other countries desire to be involved in decisions regarding Arctic tipping points. Such a desire could arise, for example, when a country believes it will be affected by an Arctic tipping process or by a cascade of Arctic and other tipping systems. Such tensions and questions around membership and participation already arise today in the context of new mineral discoveries and extractive interests, as well as changing security profiles as ice sheets recede and geographic conditions change.

The Arctic Council also illustrates some more general challenges of intergovernmental tipping-point governance. Its current operations (as of October 2023) are suspended following the Russian invasion of Ukraine. International politics, conflicts and other developments that are not directly related to the Arctic or climate change can hobble this and other institutions at any point in time, possibly undermining the chances of effective governance. Given the need for stable and continuous cooperation and decision making over very long time horizons, coupled with the potential need to respond swiftly to new scientific information, it is unclear how effective, uninterrupted governance institutions can be designed for Earth system tipping points.

Third, **governance could follow the Earth system component** relevant for a tipping system – for instance oceans, corals, forests, etc. However, for some of these issue areas, global and regional institutions are weak (e.g. tropical forests) or non-existent (e.g. corals, permafrost). Regarding the cryosphere, existing bodies are primarily of a scientific character (e.g. the Arctic Monitoring and Assessment Programme), pointing back to a responsibility for the climate regime. Further, the impacts of Earth system tipping processes will always be felt at the local (municipal), national, and regional scales, where most adaptation and impact governance will take place.

Given the relevance of multiple scales and their interactions, a **polycentric approach** (Ostrom, 2010; Jordan et al., 2018) that purposefully crosses these and governance sites would be most suitable for addressing ESTPs. "Polycentric systems are characterised by multiple governing authorities at differing scales rather than a monocentric unit" (Ostrom, 2010, 552), with each unit having significant independence and rule-making authority. Polycentricity builds on the concept of multilevel governance, which "takes place through processes and institutions operating at, and between, varieties of geographical and organisational scales involving a range of actors with different forms of authority" (Duit and Galaz, 2008, p. 318).

A polycentric governance network for ESTPs would distribute responsibility across scales, where some issues are addressed with global frameworks (e.g. emission reductions, financial mechanisms, international migration), while others are tackled at the regional scale (e.g. addressing secondary drivers of tipping processes), and some centre on local communities (e.g. adaptation). Regional actors might play important roles for framing, norm setting, mobilising action and building adaptive capacity related to a specific tipping element. They are often best positioned to support knowledge production regarding the tipping system in question, including the detection of early warning signals, by drawing on local and Indigenous knowledge. For example, in 2023, the Inter-American Network of Academies of Sciences launched a new initiative on the Amazon region that could provide the knowledge base for governance efforts at the scale of the Amazon rainforest (e.g. in regional bodies like ACTO or the Organization of Amazon States), and in 2022 Indigenous organisations under COICA from across Amazonian countries collaborated with scientists on a report highlighting that localised dieback is already occurring in some areas (Quintanilla et al., 2022).

Regional governance bodies also provide strong platforms for mutual learning and sharing governance experiences, amplifying the effects of successful interventions. Importantly, they could be responsible for addressing regional drivers of tipping processes – e.g. deforestation in the case of forest biomes. (For a more detailed discussion of multi-scale prevention approaches, see Chapter 3.2.) Bodies at this scale tend to face challenges in attracting signatories, establishing binding agreements, and enforcing and monitoring agreements. At the same time, the interests of the participating countries are more likely to be aligned, the scope for cooperation is smaller and the need for action is likely to be more immediate and salient. National and local actors also have the authority and expertise to deal with the impacts of a tipping process.

Importantly, "global networks need to build a capacity to coordinate actors at multiple levels and from different networks as they attempt to respond to potential 'tipping points' of concern" (Galaz et al., 2016, p. 198). A polycentric approach would require strategic efforts to align and coordinate across the network of governance institutions, managing institutional interplay (Elsässer et al., 2022), and maximising synergistic effects. At the same time, these linkages need to avoid rigidity and introducing their own vulnerabilities to cascading failure. Mutual learning and sharing of experiences among actors at a specific scale and across scales is an important component of effective polycentric governance.

3.1.3.2 The international climate change regime

While this report covers ESTPs beyond the climate system, climate-related tipping points present the majority of the tipping systems addressed. This raises important questions regarding the relevance and ability of the international climate change regime to govern climate tipping points.

The global climate governance landscape is polycentric, with a wide variety of actors from international regimes, transnational institutions, city and municipality-based initiatives, with a major role for national governments, but also non-governmental organisations and (transnational) civil society, the private sector and Indigenous peoples (Jordan et al., 2018). Yet, this landscape lacks institutions to specifically address tipping points. The international climate change regime orchestrates activities in this landscape (Hale and Roger, 2014) – for example, the UNFCCC and its treaties, especially the Paris Agreement, adopted in 2015.

The climate change regime is the most relevant global-scale option for the governance of ESTPs. Addressing such tipping points falls directly within the scope of the UN Convention (Art. 2 "to achieve, [...,] stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system") and its related treaties. Climate tipping points present dangers in the sense of the convention that need to be prevented (Lenton, 2011). The relevant objective of the Paris Agreement is to "strengthen the global response to the risks of climate change" (Article 2), including limiting global temperature increase, strengthening adaptation abilities and changing international financial flows to support mitigation and adaptation efforts.

Tipping points have found their way into the climate negotiations only recently with a speech by UN Secretary General Guterres at COP26 in 2021 and a first mention of tipping points in the cover decision of COP27 (UNFCCC, 2022). However, they are not yet a part of the negotiation agenda. The climate regime's rules and processes, especially regarding mitigation and adaptation, would need to be reviewed and adjusted to account for tipping points. Responsible bodies and decision-making procedures exist and could add climate tipping points to their agendas.

Even though climate tipping points squarely fall into the scope of the existing climate change treaties, relevant processes for addressing tipping point risks within the regime remain underdeveloped. The following components of the **Paris Agreement** are particularly relevant for the governance of climate tipping points and offer the potential for reinterpretation or adjustment: the global goals, especially the temperature goal, the timing of emissions peaking (i.e., reconsidering acceptable mitigation pathways), the content of Nationally Determined Contributions, and review and transparency mechanisms, especially the Global Stocktake, are relevant for efforts to prevent tipping points (see Chapter 3.2). The Paris Agreement's stipulations on adaptation, and the still-skeletal loss and damage mechanism are relevant for governing the impacts of tipping processes (see Chapter 3.3). Tipping points present a strong logic for the expansion of international loss and damage provisions, possibly adding more tensions to this ongoing, contentious debate between countries.

The important role of sub-national and non-state actors ('non-party stakeholders') for global climate governance has been formally recognised by the UNFCCC (Hale, 2016), and is the foundation for an increasing number of initiatives that bridge the intergovernmental and non-governmental spheres, e.g. the Global Climate Action Portal and the High-level Champions. These existing initiatives could be important for making and implementing decisions related to climate tipping points. For example, the High-level Champions are supporting the Breakthrough Agenda efforts to accelerate decarbonisation.

Table 3.1.1: Features of the Paris Agreement that need adjustment to account for climate tipping points.

Topic	Paris Agreement stipulations	Adjustments required
Global goals	Art. 2 (1)	Reinterpretation of the global temperature goal to minimise the risk of transgressing a tipping point; strengthening rationale for 1.5°C and recognising that an even lower long-term global temperature goal would be safer.
Emissions peaking	Art. 4 (1)	Establish an ad-hoc working group on acceptable mitigation pathways that takes tipping point risks into account, especially the need to minimise peak temperature and temperature overshoot period.
NDCs	Art. 4 (2) - (19)	Include climate tipping point risks in NDCs; Parties should map and describe their exposure and contribution to tipping point risks (which tipping points, what kinds of contributions and impacts), and how their plans and actions address these risks (e.g. mitigation ambition, measures to address secondary drivers of tipping processes, adaptation measures, support for knowledge development).
Adaptation	Art. 7	Account for tipping points in adaptation frameworks, especially the possibility of trend reversals, non-linear changes and new vulnerabilities to tipping points.
Loss and damage	Art. 8	Interpreting Art. 8 (4) items c and d to include climate tipping points. Anticipatory expansion and funding of the loss and damage framework, taking the risk of climate tipping points into account.
Public engagement	Art. 12	Experiment with and foster novel forms of public engagement and anticipatory learning, including participatory, active, immersive, multi-sensory learning – e.g. using serious games, storytelling and visioning.
Transparency framework	Art. 13	Within their obligations under the Transparency Framework, especially (7) item b, Parties should include information regarding their achievement of goals related to climate tipping points, differentiating prevention and impact governance.
Global Stocktake	Art. 14	Include climate tipping points as a distinct item in the agenda of future GST processes, including material collection and assessment of collective progress towards prevention and impact governance in the technical phase and deliberation in the political phase.

The international climate regime appears to be the most relevant global avenue for addressing tipping points for now, but the effectiveness of such an approach is not clear. Discussions under UNFCCC are heavily politicised, making progress hard to achieve, while the number of agenda items is becoming unmanageable. In this context, introducing a new set of challenges that has implications for many existing governance processes and negotiation topics will doubtless be challenging despite its significance and far-reaching implications.

3.1.3.3 Other existing institutions and actors

Beyond the UNFCCC and IPCC (see Chapter 3.4), a number of other international and transnational fora may be relevant to consider for the governance of ESTPs. The UN Secretary General could establish a governance forum to make recommendations to be taken up by the UN General Assembly. The UN Environment Programme (UNEP) is an issue-specific UN agency and general authority regarding global environmental governance which could serve as a facilitator, agenda-setter and authoritative source of information on tipping points. The World Meteorological Organization (WMO), also a specialised UN agency, could continue to provide scientific assessments and advice regarding ESTPs, building on its most recent effort to coordinate multiple international science bodies for an up-to-date assessment of climate change science (World Meteorological Organization (WMO) et al., 2022). And while not part of the UN system, the International Energy Agency (IEA) could lend its modelling and assessment capacity related to the world's energy system. (Issues of data ownership and access, model selection and transparency will have to be addressed.)

The Convention on Biological Diversity (CBD) should consider the potential for tipping points in various biological and ecological systems, including tropical coral reefs, forest biomes, savannas and drylands, and marine systems. The recent UN High Seas Treaty might address tipping points in marine ecosystems and its relationship to tipping points in ocean circulation patterns.

A set of global and regional institutions that address global forest governance can consider forest-related tipping elements, including ACTO, the UN Forum on Forests, the International Tropical Timber Organization, the Food and Agriculture Organization and the Forest Stewardship Council (a mixed membership organisation). Given the highly fragmented landscape for forest governance, it might be challenging to create a focal point and momentum for addressing tipping points. At the same time, this setting provides opportunities for polycentric, multi-scale governance.

A range of existing international actor coalitions and initiatives might engage with tipping points, including the High Ambition Coalition, the Climate Overshoot Commission, or the Climate Vulnerable Forum. All national governments are policymakers with relevant authority regarding Earth system tipping processes – e.g. fostering energy transitions, managing deforestation, regulating pollution or conducting climate adaptation planning. For example, the UK government's net zero target and associated revision of the national Climate Change Act explicitly reference tipping point risks as part of the regulatory rationale. Other legislatures might also have to take tipping points into account when developing future regulations and policies. Several industries, corporate actors and private-sector alliances, such as the Global Commons Alliance, might also have relevant interests and authority as, for example, research on the financial industry has pointed out (Galaz et al., 2018; Folke et al., 2019). And of course, a diverse set of civil society actors and NGOs will be engaged in the governance of ESTPs.

3.1.4 The politics of tipping-point governance

Several political dynamics will accompany the development of governance institutions related to climate tipping points. While many of these are unpredictable, the following are likely to emerge, especially in the early phase of agenda setting and governance venue identification.

Governance of ESTPs is currently in the agenda-setting phase, where the provision of knowledge needs to be accelerated and diversified, attention needs to be created and existing institutions need to be engaged in conversations about governance venues and priority topics. Science-policy interactions, policy and institutional entrepreneurs, and certain international organisations like UNEP, the WMO and the IEA can play a critical role in this phase, constructing shared knowledge and concern, and building momentum towards discussions and meetings.

Another key actor with the power to galvanise action on new topics through speeches and convening power is the UN Secretary General (Johnstone, 2003). For example, the UNSG could establish a high-level forum, science advisory panel, or similar initiative to foster immediate engagement with ESTPs across the UN system.

Importantly, in this phase different meanings of the concept of ESTPs are created through the interactions between scientific and political actors. Different interpretations and understandings of the problem will lead to different proposals for its solution and corresponding priorities for governance, dividing some actors and aligning others. As with the climate agenda generally, we should expect deliberate resistance and disinformation as well as genuine diversity on interpretations of tipping points rooted in cultural and epistemic differences. Governance mechanisms should seek to anticipate this and enable inclusion of diversity while resisting bad-faith interventions.

To the extent that a deeper understanding of ESTPs unite and mobilise new groups of actors, for example those with a shared regional interest in preventing certain tipping elements (e.g. the Arctic, or actors with livelihoods that depend on a thriving rainforest), **new political coalitions** may emerge that could differ from the well-established groups and their relationships in the regime complex for climate change. In some instances, existing actors might be reinforced in their shared positions, such as the Alliance of Small Island States (AOSIS). When AOSIS was formed more than 30 years ago, the concept of climate tipping points did not exist. Today, especially tipping points that can affect the speed and degree of sea level rise (e.g. the Greenland and West Antarctic ice sheets) have major implications for small islands' climate vulnerability and are likely to strengthen the group's identity and interests. In other cases, tipping points might lead to alliances between state and non-state actors.

The possibility of new actors emerging or existing actors adopting tipping-related positions also applies in various national and regional (e.g. European) contexts of climate policymaking. New alliances may try to shape domestic, regional and international policy to mitigate the impacts of tipping, in particular if they represent the interests of constituencies who will be negatively impacted by certain tipping points or by the immediate impacts of efforts to prevent tipping (Aklin and Mildenberger, 2020). Earth System tipping thus opens the possibility for new interest groups and actor coalitions to form, which could set in motion new political dynamics domestically and internationally.

In this context, the key task for the multitude of potential governance actors for ESTPs, including national and sub-national governments, international organisations, non-state actors, business actors, etc, consists of developing a sufficiently detailed understanding of ESTPs that allows them to assess the risks they present to the communities they represent. This understanding forms the foundation of each actor's political interests, goals and strategies for engaging in governance processes. It is also a pre-condition for identifying partners with shared interests and forming coalitions. Raising interest in and creating political momentum for addressing specific tipping points – or the phenomenon of tipping points in general – will depend on the affected countries' status in the negotiations, and their ability to influence other parties and negotiation groups.

Different countries and political actors will care more about certain tipping points than others depending on the extent to which they expect to be impacted. Countries that expect to experience impacts of ESTPs in the near future (e.g. countries with tropical coral reefs or hosting a part of the Amazon rainforest) will likely be more interested in developing prevention measures, especially by increasing mitigation ambition globally, than countries without obvious or direct expected impacts. National-scale factors, such as changes in political leadership, will play a big role in shaping a country's interests in tipping points, as the cases of Australia (Great Barrier Reef) and Brazil (Amazon rainforest) demonstrate. Mirroring existing patterns of climate politics, major emitters or beneficiaries of greenhouse gases are more likely to resist efforts to increase the speed and scale of mitigation.

While the urgency of ensuring that we do not cross critical thresholds strengthens the case for rapid transformations to just and sustainable futures, actors with a vested interest in the status quo might – and already do – predictably engage with the topic of tipping points using an increasingly well-understood repertoire of delay and obstruction tactics (Lamb et al., 2020) to obscure or avoid engaging with needed structural changes, social challenges and environmental justice.

This includes the strategic creation and distribution of mis- and disinformation, sowing doubts regarding the science of ESTPs and shaping public opinion to prevent the passing of policy response measures. The long time horizons and non-linearity of many tipping elements invite arguments that these are not the most pressing issues of the day, that anticipated impacts are exaggerated, while scientific uncertainties can be exploited to advocate for more knowledge rather than action. At the same time, actors can use climate tipping points to spread fatalistic ideas that also inhibit effective responses. Fatalists would (and already do) argue that preventive action regarding tipping processes is pointless because massive impacts are already inevitable. Since these tactics of delay and disempowerment can be anticipated, it is possible to attempt 'public inoculation' and 'prebunking' against misinformation (Lewandowsky and van der Linden, 2021).

3.1.5 Public communication and risk perceptions

Public risk perceptions shape the politics of climate change (Sjöberg, 2001) and will be important for the policy trajectory of ESTPs. Public risk perceptions can both enable and constrain public policymaking and are a good indicator (Sjöberg, 2001) for the public's willingness to engage in behaviour change. In recent years, international polls have found growing concern about climate change and strong global support for urgent and decisive action (UNDP, 2021, Ipsos-MORI, 2023). A recent Ipsos MORI survey conducted for the Global Commons Alliance finds that three quarters of people in G20 nations believe that human activity has pushed the Earth close to tipping points (Gaffney and Tcholak-Antitch, 2021). At the same time, significant misperceptions and public knowledge gaps remain (Galaz et al., 2023). However, very limited research has been conducted on public understanding and risk perceptions specifically related to climate (or Earth system) tipping points.

Contrary to researchers' expectations, work so far suggests that the concept of climate tipping points, especially the feature of non-linear change, does not generate increased concern when compared to climate change more generally (Formanski et al., 2022). Higher risk perceptions in response to information about tipping points tends to be limited to specific cultural groups with egalitarian values (Bellamy, 2023) and to people who are highly engaged in climate change policymaking (Van Beek et al., 2022). However, these preliminary findings might be based on a broad lack of understanding of the issue and its implications rather than public indifference (Nadeau et al., ESD preprint). Given the learning challenges related to tipping points, non-linear change, and complex systems dynamics more generally, media coverage and public communication related to tipping points might face serious challenges.

While risk perceptions can drive action on tipping points, overwhelming fear of them may have the opposite effect and paralyse action (O'Neill and Nicholson-Cole, 2009). When communicating about tipping points, a careful balance needs to be struck between accurately characterising the risks and potential impacts, but also conveying potential solutions and agency. Further, the same message will be received very differently by different audiences, depending on, for example, their age, profession and ideology. Overwhelm and/or avoidance may lead to inaction or, even worse, to polarisation and the exacerbation of social and political divisions, which could hinder any progress in tackling those risks. In addition, an overemphasis on the potential impacts and the wrongful idea that 'it's too late' may warrant the consideration of deployment of dangerous unproven solutions, which could have harmful and unforeseen consequences in the Earth system. Addressing these fears and overcoming their potential paralysing effects requires effective communication, education and engagement strategies.

Emphasising the wide-ranging and tangible co-benefits of action to avoid tipping points, providing tangible solutions, and building a sense of empowerment, and shared responsibility can help alleviate fear and inspire meaningful action.

3.1.6 Final remarks

ESTPs present a distinct set of challenges that should be addressed with policy and governance measures. The time is now for state and non-state governance actors across multiple scales to engage with this topic and elevate it on the international political agenda. Actors need to understand how tipping points affect their interests to develop agency, form coalitions, and actively engage in the agenda-setting process. A range of existing principles of global governance and international law should shape discussions and decisions, including the need for anticipatory approaches, precaution in the face of uncertainty, and the need for intergenerational, intra-generational and international justice.

Given the nature and scope of ESTPs, governance efforts must be coordinated across multiple spatial and temporal scales, managing cross-scale dynamics and potential tipping cascades in coupled human-Earth systems. It is useful to distinguish three phases of tipping processes (pre-tipping, re-organisation and stabilisation), and to shift the focus of governance efforts corresponding to these phases. There is significant scope for incorporating governance of ESTPs into existing institutions, especially the UNFCCC, but novel actors, approaches and institutions will likely be needed to cover the full range of emerging challenges, especially at the scale of tipping systems.

3.2 Prevention of Earth system tipping processes

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Summary

Preventing the transgression of Earth system tipping points (ESTPs) (hereafter 'prevention of tipping points') should become the central objective of this domain of global governance. This chapter addresses the question of how governance actors, especially governments, could achieve this objective.

ESTPs have multiple interacting drivers that operate at different scales. Effective prevention strategies need to address all drivers with coordinated cross-scale approaches (polycentric prevention). Many institutions, from the Convention on Biological Diversity (CBD) to the Arctic Council, can assume prevention responsibilities and will need to be involved in governance. Global temperature increase is the most common driver of tipping processes, making climate mitigation the most effective prevention strategy across the diverse set of ESTPs identified to date. Hence, we see important opportunities for UNFCCC to provide a context for preventive governance measures. Beyond strengthening mitigation efforts for long-lived GHG, we discuss the need to manage short-lived climate pollutants (SLCPs), and advance carbon dioxide removal (CDR). We also assess the potential contribution of novel kinds of climate intervention (geo-engineering), concluding that, for the time being, these are not available options to support prevention.

Non-climate drivers are diverse and specific to each (type of) tipping element – for example, deforestation as a driver of forest dieback, or pollution contributing to coral reef die-off. Given this diversity, each tipping system requires a tailored prevention approach, likely involving different constellations of regional and national actors and institutions, cooperating and coordinating their efforts across scales.

Many governments and other actors have not yet sufficiently engaged with the challenges presented by tipping points and still need to define national and organisational interests in this domain. Prevention efforts related to ESTPs are likely to be subject to political dynamics and contestations that mirror current global climate change politics, especially diverging interests regarding the speed, scale and responsibilities for GHG emission reductions.

Key messages

- Prevention of Earth system tipping processes should become the core goal and logic of the future ESTP governance framework. A short window for preventive action is open now and will close at different points in time for each Earth system tipping element – for some, as early as the 2030s**.**
- Preventing the transgression of ESTPs requires:
  - rapidly strengthening current mitigation efforts to minimise temperature overshoot beyond the global goals and the length of overshoot periods, by tackling both CO_2 emissions and emissions of SLCPs;
  - increasing sustainable capacities for CO_2 removal as an addition to mitigation efforts, while seeking to minimise potential side-effects on other drivers of tipping processes;
  - addressing non-climate drivers at regional and national scales, such as deforestation.
- Speculative solar geoengineering approaches to prevention face deep ethical, technical and political uncertainties, and should not be considered technically available to use safely and swiftly within the coming decades. Such approaches could at most supplement, not replace, mitigation efforts.

Recommendations

- UNFCCC member states should engage in the next Periodic Review process to assess whether the current long-term global temperature goal is adequate in light of current evidence of climate tipping points.
- Parties to the Paris Agreement should include an assessment of collective progress towards preventing climate tipping points in future Global Stocktake processes.
- Governments should immediately increase and accelerate near- and medium-term climate mitigation efforts, for example by pursuing a rapid phase-out of all fossil fuels globally, bringing forward their target year for reaching net-zero, increasing their mitigation ambition in NDC revisions, supporting the development of just and sustainable forms and levels of carbon removal, accelerating corresponding national policy measures, and through democratically validated efforts at social transformation.
- Governments should ban commercial deployment of solar geoengineering, declare a moratorium on any other deployment, and develop a multilateral regime to regulate research and experimentation.

3.2.1 Prevention as a governance goal

Given the significant risks posed by ESTPs (severe, even catastrophic, consequences for human wellbeing and ecological stability) the irreversibility of these impacts, their cascading potential, and with a view to precaution, **prevention** of all tipping processes should become the **primary objective of governance in this domain**. Given the severe threats that crossing ESTPs pose to the achievement of the SDGs (see Section 2), effective prevention is essential to support the delivery of the SDGs at a global level.

For all ESTPs, a short window for preventive action is open now and will close at different points in time for each element. For some ESTPs that are assessed to become likely beyond 1.5°C this could be as early as the 2030s, or possibly even this decade (IPCC 2018, 2021; Armstrong-McKay et al., 2022; Ditlevsen and Ditlevsen, 2023).

Box 3.2.1: The rationale for prevention

We ground the proposal to make prevention the central objective of tipping point governance in (1) the nature of tipping point impacts (severity and permanence), (2) their cascading potential, (3) the precautionary principle, and (4) the specific intertemporal nature of decision making.

1. **Impacts:** ESTPs present a variety of severe risks. They imply that the current climatic or biospheric conditions in large parts of the world will effectively be permanently lost, threatening the lives of people, the survival of species and ecosystems, the livelihoods and cultural identities of communities, the stability of local and national economies, and even the existence and sovereignty of some states (see Section 2).
2. **Cascades:** Many ESTPs have some potential to contribute to tipping-point cascades, i.e., they increase the likelihood of additional tipping processes being triggered (see Chapter 1.5). That implies the potential to create additional, more distributed harms beyond the scale of the tipping system and wider Earth system destabilisation (see Chapter 2.4).
3. **Precaution:** Some of the harmful impacts of crossing ESTPs can be predicted with confidence (such as sea level rise from ice-sheet disintegration), but many others (such as the impacts of ocean convection collapse) warrant further research. Estimates of the probabilities of triggering tipping points on any given timescale are uncertain and include an element of irreducible uncertainty. Conventional methods of policymaking and risk management that rely on quantified estimates of impacts and probabilities are therefore inappropriate (Stirling, 2007) in the context of ESTPs. Rather, we require tools for responding in the face of deep uncertainty. These include the widely adopted precautionary principle (Jordan and O'Riordan, 1999), systemic risk governance, and anticipatory governance (Guston, 2013).
4. **Intertemporality and committed change:** Importantly, due to their specific causal dynamics (internal self-amplifying feedback mechanisms), for most tipping systems, the change process becomes effectively unstoppable once a tipping point has been reached – i.e. a causal process set in motion in the coming years and decades, such as ice-sheet melting, would continue to unfold over decades, centuries, or millennia even if global temperatures are successfully reduced back to current levels, or if other causal drivers are returned to pre-tipping conditions (see Chapter 1.2 for delayed activation). It is useful to distinguish realised and committed change related to a tipping point at any particular moment in time. At the time the tipping point is crossed and amplifying feedback loops are set in motion, the system will inevitably move to a new state – it is committed to change, although none of those impending changes might be observable yet. The actual change might take a long time – decades, centuries, or even millennia –to become noticeable and disruptive. For example, it is possible that the Greenland tipping point will be crossed later this century, committing the entire ice sheet to disintegration. The melting process, however, could take several thousand years and most impacts would occur beyond the year 2100 (though would still amplify sea level rise to some extent before this). Policymakers have to consider their responsibility for future impacts that only they are able to prevent. Such long-term and intertemporal decision making faces significant practical challenges given dominant decision-making logics and policy practices, such as cost-benefit-analysis, cost-efficiency maximisation, and discounting (leading to the 'tragedy of the time horizon') (Morgan, 2021; Granoff, 2023).

Given that most ESTPs share global warming as a key driver, prevention measures that limit global temperature increase always reduce the likelihood of future tipping point transgressions and remain needed and effective even if one or several tipping points have been passed. Emission reductions will always be the primary tool for reducing the risk of passing (further) tipping points.

Prevention as a central goal does not imply that other objectives, especially fostering resilience in Earth system tipping elements and human societies, and impact governance (see Chapter 3.3) should be deprioritised. No matter how quickly we progress with mitigation, a significant risk of tipping already exists and will increase substantially within the Paris Agreement's temperature range. If prevention efforts are insufficient, impacts may accumulate too rapidly for adaptation and resilience building to cope (see Chapter 3.3). Governance actors will have to consider how to best balance their attention and efforts across these different action domains, but should seek synergies between actions that build social resilience and accelerate mitigation through sustainability transformations.

Prevention efforts can have a variety of outcomes in addition to success (permanent aversion) and failure (tipping dynamics unfold). Prevention can delay the timing of a tipping process – i.e. moving the time when the critical threshold is reached further into the future. This could be beneficial, for example for anticipatory adaptation planning, ensuring that societies are better prepared for the expected impacts of the tipping process (see Chapter 3.3). It can also slow the rate at which the impacts of crossing a tipping point unfold (for example, the rate of ice-sheet melt), somewhat easing the corresponding adaptation challenges. Another form of partial success concerns tipping systems with more than two stable states, and corresponding multiple tipping points. The GrIS might be an example for a multi-stable tipping element (Höning et al., 2023), although disagreements remain about this. If a tipping system has multiple stable states, prevention efforts might fail to avoid the first tipping point, leading to significant changes until the system settles in its first alternative stable state, but might succeed in averting further tipping to the next state. In the case of an ice sheet, prevention efforts could maintain the ice sheet in the partially melted state, avoiding full disintegration.

3.2.2 Multiple drivers of tipping processes

Most Earth system tipping processes have multiple drivers. Prevention of ESTPs requires tackling all of them. Given this multi-causality, the term prevention is related to, but not synonymous with, mitigation. The familiar concept of climate mitigation in the narrow sense of reducing GHG emissions can be applied to ESTPs; emission reductions serve to limit atmospheric GHG concentrations and correspondingly limit future increases in global average temperature, which is key for reducing the general risks of climate change. Since global temperature increase is a causal variable for most Earth system tipping processes of interest here, **mitigation in the sense of reducing emissions of GHG will be the most important approach to preventing the crossing of ESTPs**. This includes the management of SLCPs.

Most ESTPs have multiple interacting causes (see Table 3.2.1), and effective prevention strategies will also have to attend to causes other than warming. It is important to distinguish between a primary cause, which in many cases is GHG-induced climate change (through atmospheric or ocean warming pathways and precipitation changes, which we categorise as 'direct climate' drivers), and secondary causes. Some secondary causes, such as ice sheet meltwater effects on ocean currents, land 'greening' due to warming and CO_2 fertilisation, or ocean acidification, are second-order effects of climate change or other effects of GHG emissions (i.e. 'Climate-Associated' drivers). Others are independent of climate change – e.g. pollution affecting coral reefs or deforestation of the Amazon rainforest (i.e. 'non-climate' drivers). These secondary causal drivers can bring forward a system's tipping point, hence tackling them can help prevent tipping. The importance and number of additional causes differs across tipping elements.

Table 3.2.1: Multiple drivers of ESTPs

Primary and secondary drivers of the ESTPs identified in this report. DC: Direct climate driver (direct impact of emissions on meteorological variables via radiative forcing); CA: Climate-associated driver (including second-order and associated effects of climate change); NC: Non-climate driver. Drivers can enhance (↗) or counter (↘) tipping.

Tipping point	Primary drivers	Secondary drivers
Cryosphere		
Ice sheet collapse (Greenland, West/East Antarctica)	DC: atmospheric warming (↗) DC: ocean warming and circulation changes (↗ GrIS, WAIS, EA marine / ↘ GrIS)	DC: precipitation increase (↘) DC: black carbon deposition (↗) CA: sea ice decline (↗) CA: atmospheric circulation (?)
Sea ice loss (N.B. tipping unlikely in this report, but affects other key ESTPs)	DC: atmospheric warming (↗)	DC: atmospheric circulation shifts (↗/↘) DC: ocean warming (↗) DC: ocean circulation shifts (↗/↘) DC: black carbon deposition (↗) DC: storminess increase (↗) CA: ocean stratification increase (↘)
Glacier retreat (regional)	DC: atmospheric warming (↗)	DC: deposition of dust, black carbon etc. (albedo) (↗) DC: reduced snow (input & albedo) (↗) DC: local thermokarst (↗)
Permafrost thaw (regional; and subsea)	DC: atmospheric warming (↗) DC: ocean warming (subsea, ↗)	CA: vegetation change (↗/↘) CA: wildfire intensity increase (↗) CA: precipitation change (rain extremes, snow cover albedo (↗) CA: sea ice loss (subsea, ↗) CA: water pressure reduction (subsea, ↗)
Biosphere		
Tropical forest dieback (regional: Amazon, maybe Congo)	DC: atmospheric warming (↗) NC: deforestation/degradation (↗) DC: drying (↗) CA: increasing fire frequency/intensity (↗)	DC: heatwaves (↗) CA: ENSO intensification (e.g. Amazon, SE Asia (↗) CA: AMOC/SPG weakening/collapse (e.g. Amazon, (↗) CA: terrestrial greening (↘ declining)
Boreal forest southern dieback/ northern expansion	DC: drying (↗) CA: fire frequency/intensity increase (↗) DC: atmospheric warming (↗) CA: permafrost thaw (↗) CA: insect outbreaks (↗)	NC: deforestation & degradation (↗) DC: heatwaves (↗) CA: terrestrial greening (↘) CA: vegetation albedo (↗) CA: sea ice albedo decline (↗) DC: precipitation changes (?)
Temperate forest dieback N.B. (uncertain in this report)	DC: atmospheric warming (↗) DC: droughts (↗) DC: heatwaves (↗)	CA: insect outbreaks (↗) CA: windthrow (↗) NC: deforestation & degradation (↗) CA: fire frequency increase (↗) NC: fragmentation (↗)

Tipping point	Primary drivers	Secondary drivers
Savanna degradation	NC: fire suppression (↗) NC: overgrazing (↗)	DC: increased precipitation intensity (↗) CA: terrestrial greening (↗) NC: afforestation (↗) CA: regional circulation changes (e.g. Sahel) (↗)
Dryland degradation	DC: drying (↗) DC: atmospheric warming (↗) NC: land use intensification (↗)	DC: extreme events (heatwaves, floods) (↗) DC: increased rainfall variability (↗) CA: terrestrial greening (↘) CA: insect outbreaks (↗) CA: invasive species (↗)
Lake eutrophication/browning	NC: nutrient pollution (↗) CA: terrestrial greening (↗) NC: afforestation (↗)	DC: atmospheric warming (↗) DC: precipitation changes (↗)
Coral reef die-off	DC: ocean warming (↗) DC: marine heatwaves (↗) CA: disease spread (↗)	CA: ocean acidification (↗) NC: water pollution (nutrient / sediment) (↗) NC: disruption (ships, over-harvesting) (↗) CA: disease spread (↗) CA: invasive species (↗) DC: storm intensity (↗) CA: sea level rise (↗)
Mangrove and seagrass meadow die-off	DC: climate extremes increase (↗) NC: habitat loss/degradation (↗) CA: sea level rise (esp. mangroves (↗) NC: nutrient pollution (↗) NC: shoreline change (↗)	DC: ocean warming (seagrass, ↗) CA: disease spread (seagrass, ↗) NC: invasive species (seagrass, ↗)
Marine regime shifts (some fisheries, kelp, lipid pump, hypoxia)	NC: over-exploitation (↗) DC: ocean warming (↗) NC: water pollution (nutrients / sediment) (↗)	NC: habitat loss (↗) DC: marine heatwaves (↗)
Ocean/atmosphere circulation		
Ocean overturning collapse (AMOC, SPG, Southern Ocean)	DC: ocean warming (↗) DC: precipitation increase (↗) CA: ice sheet meltwater increase (SMOC ↗, in future for AMOC/SPG ↗) CA: river discharge increase (AMOC/SPG ↗)	CA: sea ice extent & thickness decrease (↗) DC: regional aerosol forcing increase (↘) CA: regional ocean circulation changes (?) CA: wind trends (SO, ?) CA: sea ice formation (SO, ?)
Monsoon collapse / strengthening (West African, maybe Indian summer and South American)	DC: increased water vapour in atmosphere (ISM ↘, WAM/SAM ↗) NC: increased summer insolation (↘) DC/NC: increased aerosols, dust (↗, ?)	NC: land-cover change, e.g. deforestation (↗) CA: desertification (↗) CA: regional SST variations (?) CA/NC: regional soil moisture/veg variation(?) CA: ENSO / Indian Ocean Dipole change (?) CA: AMOC slowdown (SAM, WAM ↗) CA: low cloud reduction (ISM ↘) CA: ocean warming (ISM ↗)

Given this multi-causality of ESTPs, prevention requires tackling all of the drivers. The familiar concept of climate **mitigation** in the sense of reducing GHG emissions applies to ESTPs. Emission reductions serve to limit atmospheric GHG concentrations and correspondingly limit future increases in global average temperature, which is key for reducing the general risks of climate change. Since global temperature increase is a causal variable for most Earth system tipping processes of interest here, **mitigation in the sense of reducing emissions of GHG will be the most important approach to preventing the crossing of ESTPs**. This includes the management of SLCPs.

At the same time, conceiving of prevention only in terms of climate mitigation is too narrow. Prevention of most tipping points will involve a combination of mitigation and measures to address other drivers. Different tipping processes have distinct causal profiles requiring a tailored approach to prevention. Some tipping processes share characteristics that might allow developing prevention strategies for groups of tipping points (e.g. for major ice sheets or forest biomes).

However, even within a cluster of similar tipping systems, significant differences might exist that affect the design of effective prevention approaches (e.g. different threshold temperatures for different ice sheets or different secondary drivers for forest dieback).

Prevention strategies that consider multiple causes might be more challenging because different causal variables can operate at different scales, both spatially and temporally. Correspondingly, effective governance approaches will have to be multi-scale and capable of taking cross-scale dynamics into account (see Chapter 3.1). For example, preventing Amazon dieback requires not only limiting temperature and precipitation changes, but also regional and national land management and other policies. Such a multi-causal approach to prevention could be advanced within the current framework of global sustainability governance with adjustments of existing institutions and strategic efforts to link and coordinate efforts across different scales.

Box 3.2.2: Multiple drivers of Amazon rainforest dieback

The Amazon rainforest plays an important role as a climate regulator and biodiversity hotspot, but is at risk of dieback. If tipped, large parts of the Amazon could change relatively quickly (over multiple decades) into either a degraded forest or dry savannah-like state, leading to impacts that would be catastrophic for natural and human systems. These impacts include increases in regional and global temperature, decrease in precipitation across the Amazon and southern South America, droughts, fires and biodiversity loss, to name a few (see Chapter 1.3 & 2.2.3.1). Recent scientific evidence based on remotely sensed vegetation data suggests that more than three-quarters of the Amazon rainforest has been losing resilience since the early 2000s, which is consistent with parts of the forest nearing a tipping point (Boulton, Lenton, and Boers, 2022). Resilience is being lost faster in regions with less rainfall (which are more at risk of dieback) and in parts of the rainforest that are closer to human activity.

Global atmospheric temperature increase leading to drying is a key driver of potential tipping in the Amazon (see Chapter 1.3.2.1). Deforestation and forest fragmentation are also important drivers that contribute to and accelerate the shift from rainforest to degraded forest or savanna, raising the probability of crossing a tipping point during the 21st Century. Given these multiple drivers operating at global (temperature increase), regional (forest fragmentation), national and even lower (deforestation) scales, the Amazon tipping system is amenable to prevention efforts at multiple scales. Global mitigation efforts to limit atmospheric GHG concentrations present one approach, but other governance efforts need to address regional-scale drivers beyond the climate sphere. Slowing deforestation and forest fragmentation requires strong governance efforts outside the international climate change regime – e.g. collaboration among, and national policies in, Amazon states, changes in global investor behaviour and shifts in global consumption patterns. Strategic prevention efforts need to consider, and ideally coordinate, dynamics across these multiple scales.

Deforestation is an insightful example. Trends in the Amazon over the last decade have been a major concern. The annually deforested area increased by about 75 per cent between 2016 and 2022, but decreased during the first seven months of 2023 by more than 40 per cent compared to the same period in the previous year (Reuters, 2023). Deforestation in the Amazon has many interacting drivers linked to the global economy, but it is influenced primarily by national-scale policies, especially in Brazil. Between 2005 and 2016, Brazil experienced a notable reduction in deforestation rates (approximately 70 per cent (PRODES), demonstrating the effectiveness of the government's efforts to combat it during that period. A combination of factors contributed to this, including increased law enforcement and the implementation of sustainable land use policies and programmes in the Amazon region.

In particular, Brazil's Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) played a crucial role in driving down deforestation rates and promoting sustainable practices. Its application was effectively suspended in recent years, leading to an increase in deforestation, but reinstated in 2023 by the incoming Brazilian presidency. In addition, the Amazon Fund, established in 2008, is a financial mechanism to support local communities, NGOs and governmental initiatives in their efforts to reduce deforestation, increase recognition of land rights for Indigenous peoples, and promote sustainable development in the Amazon region. Actions taken during the previous Brazilian government resulted in significant changes to the Amazon Fund, leading to its temporary suspension, which may have contributed to the increase in deforestation. New pledges have been made in 2023 with the incoming presidency of Brazil.

The successful deforestation programmes in Brazil, as well as the dramatic impacts accompanying their suppression over recent years, demonstrate the importance of national-level politics for tipping point prevention in addition to, and largely independent of, global-scale climate governance institutions. Effective approaches to prevent a tipping point of the Amazon rainforest have to address deforestation locally and nationally in the Amazon states, but also global temperature change in the UNFCCC to protect and maintain this critical biome.

For some, especially biosphere-related, tipping points, one could conceive of tipping point prevention more broadly as efforts to build social-ecological resilience of a tipping system in its current stable state. Beyond countering the destabilisation of tipping systems by reducing tipping drivers, resilience-building measures can increase the capacity of the system to withstand disturbances. Fostering resilience can be achieved with a variety of strategies, including restoring diversity and redundancy in a system (e.g. species diversity in forests), reducing stressors and fostering sustainable land use. Efforts to protect and at least partly restore biosphere tipping systems such as the Amazon rainforest or coral reefs can both reduce pressures on them and increase their resilience to tipping event drivers like climate change. For example, restoring degraded or lost rainforest and protecting remaining rainforest (through, for example, improved land rights for Indigenous peoples, promoting agroforestry, and improved governance) can reduce deforestation and lead to substantial recovery of a degraded forest within a couple of decades (Poorter et al., 2021; (Science panel for the Amazon, 2021). This can maintain moisture-recycling feedbacks (see 1.3.2.1), thereby helping to maintain rainfall in at-risk forests downwind, as well as improving local resilience to climate change-induced droughts.

3.2.3 Prevention approaches and institutional options

The recognition of multiple drivers of tipping processes is important for thinking about prevention approaches. But given the important (direct or indirect) role of increasing atmospheric temperatures for almost all Earth system tipping processes, the central focus of tipping point prevention efforts has to be mitigation – the reduction of both long-lived and short-lived GHG emissions to the atmosphere. These need to be coordinated with parallel efforts to address various other drivers.

Deep and early emission reductions based on principles of international law (Rajamani et al., 2021) are a core part of any effective prevention strategy for almost all tipping points (see Section 4 for approaches to accelerating decarbonisation). It is the only reliable way to limit global temperature increase, which can prevent the crossing of most tipping points altogether. Existing global governance efforts supporting mitigation should be strengthened immediately and maximised in the future (see Chapter 3.1). Urgent efforts to support social transformations, reducing emissions more deeply and rapidly than can be achieved through conventional policies, market mechanisms and technological substitution, are justified by the substantial co-benefits for health, livelihoods and equity that such transformations offer (see also Section 4 on positive social tipping points). To best support tipping point prevention, mitigation efforts should focus on long-lived GHG emission-reduction efforts, supported by measures to cut SLCPs and to develop and scale up GHG removal as a supplement to emissions reduction.

Other drivers of Earth system tipping processes (see Table 3.2.1) are tipping point specific and may work at different spatial and temporal scales to global temperature change. These other causes are frequently more localised (e.g. the role of deforestation in accelerating the tipping of the Amazon, or water pollution in influencing the die-off of coral reefs), and can be associated with a specific set of stakeholders. Therefore, more national, regional or local prevention strategies that can take the specific characteristics of the tipping system into account will be needed. Many governance actors, especially local jurisdictions, will need guidance and support to identify and effectively prioritise prevention measures.

The following sections explore existing governance mechanisms for the mitigation of long-lived GHGs (3.2.3.1) and SLCPs (3.2.3.2), the emerging conversation regarding carbon removal (3.2.3.3) and solar geoengineering (3.2.3.4), as well as existing institutions that can address non-climate causes of specific tipping elements (3.2.3.5). We discuss how existing governance efforts could be strengthened or complemented with new approaches to consider the risk of crossing climate tipping points.

3.2.3.1 Mitigation

The Paris Agreement adopted in 2015 provides the foundation for current global climate mitigation efforts. Three components of the agreement are central for mitigation efforts and should be re-evaluated in light of the growing knowledge of tipping points: global goals related to global temperature and corresponding discussions about suitable mitigation pathways, Nationally Determined Commitments (NDCs), and the system of transparency and review mechanisms that are supposed to ensure accountability and drive ambition (see 3.1.3.2 for more detail).

The Paris Agreement established a two-pronged global long-term temperature goal – limiting warming to well below 2°C, and aiming for 1.5°C, above pre-industrial levels (Art. 2 (1) PA), combined with an objective of global peaking of GHG emissions (as soon as possible), and balancing emissions and removals of GHG (in the second half of this century) (Art. 4 (1) PA). These objectives need to be read in the context of the overarching aim of the Agreement to "significantly reduce the risks and impacts of climate change" (Art. 2), which requires the consideration of the most recent climate science. The newest scientific evidence regarding ESTPs creates an imperative to revisit the meaning of the global long-term temperature goal, its adequacy and its implications for the types of emission pathways that can achieve it (Pouille et al., 2023).

Adopting the prevention of climate tipping processes as an explicit objective of global climate governance has important **implications for the selection of global and national emission pathways** towards the temperature goals established in the Paris Agreement. Only a subset of the emission scenarios included in IPCC AR6 are suitable if decision makers take into account the need to prevent the passing of tipping points.

A recent OECD working paper (Pouille et al., 2023) identified a set of criteria for the selection of emission pathways that are consistent with the temperature and mitigation objectives of the Paris Agreement (see above), and specifically considering the risk of crossing ESTPs. These criteria include, among others, the likelihood of keeping global warming below 1.5°C by 2100, avoiding or limiting temperature overshoot to 1.6°C, and early peaking of global emissions (2025/2030). Applying these criteria at two levels of stringency to the emission scenario database for IPCC AR6, the analysis demonstrated that only a subset of all 'likely below 2°C' emissions scenarios used by the IPCC can be considered in line with the long-term goals of the Paris Agreement, especially when also considering the objective of minimising tipping risks.

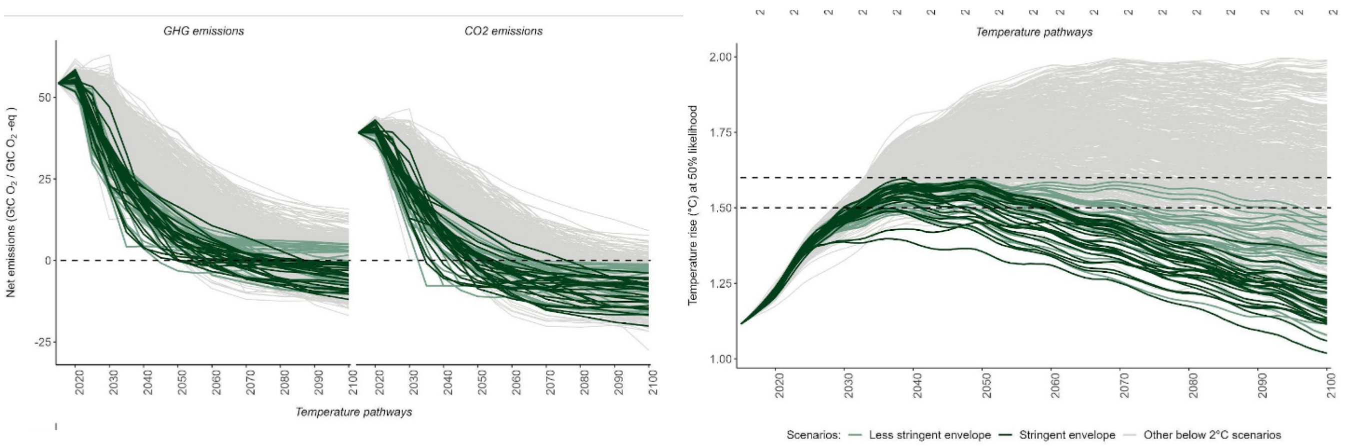

Fig. 3.2.1: Mitigation pathways minimising the risk of transgressing ESTPs. Modelled mitigation pathways to 2100 compatible with achieving the temperature goal of the Paris Agreement are depicted in green. Pathways in dark green satisfy the more stringent interpretation of the language in the Paris Agreement ([1] 50% chance of holding warming below 1.5°C by 2100, [2] 50% chance of keeping global warming below 1.6°C throughout the century, [3] 90% chance to keep warming below 2C throughout the century, [4] global GHG emissions peak at or before 2025, [5] global net-zero GHG emissions before 2100), while pathways in light green satisfy a less-stringent interpretation of the Agreement (detailed in Pouille et al., 2023). The pathways in grey correspond to all other scenarios that remain below 2°C with a likely (66%) chance or more throughout the century. Graph from Pouille et al., 2023, using data from the IPCC AR6 scenarios database (Byers et al., 2022).

More specifically, emission pathways that are consistent with the objective to prevent climate tipping points have three important common features. First, they minimise 'temperature overshoot'. While accepting that warming of more than 1.5°C warming above pre-industrial levels can likely no longer be avoided, emission pathways that **minimise temperature overshoot** beyond this level have a higher chance of avoiding the crossing of tipping points (Palter et al., 2018; Drouet et al., 2021; Wunderling et al., 2022). In other words, considering only long-term (end of century in most analyses) temperatures is not sufficient; global peak temperature is an equally important measure for achieving global objectives, Second, emission pathways that are more likely to avoid tipping points **keep the duration of the overshoot period as short as possible** (Wunderling et al., 2023). These two features lead to a third characteristic of emission pathways that effectively prevent tipping points: **rapid, early emission reductions (this decade)** coupled with rapid scaling of carbon removal capacities.

The UNFCCC Periodic Review and the Global Stocktake provide opportunities to discuss and adjust the shared understanding of the long-term global temperature goal within the current institutional framework of the Paris Agreement. These processes should be used to consider the risk of ESTPs and the need to prevent their transgression. Further, in 2021, the UNFCCC established a Mitigation Work Programme with the objective to scale up mitigation ambition and implementation. This negotiation stream offers opportunities to discuss the question of 'tipping safe' emission and mitigation pathways, for example as a topic of a future global dialogue. Specific criteria for acceptable emission pathways that comply with the temperature and mitigation objectives of the Paris Agreement should also inform short- and medium-term national policymaking – e.g. mitigation strategies to achieve net-zero goals.

The Paris Agreement's pledge and review system requires all participating countries to iteratively submit **Nationally Determined Contributions** (NDCs), which include national pledges of future emissions reductions, sink management measures, and the development of carbon-removal capacity. Future NDC revisions should include specific considerations of ESTPs, and to what extent national mitigation plans, policies and decarbonisation strategies contribute to their prevention. This should include an effort to identify the country's historic and current contributions to creating tipping point risks. In addition to affecting most ESTPs with domestic GHG emissions, multiple national processes can contribute to secondary drivers of tipping processes – e.g. deforestation, pollution or other extractive activities, and globally sourced consumption via international trade. Based on an understanding of its responsibility and capacity to engage in tipping point prevention, countries could describe how national measures and cooperative initiatives with other countries and non-state actors contribute to the prevention of specific tipping points. For example, Norway, Canada, the US and Russia could detail efforts to reduce pressures on boreal forests to prevent dieback at their Southern boundary, including logging policies and other extractive activities, fire and pest management (see 3.2.2).

Countries are also required to develop longer-term (**mid-century**) **strategies** for national decarbonisation. Many countries have adopted 'net-zero' commitments when developing their mid-century strategies, setting specific dates for reaching the point where remaining emissions are balanced by removal. These mid-century strategies have important implications for mitigation pathways and the governance of tipping point risks. Future revisions of these strategies should include an analysis of ESTPs, and to what extent long-term national decarbonisation strategies contribute to their prevention. For example, many net-zero strategies today imply high reliance on carbon-removal methods, which are needed but could impose additional pressure on other drivers of Earth system tipping (e.g. from afforestation in unsuitable locations that add pressure to biosphere tipping systems like grasslands or lakes). Further, countries should consider shortening net-zero timelines to accelerate decarbonisation and reduce tipping point risks.

The architecture of the Paris Agreement encourages increasingly ambitious NDCs and national action over time through transparency and review mechanisms like the **Global Stocktake**. The reporting requirements of the transparency mechanism provides another opportunity for countries to describe national mitigation measures and their impacts, not just with a view to the global temperature goals, but to the prevention of tipping points. The Global Stocktake serves to review collective progress towards the goals of the Paris Agreement – i.e. illuminating whether the international community is on track towards achieving the temperature goals, allowing countries to adjust their levels of ambition if needed. **Starting in 2028, the Global Stocktake could explicitly address to what extent national and collective prevention efforts have limited the risk of passing ESTPs.** This would require collecting tipping point-specific materials (e.g. this report, a potential IPCC special report on tipping points, a report by IANAS on the state of the Amazon rainforest, reports by AMAP on the state of Arctic tipping points) in the technical phase and providing a technical assessment of collective progress on reducing tipping risks. Building on our discussion of criteria for acceptable mitigation pathways above, this assessment would consider whether actual mitigation pathways fall within the envelope of modelled pathways that limit tipping risks. The political component of the GST could include deliberations on tipping point prevention and to what extent tipping point risks warrant increased global mitigation ambition. Including tipping points in the GST could stimulate the formation of multi- and minilateral initiatives for tipping point governance.

While the Paris Agreement provides an international framework for climate mitigation efforts, the actual work of reducing emissions takes place at the **national scale**. Countries pursue the aim of decarbonising economies and societies using a vast range of national policies, especially in the domains of energy production (transitions towards renewable energy sources) and use (energy efficiency), mobility (e.g. electrification of road transport), housing and agriculture. There are vast differences among the approaches and successes of different countries so far. While decarbonisation measures often create resistance and face political challenges (Egli, Schmid, and Schmidt, 2022; Martin and Islar, 2021), they need to accelerate and expand in scope to address the growing risk of transgressing tipping points. This includes the removal of fossil fuel subsidies (Skovgaard and van Asselt, 2019; Coady et al., 2019) and other forms of government support for the fossil fuel industry, cancellation of government licences for new extraction projects, and ultimately publicly guided deliberate phase-out strategies for fossil fuel industries that proactively and carefully consider justice implications (Pellegrini et al., 2021; Whitfield et al., 2021; Heffron, 2021; Newell and Mulvaney, 2013). Civil society actors also play a crucial role in advancing mitigation and societal decarbonisation efforts, including by pressuring national governments to acknowledge that effective climate change mitigation requires phasing out all fossil fuels.

3.2.3.2 Short-lived climate pollutants

Outside of the UNFCCC, intergovernmental efforts to manage SLCPs are an important dimension of global climate mitigation efforts, especially because they can have short-term benefits. SLCPs, including methane, tropospheric ozone and black carbon, can have disproportionate regional impacts on particular tipping systems. For example, black carbon deposition is particularly effective at melting snow and ice. Hence the mitigation of specific SLCPs can have a disproportionate benefit in preventing specific ESTPs. Mitigating SLCPs can also contribute to limiting global warming pressure on most ESTPs. According to IPCC AR6 WG1, across the Shared Socioeconomic Pathway climate scenarios, "the collective reduction of methane, ozone precursors, and hydrofluorocarbons (HFCs) can make a difference of 0.2°C with a *very likely* range of [0.1 to 0.4]°C in 2040 and 0.8°C with a *very likely* range of [0.5 to 1.3]°C at the end of the 21st Century".

On global and regional levels, several institutions address SLCPs. A focal arena is the Climate and Clean Air Coalition (CCAC), a state-led transnational partnership established under UNEP in 2011, which has become a key actor in global policy advocacy and knowledge exchange on SLCPs. In addition, other international fora have made concrete steps to mitigate specific SLCPs. For instance, in the Northern hemisphere, black carbon emissions are integrated into the targets to reduce particulate matter pollution under the Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone. In 2015, the Arctic Council agreed on the Framework for Action on Enhanced Black Carbon and Methane Emission Reductions. In 2016, the Montreal Protocol on Substances that Deplete the Ozone Layer was complemented with the Kigali Amendment on the phase-out of HFCs. Further, under the Paris Agreement, some countries have included SLCP mitigation targets or policies in their NDCs, and various global cooperation efforts, including the Global Methane Pledge (Sun et al., 2021), have been launched to address methane emissions. Elevated action on SLCPs is essential because the effects are felt more rapidly than those of CO_2 abatement.

Other short-lived pollutants, such as sulphates and particulates, can have cooling effects, and their elimination would increase warming (also on short time scales) (IPCC SR1.5 2018). For example, reducing sulphate emissions from shipping for health reasons has a climate trade-off (Sofiev et al., 2018). While this creates challenges for policy design, it cannot justify the intentional release of sulphates or other particulates (even sea salt) in efforts to compensate for warming effects through deliberate geoengineering. In addition to the ethical differences between deliberate interventions and unexpected side effects (Morrow, 2014), we discuss the practical and political uncertainties of geoengineering below.

3.2.3.3 Carbon dioxide removal

With some exceptions (Riahi et al., 2021), the bulk of emissions pathways for reaching ambitious temperature goals still *exceed* the near-term carbon budget, lead to temperature overshoot, and are brought down in the latter half of the century by a speculative scale of novel carbon sinks (IPCC AR5, 2014; IPCC, 2018; IPCC AR6, 2022). Carbon removal is emerging as a key pillar of climate assessments and policy. IPCC AR6 argued across all three working groups that carbon removal will play an essential role in strategies that limit warming to no more than 1.5°C and is an important feature of "well below 2°C" scenarios. Correspondingly, countries increasingly integrate carbon sinks into their net-zero goals, NDCs (Hale et al., 2022) and mid-century strategies (H. B. Smith, Vaughan, and Forster, 2022). For now, they predominantly repurpose land use and ecosystem management practices as carbon removal. Engineered carbon removal prototypes and practices are piloted at small scales, but these remain immature or speculative as socio-technical systems (Sovacool, Baum, and Low, 2023). The prospects for scaling to the multi-gigaton levels foreseen in integrated assessment modelling are doubtful, with only limited attention so far to the demand side and policy beyond research and development (Nemet et al., 2018). It is uncertain if these can reach the scale envisioned in pathways in line with well below 2°C or 1.5°C. Hence some filtering of plausible emissions pathways to not rely on excessive carbon removal is necessary.

It is important to recognise that carbon removal is understood as playing two roles. First, it can balance residual, recalcitrant emissions in a net-zero state. The currently projected scale of such residuals and removals is substantial at close to 20 percent of current emissions (Buck et al., 2023). The second role is to reverse overshoot of carbon budgets (reducing ultimate outcome temperatures). The more removal capacity required for the first task, the greater the challenge of providing sufficient, rapid, sustainable capacity for the second.

The development of removal approaches also requires careful governance to avoid their use as a substitute for achievable mitigation, rather than a supplement. One analysis of the risk of mitigation deterrence through carbon removal estimates as much as 1.4°C additional warming (over the 1.5°C goal) could result (McLaren, 2020).

Assessment of the relationship between carbon removal and tipping points is nascent. While **large-scale CDR efforts might have desirable effects on global temperatures**, it faces significant scaling challenges and would likely operate more slowly than many other mitigation approaches. These challenges likely limit its potential as a prevention tool in comparison to GHG emission reduction.

Carbon removal techniques could also have other positive and negative effects on ecosystems and hence tipping point risks. For example, some carbon-removal approaches, such as forest conservation and afforestation, could increase forest resilience and counteract tipping dynamics. But opposite effects are also possible. At scale, most carbon-removal techniques compete for land and/or low-carbon energy supplies, with negative effects on both sustainability and justice (Smith et al., 2015; McLaren, 2012). Moreover, large-scale conversion of natural forests for the purpose of Bioenergy with Carbon Capture and Storage (BECCS) might increase ecosystem vulnerability and the possibility of forest loss, and afforestation in drylands and grassland ecosystems could make tipping more likely in those ecosystems (see Chapters 1.3.2.4 and 1.3.2.5). Proposals for large-scale oceanic carbon removal through alkalinisation or fertilisation also raise questions about their interactions with tipping point drivers, effectiveness and ecosystem disruption (Fakhraee et al., 2023; Tagliabue et al., 2023). Overall, there is so far limited research on the nature and net balance of such effects.

3.2.3.4 Solar geoengineering

Solar geoengineering or solar radiation modification (SRM) is a group of hypothetical and controversial methods that might help decrease global temperature by directly altering the Earth's energy balance, typically by reflecting a small fraction (around 1 per cent) of the incoming sunlight (NASEM, 2021). The best-known suggestions are Stratospheric Aerosol Injection (SAI), which would involve creating a thin reflective cloud layer of reflective aerosol in the higher atmosphere, and Marine Cloud Brightening (MCB), which would involve making oceanic stratocumulus clouds more reflective by providing sea salt dust particles to increase the number of cloud droplets.

It has been suggested that solar geoengineering techniques might reduce the likelihood of crossing temperature-related tipping points, postpone their arrival, or, more speculatively, even reverse ongoing tipping processes (Heutel, Moreno-Cruz, and Shayegh, 2016; Felgenhauer et al., 2022). The latter possibility is ruled out by Lenton (2018). The linkages between different kinds of solar geoengineering and the drivers of tipping points are understudied and uncertain. Moreover, proposed techniques are currently hypothetical, and not practically available as options to contribute reliably to the prevention of ESTPs. There is already early consensus that geoengineering techniques would not offer an emergency response to anticipated tipping events (Horton, 2015; Lenton, 2018). However, assessment over whether they might provide pre-emptive measures to support prevention is ongoing, and heavily contested (Gupta et al., 2020).

Modelling studies on stratospheric aerosol injection suggest beneficial effects on particular tipping systems (e.g. delay), such as AMOC decline (Xie et al., 2022), Greenland ice loss (Moore et al., 2019), West Antarctic ice loss (Sutter et al., 2023) or permafrost thaw (Chen et al., 2023). However, in these studies **geoengineering interventions typically appear less efficacious than GHG mitigation**. This underscores that they could at most complement, but not replace, mitigation. Nevertheless, these studies come from modelling simplified or idealised deployment scenarios at the global scale, which suffer from model uncertainties and bracket out technical, social, ethical, political and economic considerations which would be crucial for the conditions of deployment (Corry, 2017; McLaren, 2018). For other, more regional or localised techniques – including marine cloud brightening and ice albedo modification (see Box 3.2.3) – even the direct effects remain uncertain (Diamond et al., 2022; Johnson et al., 2022; Webster and Warren, 2022).

All approaches are poorly researched with respect to outdoor experimentation, technology development, side-effects, justice and ethics, public acceptability, and governance frameworks. Furthermore, deployment would be accompanied by the risk of termination shock (Parker and Irvine, 2018) – a risk of rapid warming if deployment were to be abruptly halted – along with other challenges and uncertainties regarding effectiveness and the regional-to-global distribution of their effects on various environmental and social systems such as weather, agriculture, health and biodiversity.

The prospect of collaborative, effective and democratic international governance – particularly of the global SAI approach – faces many practical and political challenges (Szerszynski et al., 2013; Horton et al., 2018; Flegal et al., 2019; Gardiner and McKinnon, 2020). Expectations that solar geoengineering might be deployed to avoid tipping points would carry a risk of deterring or slowing mitigation efforts (Corner and Pidgeon, 2014; McLaren, 2016; Merk, Pönitzsch, and Rehdanz, 2016). Idealised deployment that would mirror idealised modelling studies is unlikely: actual deployment would be beset by significant ethical and distributional challenges (McLaren, 2018) and would need to be sustained for decades or centuries (Baur et al., 2023). Developing required long-term, stable governance institutions (Parker and Irvine, 2018) would be difficult and slow, reflecting challenges in global climate governance on historic and future responsibilities, unequal capacities, and loss and damage (Biermann et al., 2022). In their absence, unilateral, club-based, or even corporate efforts to deploy geoengineering would present challenges regarding accountability and liability.

The prospective value of solar geoengineering approaches is greatly disputed among scientists, with networks emerging around an international non-use agreement (Biermann et al., 2022) and calls for further research and funding (Doherty et al., 2023; Wieners et al., 2023). Recently, the Overshoot Commission called for a moratorium on SRM deployment and large-scale experiments combined with 'exploration' by appropriately governed research and governance dialogue. Without commenting on these strands of activity,

We strongly caution against reliance on solar geoengineering as a major tool for preventing tipping points, or the expectation that this kind of approach will be available and politically acceptable in the future to contribute to prevention efforts. Nor should SRM ever be considered a possible replacement for mitigation.

Governments should therefore take measures on both international and national scales to prevent premature, uncoordinated, or self-interested actions on SRM, by means of an (at least temporary) international moratorium on SRM deployment and large-scale experiments, as well as a ban on commercial activities even at a small scale. Multilateral efforts should also be undertaken to govern research and enable timely public debate on SRM's potential, limitations and risks, including its potential to reduce or possibly exacerbate ESTP risks and to interact with social tipping points. The provisions of the London Protocol, prohibiting ocean iron fertilisation, with exemptions for legitimate scientific research, may provide a starting point for drafting regulations to ensure that any exploration of SRM is conducted in a responsible, safe and inclusive manner.

BOX 3.2.3: Engineering approaches at the scale of Earth system tipping elements

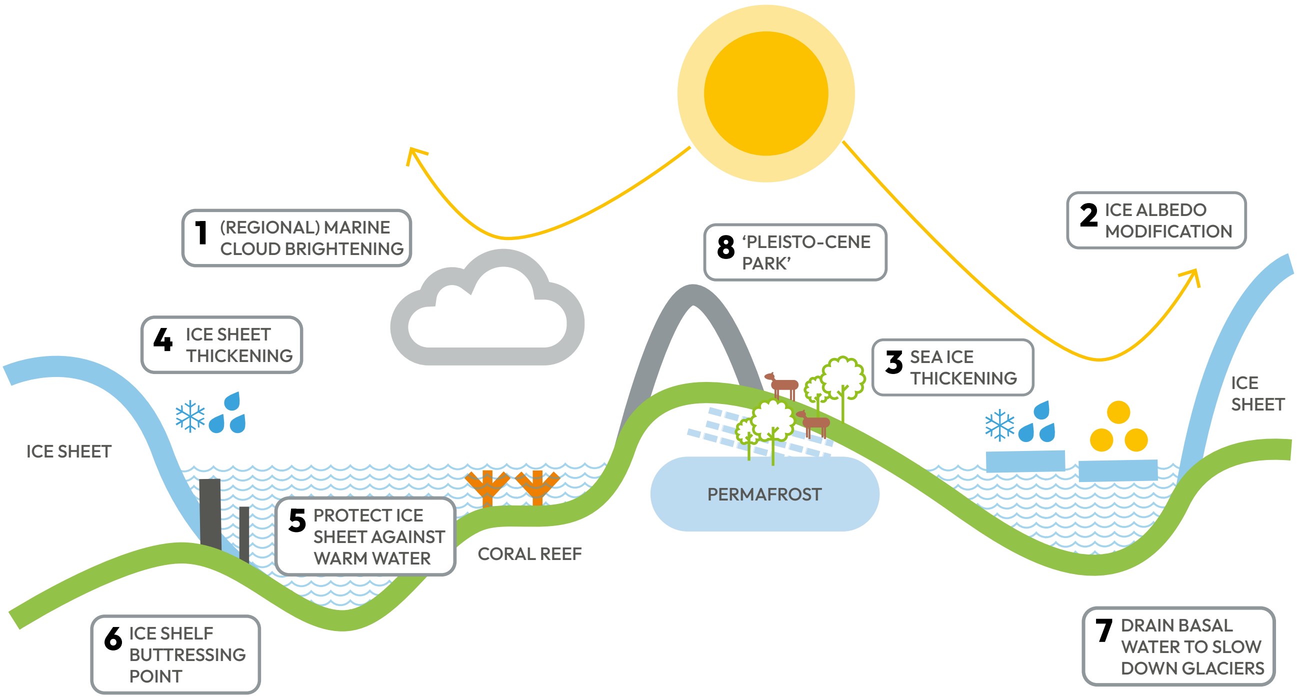

Figure. 3.2.2: Proposed engineering techniques at tipping-point scale. All of these techniques are controversial and speculative, with varying degrees of uncertainty regarding their technical feasibility, efficacy, side-effects and governance challenges, including mitigation deterrence.

1. Solar geoengineering techniques aiming to make marine stratocumulus clouds more reflective by injecting sea salt dust, either regionally, e.g. coral reef protection, or intending global cooling; technical means non-existent currently but potentially feasible and inexpensive; direct environmental issues likely limited, effectiveness uncertain (National Academy of Sciences, 2021).
2. Brightening sea ice by covering it with small reflective glass spheres. Some outdoor experimentation. Conflicting results from modelling, and concerns about side-effects and effectiveness (Field et al., 2018) vs. (Webster and Warren, 2022).
3. Thickening sea ice by spraying with water in the freezing season or applying snow cannons. Speculative ideas suggested, some modelling. Pumped seawater would release CO_2, limiting overall efficacy. Energy costs likely prohibitive. Sea ice preservation may have local benefits but the approach would have limited or even negative effects at global scale. (Zampieri and Goessling, 2019).
4. Thickening ice sheets at areas with low flow velocities to directly remove water from the sea. Technical feasibility speculative, low leverage (Moore et al., 2020).
5. Protecting ice shelves and calving glaciers in Greenland or West Antarctica from warm sea water by means of dams or membranes. Technical feasibility uncertain (Wolovick and Moore, 2018).
6. Providing additional buttressing points to ice shelves to slow down their movement and hence the flow of the glaciers behind them. Technical feasibility uncertain (Wolovick and Moore, 2018).
7. Draining meltwater at the base of glaciers in Greenland or West Antarctica to reduce lubrication and slow down their flow. Technical feasibility uncertain (Moore et al., 2020).
8. Rewilding permafrost areas with grazing animals to reduce shrub and compact snow layer and eventually conserve permafrost carbon. Speculative concept, supported by one modelling experiment (Beer et al., 2020) with some non-scientific experimentation in Russia (Moore et al., 2020).

3.2.3.5 Addressing other causes of tipping

While GHG emissions are the primary drivers of Earth system tipping processes, additional drivers need to be managed to avert the crossing of tipping points. For example, deforestation and land use intensification could trigger the tipping of the Amazon rainforest, while nutrient pollution and over-exploitation could lead to the rapid collapse of marine fisheries and habitats. While some of these drivers are tied to global activities (e.g. large-scale commercial fishing or deforestation in the Amazon, due in part to demand for food products in China, Europe and the US), the primary or most immediate locus of governance of some of these non-climatic drivers may be regional or national, closer to the immediate scale of the tipping system, rather than in international organisations. For example, despite global drivers of deforestation in the Amazon, the rate of deforestation depends critically on the actions of Brazil's federal government (see Box 3.2.2), with relatively low deforestation during President Lula's term replaced by increased deforestation during Bolsonaro's presidency (Peres et al., 2023).

The prevention of ESTPs may thus call for national efforts and new regional entities to facilitate cooperation across relevant states and sub-national jurisdictions regarding the governance of specific secondary drivers of tipping processes. Such regional initiatives could coordinate and align prevention measures with cross-border effects, pool resources, share knowledge and technologies, and engage in mutual learning about the effectiveness of prevention measures. More generally, such a regional approach would foster preventive capacities at the scale of the tipping system (see Chapter 3.1 on regional governance).

Additionally, regional entities may be able to reduce the likelihood of unintended consequences — for example, the displacement of deforestation from one region in Brazil to another or from Brazil to another Amazonian country — by facilitating coordination and consultation. Further, to the extent that global action is needed to mitigate secondary drivers or to allocate resources to support regional prevention efforts, regional entities will need to be meaningfully embedded within broader governance arrangements (see Chapter 3.1 on polycentric governance).

In addition to public entities, including intergovernmental fora and councils, there are several non-governmental organisations and private-sector coalitions focused on specific sectors or resources – such as the Marine Stewardship Council, the Forest Stewardship Council, or the Roundtable on Sustainable Palm Oil – that could play an important role in mitigating non-climate drivers of ESTPs. The consolidation of control over certain industries by a handful of companies means that the decisions of certain corporate actors play a large role in their respective sectors, and in shaping environmental conditions. Due to this influence, they have been called 'keystone actors' drawing on the term 'keystone species' in ecology (Österblom et al., 2015). Recent efforts to quantify and draw attention to the impacts of the financial sector on deforestation of the Amazon (and other forests) through NGOs such as Forests & Finance Coalition could serve a similar role for the Amazon by redirecting financial flows away from destructive activities and towards regenerative ones.

3.2.4 The politics of prevention

Given the close relationship between the prevention of ESTPs and climate change mitigation, prevention politics are likely to mirror the politics of mitigation to a large extent. At the same time, the multi-scale nature, diverse drivers (including non-climate drivers) and distinct geographic distribution of tipping-related risks can generate a set of novel political dynamics, especially at non-global scales.

Key factors that shape the politics of mitigation are countries' national interests (often defined in terms of economic growth), power distribution between high-emitting and other countries, vested economic interests, especially those of the fossil-fuel industry, and the strength of civil society forces creating pressure and public demand for action (Stoddard et al., 2021). Here, we only focus briefly on the likely role of national interests in future political dynamics related to the governance of ESTPs. Other factors deserve equal attention. All of these issues are currently under-researched.

Each government will have to assess the relevance of ESTPs for the national interest, especially through the lens of risk: the more a government expects their country be negatively affected by tipping points (or to gain from co-benefits arising from preventive action), the more it will likely favour preventive action to protect its people (including future generations), infrastructure, the position and security of borders, social stability and economic functioning, including trade flows and supply chains, from these impacts. Countries will need to consider how many and what kind of tipping systems will affect them (multi-exposure), and the possibility of complex interactions. For example, low-lying island states will likely face disproportionate tipping risks from ice sheet disintegration, while countries around the North Atlantic (Western Europe, US, Canada) would share concerns related to the North Atlantic Subpolar Gyre. Some countries might be indifferent to the topic, assuming that they will not be affected, at least in the foreseeable future. Others might expect significant challenges related to tipping points, yet oppose mitigation or other prevention efforts because of the expected costs of these measures, or even because they anticipate relative geopolitical advantage as a result of tipping points.

An additional factor that might affect the determination of national interests is the **cascading potential** of ESTPs. For example, a landlocked European country might not be directly affected by GrIS melt, and therefore not be motivated to engage in prevention when considering the GrIS. However, since the melting of the GrIS contributes to the slowing of the AMOC (cascading effect), and a collapse of the AMOC would have significant impacts on landlocked countries in Europe (e.g. changes in temperature, precipitation and storm patterns), decision makers in the country in question would have a well-founded interest in preventing the crossing of the ice sheet's tipping point. Such cascade considerations might be very different for each country.

To a large extent, such national interest determinations with respect to ESTPs have yet to be made. If such risk assessments were undertaken, they might be expected to lead to the formation of political alliances among countries with shared interests (e.g. rapid prevention, opposition to action) and disagreements among groups with opposing interests. National interests and the political alliances they give rise to are dynamic. They will change over time in response to several factors, including increasing scientific understanding of tipping points and what will be perceived as signals or impacts of ESTPs.

The choice of **prevention approaches** will be subject to political debate based on actors' diverging preferences and expectations of implications regarding the mix of emission reductions, carbon removal, and other technological solutions, including solar geoengineering. This will also be relevant at national, regional and local levels and when dealing with non-climate drivers.

An important factor to trigger action on tipping points is how national governments and publics evaluate the risk of ESTPs and risks related to potential preventive measures. The way individuals, communities and policymakers perceive the risks associated with crossing tipping points can be expected to influence their willingness to demand and/or take action and implement measures to prevent tipping points (see 3.1.5). However, based on the experience of the last three decades, even intensifying impacts of climate change do not necessarily drive accelerated mitigation motivation and action. A number of dynamics at the national scale, including strategic obstruction efforts by vested fossil-fuel and ideological interests, limit the climate response of various political systems around the world (Stoddard et al., 2021; Ekberg et al., 2022; Jacques, Dunlap, and Freeman, 2008). The prospects of future acceleration and intensification of impacts is therefore unlikely to change the slow and contentious politics of climate mitigation.

All of these dynamics are likely to unfold over the coming decade as knowledge of ESTPs expands in the international community. At the moment, the politics of governing ESTPs takes place primarily in the domain of science-policy interactions, where actors tie different techniques of knowledge production to specific future visions that create a rationale for the pursuit of specific prevention approaches and related governance proposals (Gupta et al., 2020). This form of anticipatory governance can shape the direction of future decision making related to ESTPs in ways that depend on the actors involved and their interests, the design of the knowledge production and visioning process, and other factors (Moore and Milkoreit, 2020).

3.2.5 Final remarks

Prevention has to become the central objective of Earth system tipping point governance, as a means to defend and promote achievement of other societal objectives like the SDGs. Prevention efforts need to distinguish between multiple drivers of tipping processes at different scales, including non-climate drivers. Governance needs to address all types of drivers, operate on multiple scales of the international system, and consider cross-scale dynamics and challenges in a polycentric fashion. Each tipping system and each driver of tipping requires a distinct approach, likely involving different institutions, actors and solutions. However, equitable mitigation is an indispensable and overarching tool that is vital to reduce risks in nearly all tipping elements.

Given the important role of global temperature increase as a key driver for many Earth system tipping processes, rapidly strengthening current global climate change mitigation efforts will be essential for successful prevention efforts, including boosting efforts to reduce SLCPs. Their aim should be to minimise the magnitude and length of global temperature overshoot periods beyond the global temperature goals, which requires careful reconsideration of mitigation pathways. Carbon dioxide removal could also help reduce the primary drivers of climate tipping, but is slow and difficult to scale, risks deterring or slowing other mitigation, and some methods could add to other drivers of Earth system tipping. Policy should seek to increase sustainable capacities for carbon dioxide removal as an addition to mitigation efforts, while minimising deterrence effects and potential side-effects on other tipping drivers.

Several existing institutional arrangements for climate mitigation provide opportunities for prevention efforts regarding tipping points. These include the Paris Agreement (especially NDCs, the GST and periodic review of the long-term goal) and related national decarbonisation efforts, but also other international or transnational institutions.

While there are some limited indications that solar geoengineering might have beneficial impacts on the drivers of some tipping points, they remain speculative with profound technical and political gaps in understanding, and based on limited, largely technocratic analysis. Currently, solar geoengineering is not technologically available to implement safely with a short ramp-up time. Political uncertainties cannot be eliminated through further research, assessment or monitoring. Expectations that solar geoengineering might be deployed to avoid tipping points would carry a risk of deterring or slowing mitigation. For the time being, they are not available to support prevention efforts. In any case, such approaches could at most complement, but not replace, mitigation.

Chapter 3.3 Tipping point impact governance

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Summary

Given the now substantial risk of passing several Earth system tipping points (ESTPs) in the foreseeable future, it is imperative that governance actors begin to anticipate and prepare for their impacts. ESTPs present threats that are distinct from climate change as it is currently understood in important ways. We identify five such differences and discuss how these challenge current frameworks, plans, practices and resource allocation for impact governance. Multiple policy domains, including adaptation, loss and damage, international development, disaster preparedness and migration, should account for ESTPs to ensure effective decision making in pursuit of peace and prosperity for people and the planet, now and into the future.

While the literature on ESTP impact governance is nascent, we identify important considerations. The objective of impact governance is the prevention and minimisation of harm caused by ESTPs in the context of just and sustainable development. Efforts should be distributed across multiple scales and differentiate between governance tasks before and after a tipping point is crossed (i.e. match strategies to different phases of tipping processes). Early warning systems that can support timely responses to changes in Earth and social systems would be desirable, but there are significant concerns about the availability of reliable early warning signals. Attending to equity and justice requires that impact governance for ESTPs takes into account the needs and perspectives of the most vulnerable and marginalised communities.

A broad set of governance actors and institutions involved in addressing the impacts of global environmental change today will play a role in this domain. This includes global-scale and international institutions, national governments and local communities, but also the private sector and civic actors. We briefly illustrate the potential and need for changes to current governance structures in two domains. One is the UNFCCC, a treaty-based international institution with global scope. Here we focus on adaptation and loss and damage. The second is the less-formalised institutional context for governing migration, where we consider local, national and international processes of planned relocation.

Key messages

- The impacts of Earth system tipping processes differ from climate change impacts in ways that matter for impact governance. Key differences include greater magnitude and acceleration of change, novel types of impacts and distributions of vulnerability, and irreversibility of change.
- Existing governance frameworks and institutions (for climate change adaptation, migration and sustainable development, for example) do not account for the specific threats of ESTPs.
- Given the nature of Earth system tipping processes, provisions for addressing Loss and Damage would play a much bigger role than today if ESTPs were transgressed.
- The objectives of ESTP impact governance, especially minimising harm, reducing vulnerability, building resilience and preventing impact cascades, are best achieved with just transformations towards sustainability.

Recommendations

- Existing impact governance frameworks and mechanisms need to be adjusted and significantly expanded to address the risks posed by crossing ESTPs. More resources and funding should be made available, especially if and when an Earth system tipping point has been crossed.
- Adaptation governance needs to significantly strengthen anticipatory work and adopt a multitemporal perspective tied to the scale and dynamics of specific tipping systems.
- Governments should advance the institutionalisation of global migration governance, building on the Global Compact for Safe, Orderly and Regular Migration.
- Science and governance actors should co-develop early warning systems to monitor both the biophysical changes (especially indicators for tipping-point transgression) and potential societal impacts of ESTPs. For that purpose, investments in the quality and availability of data should be made, including data from low-income countries.
- Governments should increase the use of participatory approaches to impact governance, involving local/Indigenous communities and knowledge.

3.3.1 Rethinking impact governance for global environmental change

Based on current scientific assessments, including in this report (see Section 1), the likelihood of transgressing one or several ESTPs has been increasing and will likely grow substantially beyond 1.5°C warming, but no tipping process has been set in motion yet. Given that several tipping systems have been destabilised, and could be transgressed in the near term, it is imperative that decision makers start to develop appropriate governance frameworks to address the potential future impacts of ESTPs. If transgressed, ESTPs would severely undermine the pursuit of the SDGs, and reverse recent development progress around the world. The possibly short remaining window of time before the impacts of a tipping process could be felt should be used to increase preparedness, foster community resilience and invest in resources, processes and institutional capacity that would be needed to effectively respond to tipping-point impacts.

Section 2 of this report has assessed the highly diverse expected impacts of ESTPs which are summarised in Table 3.3.1. The assessment shows that ESTPs are very diverse, each with a distinct set of **impact types** and impact distribution over time and space. Given this diversity, different tipping points (or groups of tipping points) might require distinct kinds of policy responses and impact governance strategies, involving different sets of actors.

Table 3.3.1: Impacts of ESTPs

Overview of impacts and challenges of the various Earth system tipping elements. Please note the anticipated timescales of tipping points unfolding until new equilibrium is reached are best average estimates. GW = global warming; red highlights are temperature thresholds that we are currently approaching, the colouring of the ESTP column signifies the expected severity of the impacts, with darker red shades demonstrating greater severity. We also note the high uncertainty around secondary impacts (see Chapter 2.3 and 2.4)

Earth system tipping point	Sea level rise/coastal erosion	Extreme weather events	Feedback on global warming	Water shortages	Changes in precipitation	Regional temperature change	Ecosystem change	Release of pollutants	Infrastructure damage	Food security	Triggering other ESTPs	Secondary societal impacts	Thresholds, timescales & spatial extent
Cryosphere													
Greenland Ice Sheet collapse	Up to 7m sea level rise overall over 1000s years, together with WAIS potentially up to c. 2m by 2100 [IPCC AR6 WG1 Ch9], affecting 480 million people	Minor impact (local circulation changes)	Minor impact (~0.1°C over 1000s y.)	Water shortages due to coastal salinisation	Local impact possible effect on tropical monsoons via AMOC disruption [Defrance et al., 2017])	Regional amplification of warming	Coastal areas, new exposed land in Greenland	Minor (some pollutants trapped in ice)	Threat to coastal power plants, Destruction of coastal built environment	Salinisation impacting agriculture & food security	Impact on AMOC/SPG as tipping may be reached sooner (but timescales unclear)	Displacement of coastal area popula- tions, conflicts over water etc, financial crises (stranded assets)	0.8-3°C GW, long period (1000s y.), global impacts
Arctic Sea Ice loss (not considered a tipping system in this report)	Increased coastal inundation and erosion from larger waves with more open ocean	Uncertain; possible contribution to increase in extreme weather events (e.g. Extreme European snowfall)	Uncertain, possibly ~+0.25°C for summer sea ice loss & ~+0.6 °C for winter sea ice loss, included in model projections	No impact	Local impact with more open water causing increased evaporation and increased precipitation, shift from snowfall to rainfall	Regional amplification of warming (particularly Arctic and Northern Hemisphere)	Details uncertain, but loss of sea ice is expected to substantially affect the marine Arctic ecosystems; impact on land ecosystems unclear	Changes in pollutant & microplastic transport in the ice-free Arctic; increased contaminant input from the Arctic coastal erosion	Possible damage through extreme weather events and through increased coastal erosion	Extreme weather events could destroy harvests, disruption of traditional Indigenous food systems	Amplifies regional warming over Greenland, AMOC/SPG, boreal forests & permafrost; coastal permafrost loss accelerated	Coastal erosion, loss of Indigenous ways of life, & possible extreme weather events contributing to conflicts, (temporary) displacement, anomie etc	NA for tipping; 4.5-8.7°C GW for gradual winter sea ice loss in models [McKay et al., 2022], fast (20 y.), global impacts
Barents Sea Ice loss (not a tipping system, low confidence)	No impact	Unclear; potential contribution to increase in extreme weather events (Europe)	Negligible impact	No impact	Possible regional impacts in Europe	Local warming	Local ecosystems (marine & bordering land)	Unclear, but changes in circulation can affect pollution redistribution (e.g. of mercury)	Possible damage through extreme weather events	Possible extreme weather events could destroy harvests	Small impact on AMOC & regional boreal forests	Possible extreme weather events contributing to conflicts, (temporary) displacement, anomie etc	NA for tipping, (but 1.5-1.7°C GW in some models) [McKay et al., 2022], fast (25 y.), regional & global impacts
Permafrost thaw	Abrupt thaw can amplify coastal erosion	Minor impact (can lead to increased lightning strikes and wildfire ignition)	Release of greenhouse gases, driving further global warming	Complex changes to the local water table via abrupt drainage, thermokarst lake formation	Minor impact	No impact	Boreal/tundra ecosystems	Release of contaminants such as mercury into the environment	Disrupts travel in Arctic and isolates settlements Built infrastructure damage and destruction	Impact on permafrost-agroecosystems and community-level food storage in frozen underground cellars	Important but uncertain impact on Boreal forest dieback/ expansion tipping points	Anomie among regional population inhabiting the areas, due to livelihood and cultural loss	NA for tipping, abrupt thaw more common from 1.5°C GW [McKay et al., 2022], medium-term (~200 y.) regional & global impacts

Earth system tipping point	Sea level rise/coastal erosion	Extreme weather events	Feedback on global warming	Water shortages	Changes in precipitation	Regional temperature change	Ecosystem change	Release of pollutants	Infrastructure damage	Food security	Triggering other ESTPs	Secondary societal impacts	Thresholds, timescales & spatiale extent
West Antarctic Ice Sheet collapse	3-5m sea level rise overall over 100s-1000s y, together with GrIS potentially up to c. 2m by 2100 [IPCC AR6 WG1 Ch9], affecting 480 million people	Minor impact; possible massive iceberg release events in Southern Ocean	Minor impact (potentially ~0.05°C over 100s-1000s y.)	Water shortages due to sea level-induced coastal salinisation	Local impact	Regional warming amplification	Coastal area, new exposed islands and seas in West Antarctica	No impact	Threat to coastal power plants, Destruction of coastal built environment	Salinisation impacting agriculture & food security	May affect East Antarctic ice sheets & possibly Southern Ocean overturning circulation	Displacement of coastal area popula- tions, conflicts over water etc., financial crises (stranded assets)	1-3°C GW, long period (2000 y.), global impacts
East Antarctic Ice Sheet (marine & non-marine) collapse	Up to 53m total sea level rise potential; sea level rise of several metres possible over 100s-1000s of years	Minor impact; possible massive iceberg release events in Southern Ocean	Additional warming of potentially ~0.6°C over 10,000s y.	Water shortages due to coastal salinisation	Local impact	Regional warming amplification	Coastal areas, new exposed land and seas in East Antarctica	No impact	Threat to coastal power plants, Destruction of coastal built environment	Salinisation impacting agriculture & food security	Collapse of ice sheet in marine basins could accelerate land-based ice sheet tipping & Southern Ocean overturning circulation	Displacement of coastal area populations, conflicts over water etc, financial crises (stranded assets)	2-6°C GW marine & 6-10°C GW non-marine, very long period (10,000 y.), global impacts
Extrapolar glacier retreat	Up to 0.2m sea level rise	No impact	Minor impact (potentially ~0.08°C)	Impact of freshwater supply from meltwater in many regions of the world (e.g. Central Asia, Europe) leading to water shortages	No impact	Localised warming amplification	Changes in surrounding montane & downstream ecosystem, new land exposed	Minor (some pollutants trapped in ice)	Destabilisa- tion of valley sides could lead to landslides, glacier collapse events can cause floods/ mud- slides	Water shortages impacting agriculture & food security	No impact	Conflicts over water etc, anomie due to livelihood and cultural loss	Regionally variable but potentially widespread from -2°C GW, e.g. in Europe (McKay et al., 2022), medium-term (200 y.), regional impacts
Ocean/Atmosphere Circulation													
Atlantic overturning AMOC collapse	Regional sea level changes (fall in convection region & North European Shelf seas, rise further south)	Shift in jet stream and storm tracks affecting weather patterns in Europe, potential increase in extreme weather events, e.g. cold winters in Europe, south-ward hurricanes shift	Partial & temporary counteraction of global warming	Southward shift in ITCZ leading to drying in the Sahel and Southern Asia; Some models project drying in parts of the Amazon	Summer monsoon weakening and shifts in Africa and Asia	Up to 10°C cooling in North Atlantic and 3°C cooling in Northern Europe / Eastern Canada, warming amplification in Southern Hemisphere	Drastic shifts in many ecosystems on land and in the sea around the world, e.g. Amazon drying	Affects dust aerosols via monsoon disruption in those regions; ocean circulation changes can affect pollutant pathways	Shifted temperatures/ precipitation & weather patterns/ extremes no longer matching infrastructure tolerance ranges	Threat to food security because of impacts on marine life (reduction of plankton), changes in precipitation severely impacting agriculture (particularly wheat and maize) & food security (particularly in Europe)	Warming amplification in Southern Hemisphere accelerating Antarctic Ice Sheet melt and coral bleaching, Amazon drying; monsoon (African and Asian) shifts accelerated	Conflicts over food and water, displacement from uninhabitable areas, anomie, financial crises, etc	NA in this report, 1.4-8°C GW elsewhere (but low confidence) [McKay et al., 2022], Possibly relatively fast (~50 y. To centuries) Complex global impacts with strong regional differences

Earth system tipping point	Sea level rise/coastal erosion	Extreme weather events	Feedback on global warming	Water shortages	Changes in precipitation	Regional temperature change	Ecosystem change	Release of pollutants	Infrastructure damage	Food security	Triggering other ESTPs	Secondary societal impacts	Thresholds, timescales & spatiale extent
Labrador- Irminger Seas Convection (Subpolar Gyre) collapse	20-30cm sea level rise along North-East seaboard of North America	Similar to AMOC but possibly smaller impact, e.g. amplified cold winter blocking events in Europe & increase in summer heat wave frequency	Similar to AMOC but magnitude of impact is unclear	Similar to AMOC but possibly smaller impact	Similar to AMOC but impact is not completely clear	Up to 2-3°C cooling in North Atlantic, global warming counteracted in Northern Europe / Eastern Canada	Large changes in ecosystems in affected regions (e.g. reduced North Atlantic productivity, regional ocean acidification, deoxygenation)	Impact unclear, but could be similar to AMOC	Similar to AMOC but smaller impact	Major disruptions of agriculture in Northern Europe and Sahel, impacting food security	Similar to AMOC but impact is not completely clear, potentially a large change in N. Atlantic ecosystems	Conflicts over food and water, displacement from uninhabitable areas, anomie, financial crises, etc	1.1-3.8°C GW, very fast (10 years), regional impacts
Monsoon shifts (intensification or collapse, e.g. South Asian, West African, South American)	No impact	Monsoon intensity & extremes projected to increase with warming, or strong drop due to aerosol-induced collapse	No Impact	Shifted precipitation may lead to water shortages	Drastic precipitation changes	Change in tropical and subtropical climates	Change in vegetation and ecosystems in general relying on the monsoon	Changes to where monsoons redistribute air pollution	More intense monsoons overwhelming current infrastructure; monsoon collapse leaving infrastructure mal-adapted	Changed vegetation, agriculture dependent on monsoon rainfall will impact livelihoods and food security	WAM could drive Sahel greening, SAM could affect Amazon	Conflicts over food and water, displacement from uninhabitable areas, anomie, etc	Interhemispheric AOD asymmetry >0.15, AMOC collapse, Amazon dieback; (McKay et al., 2022), relatively fast (50 y.), regional impacts
Biosphere													
Amazon rainforest dieback	No impact	Increasing extreme weather events (e.g. wet bulb spikes, wildfires) in region	Additional global warming (0.1-0.2°C, depending on extent)	Decreased precipitation may lead to water shortages	Declining regional precipitation in Amazon and Southern Cone region	Over 1°C extra regional warming	Parts of rainforest (particularly in South & East) shift to degraded forest or savannah	Smoke from increased wildfires	Minor impact	Decreased precipitation would impact agricultural belt of Brazil and into Southern Cone	Amplified global warming, bringing other warming thresholds closer	Conflicts over food and water, displacement from uninhabitable areas, anomie,	2-6°C GW (without deforestation) ~20-40% deforestation, relatively fast (100 y.), regional and global impacts
Boreal Forest Southern dieback / Northern expansion	No impact	Increasing extreme weather events (e.g. wildfires)	Complex effects – dieback releases carbon but reduces albedo, expansion vice versa	May change with evapotranspiration-induced weather pattern shifts	Changes to evapotranspiration likely to shift regional weather patterns	Regional changes due to changes in land albedo	Shift to open, steppe/prairie-like ecosystems in south, tundra afforestation in north	Smoke from wildfires	Minor impact	Disruption of traditional Indigenous food systems	Complex interplay with permafrost thaw, northern expansion adds to Arctic warming; drives lake browning	Anomie among regional population inhabiting the areas, due to livelihood and cultural loss	1.4-5°C GW southern dieback, 1.5-7.2°C GW northern expansion, relatively fast (100 y.), regional impacts
Warm-water coral reef die-off	Decreased coastal protection (coastal erosion)	Increased vulnerability to extreme weather events	Limited impact on GW until very long term	No impact	Minor impacts	Minor impact	Tropical and subtropical coral reefs mostly die-off, resulting in great biodiversity loss	No impact	Loss of coastal protection services may require engineered replacements	Impact on marine food web, Impact on 500 million livelihoods and food security	Possible interaction with nearby mangroves and seagrass die-off and marine regime shifts	Conflicts over decreasing fish stock, anomie because of livelihood and culture loss, etc.	1-1.5°C GW, plus non-climate thresholds, very fast (10 years), regional and global impacts
Coastal ecosystem regime shifts (mangroves/ seagrass)	Decreased coastal protection (coastal erosion)	Increased vulnerability to extreme weather events	Loss of C sink and release of GHGs, but small impact at global scale	Reduced coastal protection can allow greater seawater ingress, with storms and, aquifer salinisation	Minor impact	No impact	Many mangroves & seagrass ecosystems die-off, resulting in great biodiversity & ecosystem services loss	No impact	Loss of coastal protection services may require engineered replacements	Impact on marine food web, fishery and food security	Possible interaction with nearby coral reef die-off and marine regime shifts	Conflicts over decreasing fish stock, anomie because of livelihood and culture loss, etc	~1.5°C GW, but highly uncertain and spatially variable; Regional impacts

Earth system tipping point	Sea level rise/coastal erosion	Extreme weather events	Feedback on global warming	Water shortages	Changes in precipitation	Regional temperature change	Ecosystem change	Release of pollutants	Infrastructure damage	Food security	Triggering other ESTPs	Secondary societal impacts	Thresholds, timescales & spatiale extent
Savannahs & grasslands (ecosystem regime shift)	No impact	Greater vulnerability to drought or extremely high rainfall	Shifts in carbon storage – some GHG release possible (but globally small)	Greater groundwater depletion (with shrub encroach- ment)	Regional precipitation changes	Complex regional temperature change from changes to albedo and eco- hydrology	Change in vegetation, leading to biodiversity loss, reduced fires with shrub encroachment	No impact	Minor impact	Loss of grazing lands will impact livelihoods and food security	Possible interaction with nearby dryland and tropical forest tipping points	Conflicts over food and water, displacement from uninhabitable areas, anomie, etc	Regionally variable rainfall & fire thresholds, regional impacts
Temperate forests dieback	No impact	Increased wildfires	Carbon emissions (amplifying global warming)	Less atmospheric water supply and groundwater recharge	Changes to evapotranspiration likely to shift regional weather patterns	Regional warming in summer due to less evaporative cooling and cloud cover	Change in forest ecosystems leading to biodiversity loss	Smoke from wildfires	Minor impact	Loss of indirect ecosystem services (e.g. pollinators, groundwater recharge)	Possible impacts on nearby boreal forest	Anomie because of loss of livelihoods and cultural loss	Thresholds unknown regional impacts
Drylands (ecosystem regime shift)	No impact	Greater vulnerability to drought or extremely high rainfall	Shifts in carbon storage – some GHG release possible (but globally small)	Aridification may lead to water shortage, groundwater depletion with shrub encroach- ment	Regional precipitation changes, leading to aridification in some areas	Complex regional temperature change from changes to albedo and eco- hydrology	Aridification/ desertification or shrub encroachment, leading to biodiversity loss	No impact	Minor impact	Aridification/ desertification or shrub encroachment will impact agriculture and food security	Possible interaction with nearby savannah and tropical forest tipping points	Conflict over water and land, displacement from uninhabitable areas, anomie, etc	Aridity indices (0.2, 0.3, 0.45) for aridification, regional impacts
Freshwater lakes (eutrophication-driven anoxia)	No impact	No impact	Increased GHG emissions (reduced for salinisation) could impact GW	Water quality decline could lead to water shortages	Minor impact	Minor impact	Lake ecosystem regime shift, biodiversity loss	Some algae blooms are toxic	Minor impacts	Freshwater fish stock decline could impact food security; water shortages could impact agriculture and food security	No impact	Conflict over water, anomie due to livelihood and cultural loss, etc	Variable for each lake, but higher risk beyond 50-100 mgP/m^3 and 2.5 (1–4) mg N/l Impacts in lake regions, with great regional differences in impact severity
Marine environment regime shift	Minor impact (loss of kelp forests could reduce coastal protection in some places)	No impact	Major changes in ocean productivity, carbon sinks & ocean biogeochemistry could have moderate impact on GW	No impact	Minor impact	Minor impact	Biodiversity loss from trophic cascades and regime shifts	Coastal eutrophication can lead to e.g. toxic 'red tides'	Minor impact	Fish stock collapse could impact food security	Minor impact via reduced carbon sink amplifying GW	Conflicts over decreasing fish stock, anomie because of livelihood and culture loss, etc	Multiple drivers with highly localised thresholds; global and regional impacts; multi-decadal to centennial timescales

3.3.1.1 The rationale for ESTP impact governance

In many ways, ESTPs would exacerbate well-established climate change impacts, such as increasing global temperatures, changing precipitation patterns, creating sea level rise, and more frequent and intense extreme weather events. They would worsen the disruption already experienced by ecosystems and societies in all regions of the world today (IPCC AR6 WGII). However, the threats related to ESTPs are in important ways distinct from climate change impacts as we have come to understand them or alter these expected changes in surprising ways. These differences matter for how we think about dealing with impacts. In other words, the current logics, frameworks, plans, practices and resource allocation to policy domains like adaptation, international migration, disaster risk reduction, and loss and damage will have to change to account for ESTPs.

More specifically, important differences between general climate change impacts and the impacts of Earth system tipping processes concern (1) the magnitude (extent) of change, (2) the speed of change due to nonlinearity, (3) the permanence (irreversibility) of change, (4) novel types of impacts (e.g. loss of ecosystems), and (5) the global distribution of impacts, creating new vulnerabilities. There is also uncertainty about the timing of ESTPs and substantial variation in the temporal and spatial scales on which impacts are likely to unfold, ranging from 10 to 10,000 years and from local to global; see Table 3.3.1). These features stand in stark contrast with the short-term nature of political cycles and decision making, and the lack of political will and public support for precautionary action in contexts with substantial uncertainty and deferred impacts (see Chapter 3.1). The following section (3.3.2) explores these tipping point-specific issues in more detail, outlining how they challenge current approaches and institutions for governing the impacts of climate change and global environmental change more broadly.

3.3.1.2 Matching problem scales and institutions

The geographic scope of current impact governance institutions do not always match the geographic scale of the tipping elements. Earth system tipping processes take place at large (regional or continental) scales, typically affecting multiple countries (e.g. all countries with tropical coral reefs, all countries affected by the West African monsoon), but sometimes in different ways across regions (e.g. AMOC collapse would have different effects in the Northern and Southern hemispheres). This spatial scale of the tipping system has to be added to existing frameworks of multi-level impact governance (see Chapter 3.1), because dynamics at this scale will determine the spatial distribution of future impacts and the distribution of these impacts over time. Without adding this scale as a specific lens for anticipating, planning for, and responding to impacts, governance efforts will be less effective, especially at avoiding and minimising harm, and forced to react to, rather than anticipate, change.

In addition to spatial scale, the temporal characteristics of tipping processes are key for successful impact governance. Three phases of a tipping process can be distinguished: (1) pre-tipping (anticipation), (2) system reorganisation after the tipping point has been transgressed (responding to impacts), and (3) stabilisation of a new system (see Figure 3.3.1). While the prevention of tipping points (see Chapter 3.2) focuses only on the first phase, impact governance has to work across all three. Each phase presents different challenges and tasks for impact governance, requiring a distinct approach and the involvement of different actors, institutions and resources over time.

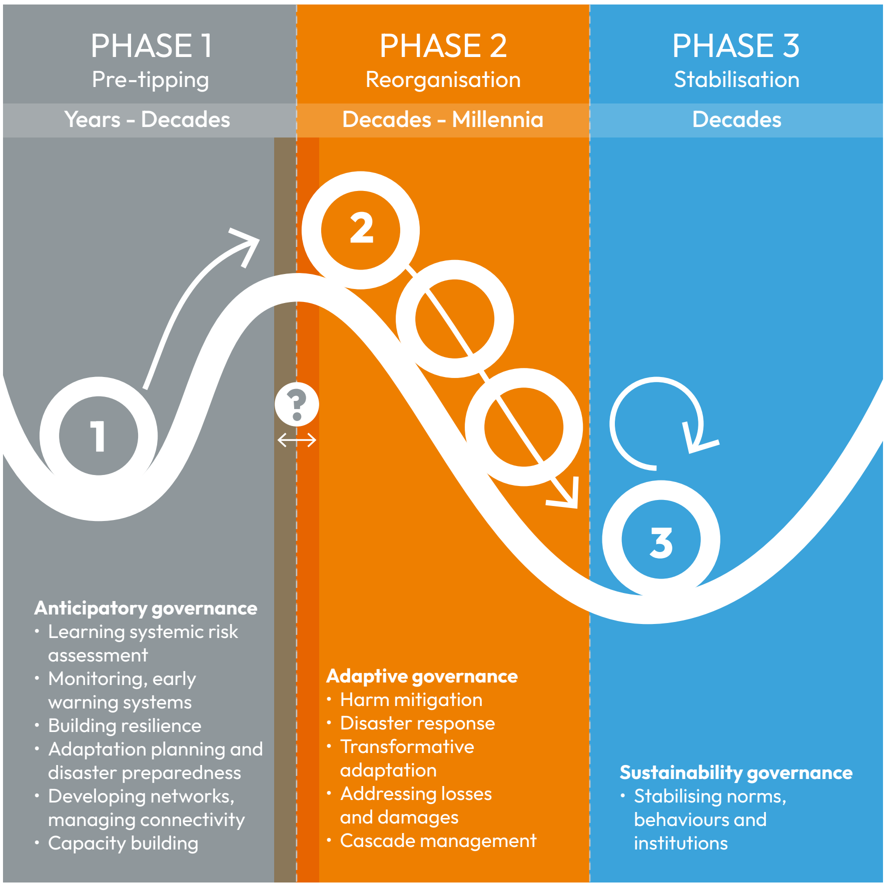

Figure 3.3.1: 3 Phases of ESTP impact governance.

Different governance approaches and tasks corresponding to three distinct phases of Earth system tipping processes: anticipatory governance in the pre-tipping phase, adaptive governance after the tipping point has been passed and sustainability governance when a new stable state has been reached.

In the pre-tipping phase (1), when a tipping system is destabilised and a tipping point might be approaching, key governance tasks include learning and knowledge-capacity building, developing early warning systems and related science-policy interaction protocols, planning and preparation for specific expected impacts, resilience building, and exploring global governance approaches for well-understood climate impacts that could be exacerbated or accelerated by tipping processes (e.g. international migration and resettlement). Network connections can be developed, including links across different governance scales to ensure well-functioning relationships in case impact governance becomes necessary in the system reorganisation phase (2). Once a tipping point has been transgressed, a period of fundamental nonlinear change – systemic restructuring – sets in, driven and accelerated by self-amplifying feedback mechanisms. In this phase, direct impacts need to be addressed, e.g. with adaptation, disaster response, or loss and damage provisions. This is a turbulent period that can extend over multiple decades or even centuries. Impact governance in this phase can be extremely challenging because of the long time period of reorganisation (e.g. multiple decades). Constantly changing system conditions would present an unreliable and unpredictable environment for decision making, disabling established modes of (adaptation) planning. This period of greater volatility would require more flexible and continuous responses by governance actors and the ability to address cascading or compounding disasters. Adaptive governance approaches with frequent learning loops, adjustments of goals and policies would be most suitable in this phase. A key aim during phase 2 is the prevention of impact cascades through multiple social systems, including negative social tipping processes (see Chapter 2.3). When the process of reorganisation comes to an end, the Earth system will settle into a new stable state, which provides an alternative environment for communities and societies. In this stabilisation phase (3), governance will be focused on stabilising human-environment relationships with new patterns of behaviours, resource extraction and corresponding institutions and decision making.

For each tipping point, each of these phases can have varying lengths. For example, the tipping point for the tropical coral reefs could be transgressed in the 2030s, limiting the remaining pre-tipping phase to about a decade. The process of repeated mass bleaching events and coral reef dieback could extend over 3-5 decades (~2035-2075). During this time, various impacts would occur in different regions and countries at different points in time. For example, reef death in a region would be followed by declining fish stocks with consequences for livelihoods, food availability and cultural identities in affected fishing communities. This could lead to changes in economic activities (e.g. transition to agriculture or migration) and social organisation (e.g. shrinking of communities, changes in family authority structures). In some locations, there would be negative effects on tourism, associated economic activities and state (tax) income. Another tipping system, such as the GrIS, would have a very different temporal distribution of the three phases. It could also reach a tipping point in the 2030s, but the second phase of reorganisation – ice melt – could last several thousand years, not settling in its new stable state on a time horizon that is meaningful for today's decision makers.

3.3.1.3 Relevant actors and policy domains

A broad set of global governance institutions is involved in addressing the impacts of global environmental change, such as climate change. Many of these will need to consider adopting responsibilities related to ESTP impacts in their mandates. This includes, for example, the UNFCCC (adaptation, loss and damage, finance, climate resilience), the CBD, the international development community, especially the UN Development Programme, and international development banks, the OECD and international financial institutions (World Bank, International Monetary Fund). Others will likely also be affected, e.g. the World Trade Organization or institutions governing international security. Impact governance is a multi-scale issue (see Chapter 3.1), with countless important actors at regional, national, and local scales (Petzold et al., 2023). Correspondingly, non-governmental and civil society organisations, transnational networks, and private-sector initiatives working in these domains will also need to consider engagement with ESTPs and their expected impacts. Below, we discuss approaches to ESTP impact governance with a specific focus on the UNFCCC and its multi-scale linkages for the governance of adaptation, loss and damage and corresponding capacity building and finance (3.3.3).

In the current pre-tipping phase of impact governance, the following questions can motivate governance actors:

- How could the international community best monitor and continuously learn about the changing risk of approaching and passing tipping points?
- What impact would the transgression of various ESTPs have on a country, community and potential migratory movements, e.g. the effects of WAIS disintegration on coastlines, coastal cities and infrastructure, expected extreme weather damage, and forced migration?
- How should the international community and individual countries prepare for and manage the passing of tipping points and their diverse consequences?
- What criteria can guide the prioritisation of measures? For example, number of affected people, critical infrastructure at risk, economic value of threatened buildings or activities.

3.3.2 Challenges of tipping point impact governance

A number of characteristics of ESTPs, especially the nonlinearity of the change process and the irreversibility of those changes, present significant challenges to current conceptions of global environmental change and the corresponding patterns and institutions to address impacts. Here, we discuss some of these characteristics in more detail. ESTPs make a major difference regarding both the magnitude of change compared to a state without tipping processes (3.3.2.1) and the speed of change expected (Lenton, 2011) (3.3.2.2). Third, the global distribution of tipping point impacts could create new vulnerabilities (3.3.2.3). Further, we discuss the potential for novel types of impact (3.3.2.4) and the permanence of change due to the reorganisation of the Earth system (3.3.2.5). Finally, section 3.3.2.6 adds important concerns about cascading effects.

3.3.2.1 Magnitude of change

Passing ESTPs can increase the magnitude of global, regional, and local changes. At the global scale, the magnitude of (eventual) sea level rise will be much increased by passing ESTPs for Greenland and Antarctic ice sheets, and the distribution of sea level height will adjust – increasing furthest away from the ice sheet that is lost (as the Earth's gravity field adjusts). AMOC collapse would cause sea level rises of up to a metre in the North Atlantic region, while SPG shift would raise them by up to 30 centimetres along the northeast seaboard of North America. Passing ESTPs can also add significantly to global warming by releasing carbon – for example, from abrupt permafrost thaw or Amazon rainforest dieback – or lowering planetary albedo – from lost cloud cover associated with the Amazon forest, or lost snow/ice cover.

At the regional scale, passing ESTPs can increase the magnitude of climate changes. For example, Amazon dieback would amplify warming and drying in the region and the neighbouring agricultural region. At the local scale, passing ESTPs can increase the frequency and magnitude of extreme events. For example, boreal forest dieback can greatly increase the severity of wildfires. These also have regional impacts on air quality.

3.3.2.2 Speed of change

Two time-related characteristics of tipping points create distinct challenges for impact governance. One is the acceleration of change during a tipping process (non-linearity). The other concerns the duration of the tipping process, which varies widely between different tipping systems (see Figure 3.1.1 and Table 3.3.1), from years (e.g. SPG) to decades (e.g. Amazon rainforest) and even millennia (e.g. ice sheets).

A tipping process involves abrupt – surprisingly fast – changes relative to the system's general patterns of development over time. Abruptness is created by self-amplifying feedback processes, which set in after the tipping point has been passed. These feedback processes increase the rate of change in the tipping system, i.e., they speed up the change process. This acceleration can have effects like higher annual rates of sea level rise and has important implications for the ability of affected communities and societies to cope with and adapt to changes (e.g. adjusting agricultural practices), and the capacity of institutions to prevent and mitigate harm (e.g. creating infrastructure resilient to quickly intensifying rain and storm patterns).

There are risks that the rate of change overwhelms existing adaptive capacities, i.e., pushes communities towards adaptation limits, or that policy measures come too late or are maladaptive (Kwadijk et al., 2010; Bentley et al., 2014; Mechler et al., 2020; van Ginkel et al., 2020; Mechler and Deubelli, 2021; Juhola et al., 2022; Schlumberger et al., 2022). For example, beyond a certain amount of sea level rise linked to ice-sheet melt, raising sea walls as a defence becomes an ineffective/unviable strategy and planned relocation must be considered (Kovalevsky et al., 2021; Sengupta et al., 2023). It is possible that social adaptation limits will be reached before biophysical ones, meaning an affected ecosystem might be capable of dealing with impacts of the tipping process, but the affected community would not (Ahmed et al., 2018).

Speed of change could also be understood in terms of the length of the change process. The amount of time it takes for a tipping system to transition to its new stable state is important for the ability of policymakers and communities to respond and adapt to the unavoidable changes. The timescale at which ESTPs can unfold is estimated to vary vastly across different tipping elements, ranging from 10 to 10,000 years. This poses immense challenges for political decision making and governance. If the tipping process occurs over a number of years or decades, the corresponding disruption of social, political and economic systems around the world could be tremendously costly and challenging to manage. This timescale could be too short for any meaningful adaptation efforts. If the changes occur over longer time periods (e.g. a century or more), adaptation processes have more time, but would struggle with identifying appropriate adaptation goals and measures because the system's new stable state would remain unknown for a long time, raising the question of what to adapt *to*. This time horizon would be too long for a consistent adaptation pathway. However, even where the timescale is very long, some effects could be felt rather soon and there would be different types of impact over time. Further, tipping processes that are perceived as slow would likely suffer from the same decision-making challenges as climate change in general: lacking a sense of urgency or motivation to act in the short term.

Combined, increases in the scope and speed of change present formidable challenges for impact governance, threatening to overwhelm adaptive and response capacities. The social-ecological impacts across various geographical and timescales might lead to 'institutional mismatches', resulting in policy measures that are poorly timed or the wrong organisational level (Walker et al., 2009).

3.3.2.3 Impact distribution and new vulnerabilities

Crossing ESTPs is likely to exacerbate existing vulnerabilities to climate change, many of which are the result of historical and current inequities. It would potentially also reveal new vulnerabilities, shifting the distributional impacts of climate change and other environmental harms. Despite a growing understanding of tipping points, there remain substantial uncertainties regarding their temporal evolution and spatial extent, which poses a challenge for efforts to mitigate their impacts (Galaz et al., 2011; Barrett and Dannenberg, 2012). Common vulnerability indices used to identify the states and communities most vulnerable to climate change, and hence most in need for adaptation (Feldmeyer et al., 2021), do not currently take into account how risks and vulnerabilities may be reinforced or redistributed or by the crossing of different ESTPs (OECD, 2021).

While we might expect that the communities identified as most vulnerable to climate change impacts are also likely to be vulnerable to some of the ESTP impacts, others will fundamentally change expected climate patterns (notably AMOC collapse) and which populations are exposed or vulnerable. Indeed, while the Global North is often depicted as less climate-vulnerable than the Global South, crossing certain tipping points would have devastating impacts on both affluent and less-affluent communities. For example, crossing the extrapolar glaciers' tipping points would heavily affect the European Alpine region, causing mega rockfalls, glacial lake outburst floods, and water shortages (see Table 3.3.1). Should the AMOC collapse, Europe would be one of the regions severely impacted, along with West Africa, India and the Amazon region (see Figure 3.3.2). The impacts of an AMOC collapse are relatively well understood, particularly in comparison to other ESTPs, as the Earth has experienced phases in its past when the AMOC was switched off. However, the projection in Figure 3.3.2 may change if several ESTPs are breached, creating compounding impacts.

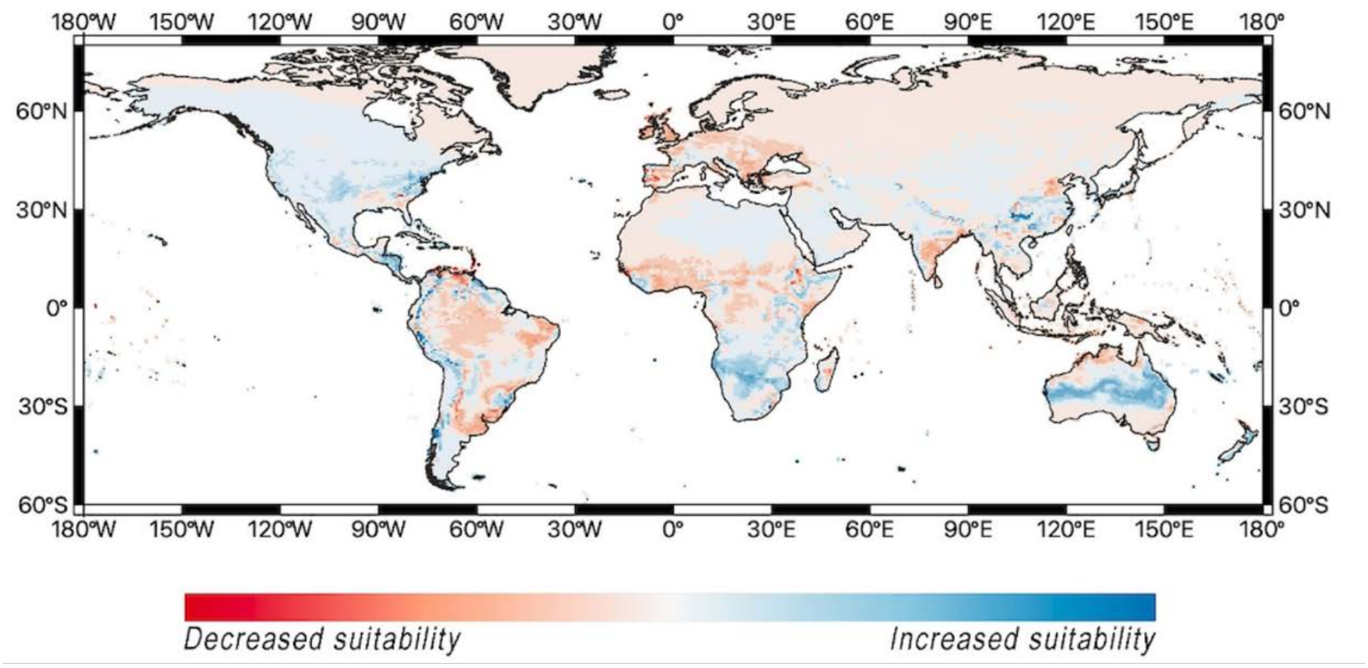

Figure 3.3.2: World map of human habitation suitability under AMOC and 2.5°C global warming.

The modelled change in the human climate niche following the simulated collapse of the AMOC after 2.5°C warming above pre-industrial temperatures according to SSP1-2.6 (Source: OECD 2021).

3.3.2.4 Novel impact types

Passing ESTPs can reverse current regional trends in climate, upsetting existing expectations, adaptation frameworks and plans. Current adaptation plans and measures may be inappropriate in the face of such trend reversals, and investments in climate-resilient infrastructure might become useless. For example, in case of a collapse of the AMOC, places like Northern Europe, that are currently adapting to marked warming and wetting, would have to adapt to radical cooling and drying instead (see Table 3.3.1 and Figure 3.3.2). Trend reversals would represent significant challenges for public communication of climate change and the justification of policy measures.

Further, the transgression of ESTPs can fundamentally alter the ecological basis of regions and livelihoods and can expose affected people and locations to novel threats. For example, the tipping of the Amazon rainforest into a savannah-like state would imply the permanent loss of the region's current ecosystems and associated loss of biodiversity, permanent changes to the region's hydrology and corresponding water availability, agriculture and power generation, and the removal of a major carbon sink. This would create tremendous cultural, economic and political disruption for all affected communities and countries, removing the foundations for much of the current organisation of social, cultural and economic life in the region (e.g. the potential for agriculture and cattle ranching). This would have radical implications for people's livelihoods, food and water security, the trajectory of industries and economic sectors, the generation of taxes, international trade and tourism, and national, regional and individual identities.

Another example is the loss of tropical coral reefs, which would impact the livelihoods of half a billion people. Loss of the fisheries they support would take away a major source of livelihood, while loss of the protection they provide to coastlines would leave them exposed to storm surges and erosion.

3.3.2.5 Irreversibility and permanence of change

A tipping point involves a shift between two alternative stable states of a system, which implies not only a fundamental (identity) change of the system in question (phase 2), but often also the stability – permanence – of the altered conditions (phase 3). For many tipping points, there would be no way back to the initial (current) conditions, at least on timescales that are relevant for decision makers today. For example, if the Amazon rainforest shifts to a savannah-like state, there would be no viable return path to a rainforest state over multiple centuries, even if temperatures were reduced back to current levels. Tipping elements such as ice sheets and related sea level rise are technically reversible, but the deposition of new glacial mass operates through a very different mechanism than those that produce ice melting. Re-establishing lost glacial mass in Greenland, for example, would thus take place on much longer timescales than the time over which current losses are occurring, and would require a decrease of the global temperature to below pre-industrial levels. The IPCC's 6th assessment report recognises the risk of irreversible climate impacts in case of temperature overshoot (IPCC AR6, WGII, SPM, 2022a), but not in a more systematic way linked to Earth system tipping processes.

The irreversibility of tipping processes is the characteristic that creates most concern among decision makers (Milkoreit, 2019), likely because it has important implications for impact governance.

First, the irreversible, structural changes associated with the crossing of ESTPs imply that **loss and damage provisions will play a much greater role** than currently recognised. Environmental conditions for human existence will be permanently altered at large scales, and current conditions – ecosystems, landscapes, natural resources, and the associated human uses and experiences of nature – will be lost. In extreme cases, these losses will be observable, like species extinctions, or the loss of a glacier or river. In other cases, the reorganisation will be more creeping, such as loss of habitable coastline, the changes to a landscape or disappearance of industries that are not sustainable in the post-tipping state. There will be a greater need for loss and damage institutions, including financing, which is already sorely lacking, to compensate for impacts that cannot be avoided by mitigation and adaptation efforts. Furthermore, as more wealthy countries grow increasingly aware of the impacts they face from the crossing of ESTPs, they may also grow wary of contributing to loss and damage funds aimed at compensating communities and countries with lower adaptive capacity.

Second, current climate change adaptation approaches might not be adequate to deal with the effects of ESTPs. Current climate adaptation frameworks focus on "reducing climate risks and vulnerability mostly via adjustment of existing systems" (IPCC AR6, WGII, SPM, 2022b). The IPCC also noted that, while there has been progress in adaptation efforts around the world, "Many initiatives prioritise immediate and near-term climate risk reduction, which reduces the opportunity for transformational adaptation." Adjustments of the current system and short-term risk-reduction measures would likely be insufficient in communities affected by profound and lasting disruptions associated with ESTPs.

The existence of ESTPs also creates risks for maladaptation, which refers to adaptation measures with adverse outcomes that reinforce, redistribute or create new sources of vulnerability now or in the future (Juhola et al., 2016; Schipper, 2020; Eriksen et al., 2021). Maladaptation can range from simply inefficient measures to those with wide-reaching negative externalities (Brink et al., 2023), including increased GHG emissions from air-conditioning in response to increasing heat, more inequitable welfare distribution or increasing social conflict (Nadiruzzaman et al., 2022).

3.3.2.6 Secondary or cascading impacts

An additional challenge is that transgressing certain ESTPs or multiple interacting tipping points may trigger not only direct impacts, but also secondary impacts or impact cascades. This can include negative social tipping points (see Chapter 2.3 and 2.4). For instance, as a result of AMOC collapse, equatorial zones could experience 'unliveable' heat, failing agriculture and water shortages, which could trigger mass displacement, poverty traps and/or political instability. Regional impacts could be further aggravated by a collapse of the West African monsoon, which could displace many people and disrupt agriculture in highly populous areas like Nigeria (see Table 3.3.1, see also Chapter 2.2). Governance should aim to avoid impact cascades and negative social tipping dynamics.

3.3.3 Governance of ESTP impacts

Guided by these challenges and the principles introduced in Chapter 3.1, especially anticipation, polycentricity/multi-scale governance, systemic risk governance, and equity and justice, here we explore where and how impact governance related to ESTPs could take place. We begin with a discussion of multiple objectives of impact governance and how to prioritise these (3.3.3.1). Sub-section 3.3.3.2 applies the concept of polycentricity to ESTP impact governance, including the need for diversity, redundancy and flexibility in response capacity. We use examples from the UNFCCC (adaptation, loss and damage) and international migration, to illustrate opportunities and challenges in the existing landscape of governance institutions, especially at the global scale. We consider cascade prevention from a systemic risk governance perspective in 3.3.3.3 and the need to generate reliable early warning signals and systems in 3.3.3.4. Finally, we discuss equity and justice implications for future impact governance efforts (3.3.3.5). This is a domain where the social science knowledge and evidence base is particularly thin, and our discussion is to a large extent speculative.

3.3.3.1 Objectives of ESTP impact governance

The core objective of impact governance for ESTPs is to prevent or minimise harm from potential tipping processes, with a special focus on preventing impact cascades. Mirroring existing objectives of adaptation and disaster preparedness, governance in this domain should aim to reduce risk and vulnerability, strengthen resilience, increase preparedness and adaptive capacity, and foster anticipatory and response capacities in relevant institutions.

It is crucial to enhance adaptive capacity and resilience in potentially affected communities and institutions to manage the significant risks associated with crossing tipping points. Given the challenges outlined above, Adaptation governance in this domain should prioritise **transformative adaptation**, which changes the fundamental attributes of a social-ecological system in anticipation of climate change (here tipping points) and its impacts (IPCC-AR6-WG2, 2022a) rather than making incremental adjustments to the existing system in response to observed changes. Transformative adaptive measures can mitigate immediate disruptions to economic and social activities, and also help prevent mid-term losses, promoting long-term human wellbeing and planetary health (OECD, 2023). More generally, transformative responses are desirable because they can simultaneously address the key drivers of tipping points, reduce vulnerability and minimise the connectivity that facilitates cascades. In turn such responses imply rapid social and cultural change (positive social tipping points, see Section 4).

One key goal of ESTP impact governance is the **prevention of impact cascades**, including negative social tipping dynamics. This is a challenging task with limited experience and expertise in existing governance institutions. Given the currently limited understanding of successful strategies for cascade management, especially the design of interventions to halt a cascade that is in progress, we suggest focusing on strengthening the resilience of societies and building adaptive as well as transformative capacity.

3.3.3.2 Multi-level, multi-phase, and multi-network governance

Responding effectively to ESTPs requires drawing on the competences and resources of actors at multiple levels, usually embedded in different organisational networks. It is important that these linkages between actors at various levels and organisations are established and functioning before a response is required (i.e. in the pre-tipping phase 1 of a tipping process, see Figure 3.3.1). It is these 'connective capacities' that allow actors to coordinate across scales, domains and sectors in response to a tipping event (Folke et al., 2005; Edelenbos et al., 2013; Galaz et al., 2016). At the same time, strongly connected, interdependent systems can be a source of instability. Care is required when building connective capacities to avoid introducing new sources of instability, abstaining, for instance, from tight coupling and instead prioritising decentralised coordination (Perrow, 1999; Scheffran, 2008; Helbing, 2013; Leonard, 2021).

Figure 3.3.3 presents a multi-level, multi-phase, multi-network governance response scheme, highlighting the importance of actors and institutions across all levels to be involved in tipping points impact governance. The multiple scales include local, regional, national and global governance institutions. The multiple phases expand on Figure 3.3.1, differentiating between anticipation, detection and four different time horizons of impact response after the transgression of a tipping point, from immediate to 1,000+ years.

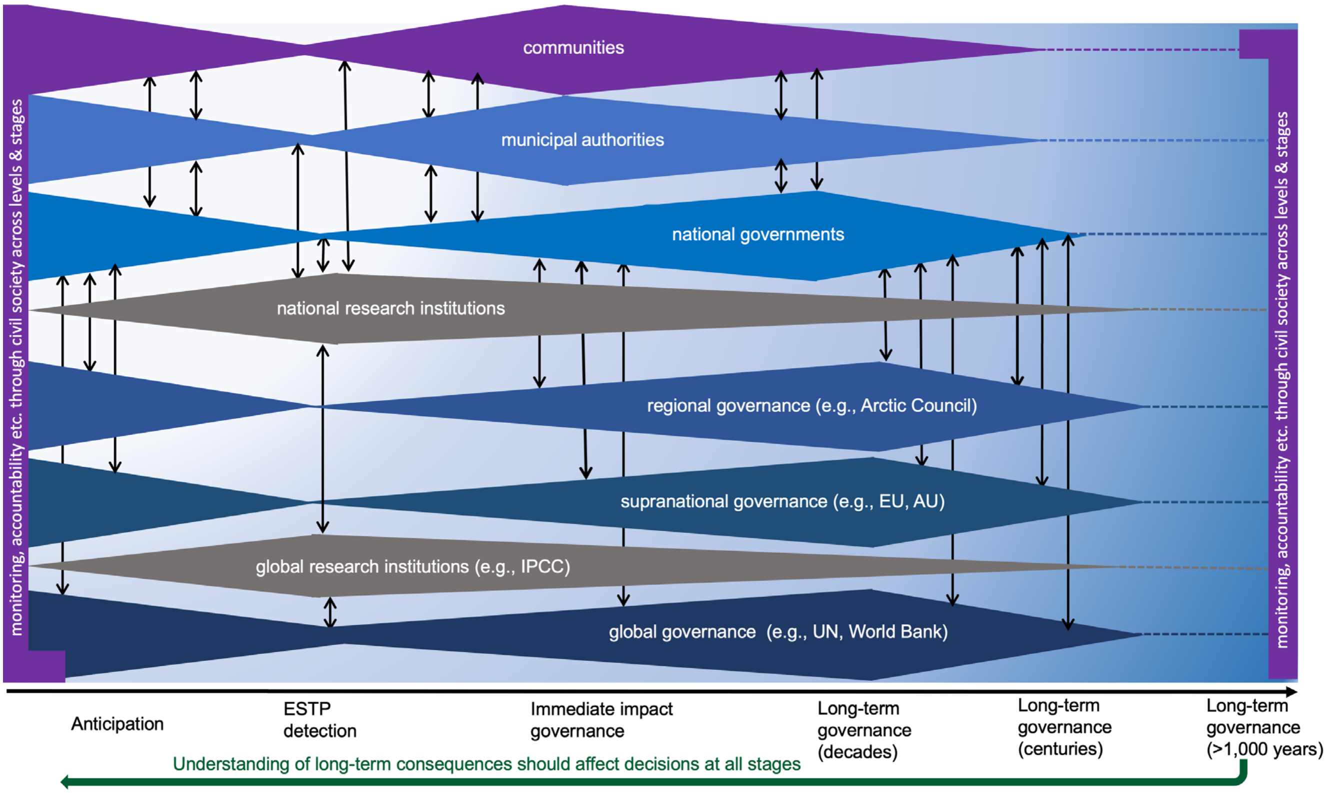

Figure 3.3.3: Multi-level, multi-phase ESTPI impact governance.

Governance institutions at local, national, regional and global level and their involvement in ESTP governance at different phases of ESTPs and their impacts. The thickness represents the importance of the respective governance institutions in a given phase. The arrows represent interactions. All interactions are two-ways with the main purpose being coordination, resource distribution, knowledge exchange and backup planning. Interactions at the regional level can include sectoral planning and cross-border initiatives. Civil society is tasked with monitoring and ensuring accountability at each governance level.

It is difficult to accurately predict the timing, scope and location of a tipping event and its various impacts. Therefore, developing and maintaining a diversity and redundancy of resources (human and economic), institutions (non-governmental to international organisations) and knowledge (scientific to local) is important to prepare for the unexpected (see 3.1.2.2). While these institutions together comprise enormous resources for problem-solving, a key challenge is to coordinate them to adequately respond to the impacts of tipping points to enable their rapid mobilisation when needed. A networked, decentralised, polycentric impact governance approach would facilitate access to these diverse resources and empower agency by balancing self-organisation and coordination (Folke et al., 2005; Bodin and Crona, 2009; Helbing et al., 2015; Galaz et al., 2016). In some instances, governance capacities and resources might be weak or lacking at particular scales or sites, or responsibilities might not be matched with required resources. Identifying and filling such gaps with a view to ESTPs will be an important component of pre-tipping governance. For example, current adaptation approaches often defer adaptation planning to the level of local governance, which has been criticised as inadequate (Nyberg et al., 2022)). This might be even more the case for ESTP impact governance. While local government and community groups are key actors in the multi-level governance set-up, they alone will not have the capacity to respond to the effects of tipping points. National governments will play a crucial role to facilitate local response in collaboration with local actors and non-governmental actors (Nyberg et al., 2022).

Multiple spatial scales: Given the diversity of tipping-point impacts and their geographic distribution, even among tipping points of the same kind (e.g. the disintegration of different ice sheets), governance efforts should carefully consider the need for tipping point-specific approaches. Further, tipping processes demand a distribution of multi-dimensional governance responsibilities in a polycentric system of actors. For some aspects of impact governance, global coordination or even rulemaking might be needed, while planning and implementation takes place primarily at other scales (OECD 2021). The case of climate change adaptation is insightful here: a global adaptation goal, information-sharing in the UNFCCC (e.g. with NDCs and reporting requirements) guide global adaptation efforts, while adaptation planning requires national and local action, and implementation is almost always a local (e.g. city-level) task. The question of resources and finance has important global dimensions (the provision of climate finance by high-income countries) and can involve international financial institutions. There are also cross-scale issues within countries, e.g. to what extent do national governments provide support and funding for local adaptation planning and measures.

In the context of ESTPs, regional governance bodies such as the European Union or African Union, but also non-government bodies such as the OECD, might play an important role in developing regional responses and cross-border initiatives. While it is not yet clear to what extent governance arrangements at the scale of specific tipping systems (e.g. West African monsoon or tropical coral reefs) is needed to support impact governance, we suggest that there would be significant benefits in coordinating activities at this scale and in learning from each other's experience of different adaptation approaches.

National governments will play an important role in identifying which tipping point risks they are exposed to and how to prepare for potential impacts. A range of existing national policy measures and activities, related to, for example, climate change adaptation, disaster preparation or immigration, will need to be updated and likely adjusted to account for ESTP risks. Further, social cohesion is regarded as a foundation for societal resilience and transformative adaptation, and should be fostered (Grimalda & Tänzler, 2018; Orazani et al., 2023). Institutional capacity building to equip local authorities and communities to respond in just ways to Earth system destabilisation is another important task for national governments.

Multiple temporal scales: Various institutions will also play different roles regarding the different phases and temporal scales of ESTP impact governance. Time-specific governance efforts range from anticipation in the pre-tipping phase (see Figure 3.3.1) to long-term governance for impacts over several hundred years in the reorganisation phase. Institutions ranging from the local to global level should be involved in pre-tipping learning, planning and capacity building. Long-term governance with time horizons beyond this century is not yet part of the toolbox of global governance in the 21st Century, and capacity building and innovation is needed in this regard. Actors like national governments and international organisations might in many cases be more suitable to this task than actors in industry or civil society due to their higher potential for continuity (see Figure 3.3.3).

Legitimacy and trust: Successful polycentric governance of tipping point impacts requires legitimacy – i.e. the shared understanding that the actions taken are fair and appropriate. Legitimacy facilitates trust, which is crucial for coordinating a networked response (Moynihan, 2008; Young, 2011; Galaz et al., 2016). One way to increase this is through public engagement in impact governance, which gives citizens agency, empowering them to develop transformative adaptation strategies and competencies to protect themselves and their communities (Oliver et al., 2023). For instance, ESTP impact governance may involve abandoning certain economic or agricultural activities in areas with ecological regime shifts (e.g. coral reef die-off or extrapolar glacier retreat) and establishing new ones. Involving local communities in decision making and transformative pathways implementation will be crucial for legitimacy and buy-in. The format and mechanisms of public engagement (e.g. online climate assembly platforms) are crucial to achieve these positive effects and avoid inequality of participation (Nisbett et al., 2022). We suggest a potential framework for community involvement based on Oliver et al., (2023) and OECD (2021) in Figure 3.3.4.

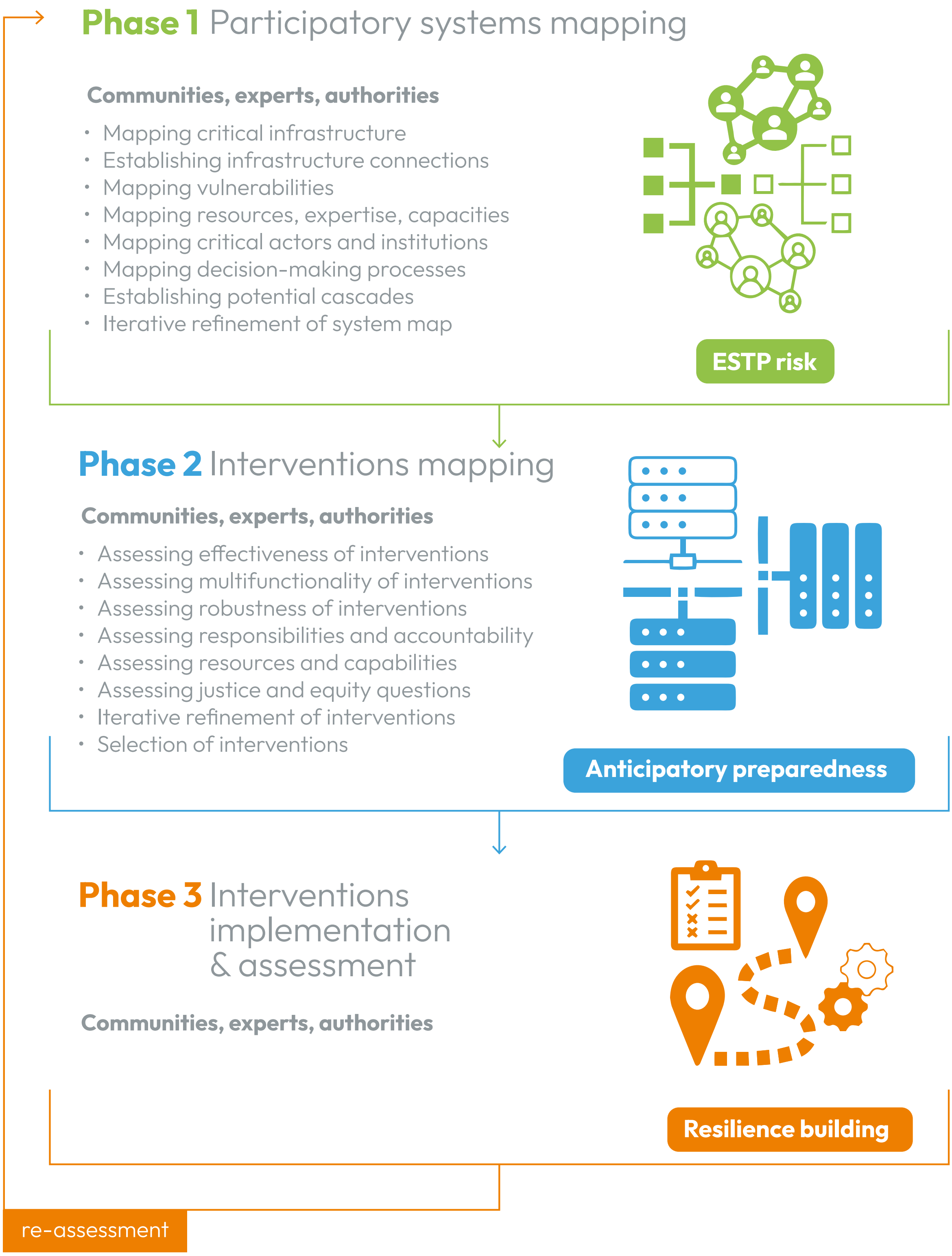

Figure 3.3.4: Community involvement in ESTP governance. The suggested scheme for community involvement in ESTP governance builds on Oliver et al. (2023) and OECD (2021) and envisions three phases: participatory systems mapping, Intervention mapping and interventions implementation & assessment. In each phase the involved actors are communities, authorities and experts.

Citizen-led adaptation approaches need to be integrated with other efforts by local and national governments within a multi-level framework. Adapting these approaches for tipping point governance likely requires the involvement of scientific experts and the acknowledgment that adaptation may not be an option in response to certain impacts (i.e. directly addressing the possibility of adaptation limits).

Box 3.3.2: Institutions for multi-level, multi-phase, and multi-network ESTP impact governance in the Amazon

Governance of the Amazon rainforest represents a complex and multi-faceted challenge due to the conflicting interests and demands placed upon its ecosystem services. Spanning the territories of nine nations, the Amazon houses various Indigenous groups, resource users and extractive industries. This multifaceted landscape has driven efforts to harmonise often-competing priorities between exogenous and endogenous forces through the institutionalisation of polycentric climate governance (PCG) approaches (Ostrom et al., 2010; Abdala, 2015). Effective governance becomes pivotal, especially when considering potential tipping points arising from the interplay of climate change, deforestation, degradation and fire (D'Almeida et al., 2007; Wright et al., 2017; Butt et al., 2020; Leite-Filho et al., 2020). The projected impacts of Amazon dieback, which could be triggered at between 2°C and 6°C global warming, are summarised in Table 3.3.1.

The triggering of the Amazon dieback tipping point would have region-wide and even global impacts. At the regional level, the main cooperation instrument deployed to promote regional coordination is the Amazon Cooperation Treaty (ACT) and its supporting forum, the Amazon Cooperation Treaty Organisation (ACTO). While ACTO has contributed to the reduction of regional discrepancies and fostered regional cooperation, its broader effectiveness as part of a polycentric governance framework remains debated. One limitation is that its membership is confined to nation states, causing some misalignment between ACTO's initiatives and the sub-national decisions of its members. This restriction also hinders the development of potential cross-boundary initiatives that could help address tipping-point drivers.

Stakeholders have responded to this absence of effective integration between regional and sub-national scales of governance through increasing participation in jurisdictional-scale intergovernmental forums, such as the Governors' Climate and Forests Task Force (GCF). The GCF currently enhances coordinated efforts against deforestation and encourages sustainable development pathways at the sub-national level (Burkhart et al., 2017). Its mandate could be extended to integrate tipping-point governance, such as water scarcity management and transformative adaptation to an ecological regime shift.

Participation of, and engagement with, local knowledge and perspectives is both a key dimension of climate justice and associated with improved governance and adaptation outcomes (Marshall, 2009; Schroeder, 2010). However, in the case of cross-scale Amazonian governance, Indigenous communities are underrepresented in decision-making protocols, particularly at the national and regional levels. The right to participate in regular ACTO meetings as observers is not explicitly afforded to Indigenous communities, nor are the latter effectively consulted in the design of policy, programmatic activities, or budget allocation (Garcia, 2011). This has decreased the legitimacy of governing authorities (Burkart et al., 2017) and undermined the effectiveness of governance efforts.

However, there are examples of effective approaches to polycentric governance in specific local contexts, where the involvement of local cooperative initiatives fosters legitimacy and social capital between stakeholders. The Brazilian state of Acre is considered as having developed one of the world's most advanced state-wide programmes for low-emission rural development, including adaptation. The state's experimentation with forest-based development and forest citizenship to address the complex challenges of sustainable forest-based development have given rise to a comprehensive approach that links policies across sectors, involves civil society, and builds institutional capacity (Schmink et al., 2014). This approach includes community and state forest management, expansion of forest-product value chains, forestry education, and technical assistance for different resource user groups (Schmink et al., 2014). Notable is the structural inclusion of the Indigenous Working Group (IWG), representing Acre's 15 ethnic groups (de Wit, 2019) in its Commission for Validation and Accompaniment (CEVA). CEVA monitors Acre's State System of Incentives for Environmental Services (SISA), which is primarily tasked with reducing emissions from deforestation and forest degradation (REDD), but which could be expanded to ESTP impact governance. The integration of the IWG in CEVA was found to have had a positive impact on Indigenous communities' internal social cohesion alongside increased trust between communities and the state.

On the other end of local-global spectrum, the question arises as to what role global institutions such as the UNFCCC could play in an Amazon dieback tipping point scenario. This would likely increase adaptation needs in the region and result in loss and damage (including loss of cultural practices, etc), suffered particularly by Indigenous communities.

(a) Impact governance in the UNFCCC

Similar to our discussion of prevention efforts (see 3.2.3), several features of climate change governance under the UNFCCC, in particular the Paris Agreement (PA), are relevant for impact governance related to ESTPs. These could be adjusted to take into account the risks of large-scale, nonlinear change processes in the Earth system. Relevant stipulations include those related to adaptation (global goal in Art. 2 (1b) and Art. 7 PA), loss and damage (Art 8 PA), finance, technology and capacity-building support (Articles 9, 10, 11), the Global Stocktake (Article 14 PA) and the obligation to regularly submit NDCs (Article 4 (2) PA).

The characteristics of tipping points and their impacts present formidable challenges for the existing global framework on adaptation. The global goal on adaptation (Art. 2 (1b) and Art. 7 (1)) sets out to enhance adaptive capacity, strengthen resilience and reduce vulnerability to climate change by supporting national-scale action. The interpretation of this goal should consider the latest scientific evidence regarding ESTPs, and the specific challenges they present (see 3.3.2). This implies, for instance, including tipping points in impact risk and adaptation needs assessments across scales and sectors, addressing ESTPs in adaptation plans and reports, and emphasising transformative adaptation. The Paris Agreement recognises the multi-scale nature of adaptation governance (Art. 7 (2) PA), and the imperative of adaptation being country-driven, taking into account major differences between affected communities around the world.

This applies in the context of ESTPs: countries need to assess their exposure to potential tipping-point impacts and determine – in a process that involves national and sub-national actors – how to prepare for and adapt to the expected changes. However, given the important scale of the tipping system, we recommend that adaptation governance increasingly considers regional coordination and cooperation regarding adaptation among all countries affected by a specific tipping process.

While the IPCC reports that progress has been made on adaptation around the world (IPCC AR6 WGII SMP 2022b), there is still a long way to go, and tipping risks have not yet been factored in adaptation strategies. There are significant risks of insufficient or maladaptive approaches, and the possibility that tipping processes push communities towards and across adaptation limits.

Based on our arguments related to Earth system reorganisations and irreversibility, loss and damage (L&D) provisions will play an ever-growing role in this domain of governance. Loss and damage is increasingly recognised as the 'third pillar' of climate change governance in addition to adaptation and mitigation (Broberg, 2021). L&D is subject of Article 8 PA, recognising "the importance of averting, minimising and addressing loss and damage associated with the adverse effects of climate change". These impacts are often described as "beyond what can be adapted to" (Huq et al., 2013; UNFCCC, 2018). As outlined above, transgressing ESTPs will make the occurrence of impacts beyond the feasibility range of adaptation much more likely.

While there is yet no official definition for L&D, a range of phenomena fall into this category, including impacts of extreme weather events, migration and displacement, and slow-onset events (e.g. sea level rise, glacial retreat, salinisation), which can cause economic and non-economic losses (NEL). The former refers to loss of income, business operations and infrastructure, while the latter concerns losses that are intangible and cannot be expressed in monetary terms. NELs are related to culture, Indigenous knowledge, sovereignty, health, or loss of territory. NELs are challenging to address or even identify, making the development of governance mechanisms difficult and slow. Given that ESTPs can result in the loss of whole territories or ecosystems, with implications for the cultural practices that were embedded in these territories and ecosystems, it is likely that breaching ESTPs would result in higher non-economic L&Ds.

Following COP27 agreements in 2022, a new L&D fund for vulnerable countries is currently being designed. ESTPs and their potential impacts should be taken into account in this process. The fund is expected to rely heavily on attribution science for any L&D claims made. If ESTPs are transgressed, the future attribution models used should include ESTPs to allow communities to make L&D claims on the basis of tipping-point impacts. Given that vulnerabilities to ESTPs are not the same as overall climate change vulnerabilities, the question arises whether (currently) affluent countries affected by ESTPs (e.g. Europe under an AMOC collapse scenario) would be eligible to access L&D funds, given they will also be expected to contribute as one of main (historic) emitters. Furthermore, the current proposals for an L&D fund tie it closely to current global finance institutions and mechanisms. Since the crossing of tipping points could destabilise the financial system (see 2.3.6), it is important to ask how the L&D fund can itself be made resilient against this ESTP impact. Finally, for L&D to effectively support communities that will be most affected by ESTPs, which often suffer from intersecting disadvantages and marginalisation, processes and actors need to be in place that can provide knowledge on L&D mechanisms and ESTPs at the local level. Empowering communities to demand compensation or other forms of support will be key for the availability of resources for re-building and transformation.

(b) Climate-related mobility

ESTP impacts are expected to increase the movement of people within and across countries. As tipping processes unfold: accelerating sea level rise, more frequent and severe extreme weather events, and the collapse of certain ecosystems and water sources are likely to increase climate-related mobility in many regions of the world. This can take different forms, including migration, displacement, planned retreat, and immobility. Voluntary migration may be an alternative to in situ adaptation, while other forms of movement, for example., forced or involuntary migration, may instead be a failure to adapt, perhaps due to insufficient public investment in adaptation measures, and a lack of anticipatory planning, leading to Loss and Damage (Pill, 2020). At the same time, ESTP impacts can increase the number of trapped or immobile populations (see chapter 2.3 and 2.4). Distinguishing among three dimensions of climate-induced human mobility-migration, displacement, and immobility-is important as each responds to different and multiple drivers, affects distinct populations, has distinct impacts, and requires different management strategies. Both those who move and those who do not move may face increased vulnerability (Black et al., 2013). Managing, anticipating, and planning for increases in temporary and permanent, voluntary and involuntary, and international and internal climate-induced population movement poses increasingly urgent governance challenges.

The ability of countries to adapt to rising sea levels varies significantly, and many coastal areas are projected to reach their adaptation limits this century, even without taking into account the transgression of tipping points. Over the past decade, weather-related events have already displaced twice as many people annually as conflict and violence, and this number is likely to grow. The United Nations International Organization for Migration (IOM) forecasts up to one billion environmental migrants by the year 2050 without taking into account the additional mobility pressures created by ESTPs. Furthermore, some nations, such as low-lying islands, are becoming increasingly uninhabitable, requiring, in extreme cases, the movement of entire populations to receiving countries. This raises new international legal questions related to self-determination and the 'right to relocation', statelessness and how to create continued political statehood after the submersion of a state's territory, and how to define exclusive economic zones or sovereign waters (Risse, 2009).

While displacement today is mostly temporary, as tipping points unfold and permanently change parts of the world (e.g., turning the Amazon rainforest into a savanna), displacement may become increasingly permanent. There is a need to anticipate these movements and understand where they are unavoidable and where they might reflect under-investment in communities. Governance reform is needed to strengthen the rights of people and obligations of governments in countries of origin, transit and destination (Kraemer, 2017). Existing reform proposals include the introduction and recognition of "climate passports" that follow the historical model of the "Nansen Passport"— internationally recognized refugee travel documents first issued by the League of Nations' Office of the High Commissioner for Refugees to stateless refugees following WWI (BMZ, 2021).

Climate-induced mobility is a complex, dynamic, and multi-dimensional issue domain. The movement of people will happen both within and across countries, necessitating robust domestic and global governance. There is currently no firmly institutionalised global governance framework for cross-border migration. Recent progress towards such a framework includes the Global Compact for Safe, Orderly and Regular Migration (GCM) adopted by most UN member states in 2018. The GCM is a non-binding cooperation framework and provides a foundation for strengthening legal and institutional conditions for cross-border migration in the future. The IPCC has pointed to expansion of opportunities for human mobility as one measure to reduce vulnerability to climatic changes. In this context, the IPCC has highlighted that expanding opportunities for human mobility can reduce vulnerability to changes in the climate and enhance human security, particularly for exposed populations that lack resources for planned migration (Adger et al., 2014).

Planned relocation is one approach to expanding opportunities for human mobility. The planned or managed movement of communities or people away from high or at-risk areas to new locations is a specific climate mobility governance challenge with international, national, and sub-national dimensions. While one aim of impact governance is to minimise displacement through local resilience building and adaptation measures, planned relocation is likely to become increasingly necessary due to environmental changes that cannot be adapted to and due to persistent under-investment in adaptation measures (Stal, 2011; Ferris, 2012; Martin et al., 2014; Ahmed and McEvoy, 2014). As a result, planned relocation as a policy response to environmental changes has gained recent attention (Koslov, 2016; Hino et al., 2017).

Planned relocation, also referred to as managed retreat or resettlement, covers a range of cases, including the relocation of communities within a country or region (e.g., moving coastal communities to locations further inland) and across borders (e.g., relocating small-island populations to another country). This process can be driven by the community itself or happen with government support and guidance. As such, the process and associated challenges vary substantially across cases. The term is not defined under international law, and views on its key elements, including resource allocation and distribution, engagement in decision-making process, and recognition, differ among various entities including governments and legal experts. Furthermore, it challenges widely held values around freedom of movement, psychological attachments to place, and the community social fabric, and has historically been associated with racist policies and inadequate community consultation, inadequate complaint mechanisms, and limited post-relocation support (Schade, 2013; Arnall, 2019). While planned relocation has had a poor record in terms of socioeconomic impacts, it also has the potential to save lives and reduce risks (Ferris and Weerasingh, 2020). However, currently the absence of national and local frameworks, meaningful community-consultation, and sufficient anticipatory plans pose challenges for successful planned relocation efforts. Case studies suggest that planned relocation processes initiated and driven by affected communities have better outcomes than government-driven processes (Bower et al., 2023). Careful and advanced planning, legal and institutional frameworks, and adequate financial resources are also important (Ferris and Weerasingh, 2020).

In recent years, there have been a growing number of examples of sizable, planned relocation efforts that help illustrate the broad range of governance challenges associated with this approach. The government-managed relocation of indigenous tribes living on Isle de Jean Charles, Louisiana set the precedent for climate-induced planned relocation in the United States (Davenport & Campbell, 2016). The small island community lost 98 percent of its territory due to subsidence, erosion, and the construction of Mississippi River levees (Ferris & Weerasinghe, 2020), and by 2017, a large part of the population had left the island due to repeated flooding. The remaining residents, mostly members of small indigenous groups, struggled to obtain financial support for relocation due to lack of federal recognition of the tribes until receiving a grant from the US government in 2016. The Jean Charles Choctaw tribe has since released a statement (2022) that the state's handling of the relocation was conducted "without meaningful consultation with, or the explicit consent from, our Tribal leadership". Principles of consultation, consent, and support are included in the United Nations' Declaration on the Rights of Indigenous Peoples (UNDRIP), which was adopted in 2009 by all 182 states of the UN, including the U.S. The Isle de Jean Charles case illustrates the need for an organised effort by a designated (federal) agency focused on community resettlements, with greater advanced planning, more money, fewer bureaucratic hurdles, and increased sensitivity to community needs.

In 2022, the Biden Administration set a new precedent for government support for planned relocation due to climate change by allocating $75 million to relocate three Native tribes from their current tribal lands (two in Alaska and one in Washington state) (Newburger, 2022). However, the funding is insufficient to rebuild homes, schools, and other community necessities. There is still no designated federal agency to manage these resettlements, nor clear national and local frameworks to ensure that the relocation benefits communities and involves meaningful community consultation.

Other countries with sizeable areas at risk from sea level rise and extreme weather have made similar efforts, including Vietnam, the Philippines (following the devastation caused by Typhoon Haiyan), and Fiji. Some Small Island Developing States (SIDS) face existential threats from sea level rise, which will be exacerbated by the crossing of ESTPs. In 2017, Fiji had already relocated three communities to higher ground and has plans to move another 43 villages. To facilitate this process, they developed guidelines for planned relocation (Fiji and GIZ, 2018). However, it is anticipated that several SIDS may need to move their populations to other countries in the future (Vaha, 2018). In 2014, Kiribati purchased land from Fiji, becoming the first nation to purchase land in another country specifically for relocation of its people due to climate change.

As the urgency and scale of planning for the relocation of entire communities and even nations grow, a coordinated, local, national, and international governance of climate risk and adaptation will need to incorporate planned relocation among its portfolio of impact governance responses. This will require multi-level coordination both within and across countries, and the development of novel governance and legal frameworks. These frameworks might build on existing rules and provisions for the resettlement of refugees, and they might fall under the L&D mechanism of the UNFCCC. But these governance instruments will need to be adjusted to consider the relocation of entire populations, challenges related to sovereignty and self-determination, and responsibility for unprecedented losses and the substantial material, social and psychological costs associated with moving entire communities and populations.

3.3.3.3 Early warning systems

Monitoring and early warning systems (EWS) aim to indicate and signal when tipping points are being approached. Anticipatory ESTP impact governance in the current pre-tipping phase (see Figure 3.3.1) should include the development of EWS that can provide timely information about changes in Earth systems that can guide decision making. Current evidence regarding the proximity of some ESTPs justifies a range of immediate actions, including the adjustment of adaptation frameworks and plans, and the development of response capacity and network connections.

In this phase, adaptive approaches are useful to deal with the possibility of rapidly changing conditions (Franzke et al., 2022). For example, Dynamic Adaptation Policy Pathways (DAPP) (Haasnoot et al., 2013; Schlumberger et al., 2022) support adaptive actions before crossing a tipping point. EWS can support such adaptive governance with timely information about the status of the tipping system as it moves towards the tipping point. At the same time, EWS regarding the proximity of a tipping point would help actors make a timely transition in impact governance strategies to the second phase of the tipping process (reorganisation, see Figure 3.3.1). In that sense, early warning systems can support adaptive governance with rapid information flows and frequent learning loops between science and policy making (Galaz et al., 2016).

EWS can be identified not only for impending state shifts in Earth or ecological systems, but also in social systems. This type of information can be important for assessing the likelihood of ESTP impacts triggering negative social tipping dynamics.

Systematic collection of event data, expert assessments, and analyses with advanced social science techniques are important steps towards implementing EWS of negative social tipping. (Grimm and Schneider, 2011).

One area where EWS is well developed is conflict prevention. Governments can use risk and prediction models to predict violent conflicts, manage risk and consider future capabilities and responses (Muggah and Whitlock, 2022). Also advanced are early warning systems for food insecurity and famines, such as the Famine Early Warning Systems Network (FEWS NET).

There are, however, important limitations in our ability to build reliable early warning systems. Tipping points are extremely difficult to predict (see Chapter 1.6 and 2.5). While signals for moving closer to a tipping point can be detected, they do not indicate when (under what conditions) the tipping point will be reached. In many cases, scientists might only be able to observe and confirm the transgression of a tipping point years or decades after the fact. Therefore, early warning systems face major obstacles to become effective decision-support tools. There are also issues around data inequality when it comes to social tipping.

Data from low-income countries is often missing, incomplete or of poor quality. This enormously disadvantages these countries in systemic risk assessment. To address data inequality, it is important to support low-income countries in building capacities for data collection and analysis.

3.3.3.4 Cascade governance

As outlined in Chapter 1.5, the linkages between different ESTPs create the potential for cascading dynamics, where one tipping process triggers one or more others. The same cascading potential exists in highly connected human systems – i.e. complex networks of economic, technological and social interactions that span across borders and sectors, underpin the functioning of our globalised world (Helbing, 2013 ; Centeno et al., 2015, Homer-Dixon et al., 2015). The 2008 financial crisis demonstrated the systemic risks posed by highly interconnected global financial markets. Interlinked financial institutions and complex derivatives markets meant that the failure of a few single entities could trigger a cascade of failures, leading to a global economic downturn (Ruhl et al., 2020). The cascading dynamics in Earth and human systems can interact, so the passing of an ESTP can trigger cascading failures in social and economic systems (see Chapter 2.4), drawing attention to the couplings between them. For instance, persistent extreme weather events and increasing sea level rise from the crossing of an ESTP can result in mutually reinforcing crises within the agriculture, infrastructure and financial sectors. Recently, the term polycrisis has been used to describe such conditions where multiple crises occur across interconnected global systems (Homer-Dixon et al., 2021).

Cascade governance is a form of systemic risk governance (Schweizer and Renn, 2019), which recognises that systemic connections can act as transmitters and pathways of risk, making highly connected systems vulnerable to chain reactions that are hard to predict (Juhola et al., 2022). The central objective of cascade governance is to minimise the risk of cascading dynamics by managing systemic linkages, including by deliberately decoupling subsystems, slowing down flows (of materials or information, for example) and ensuring transparency and traceability of chain processes in a participatory and polycentric manner (Galaz et al., 2017; Nyström et al., 2019). Depending on the system in question, this might demand a set of regulatory measures. For instance, to manage the danger of systemic risk within the banking sector, where the collapse of an individual bank can have contagion effects, macroprudential regulations have been suggested (Renn et al., 2019; Lamperti et al., 2019).

Other measures include strengthening the absorptive capacity of each of the nodes in the financial network in response to external shocks by requiring higher capital and liquidity ratios, and encouraging modularity and diversity in the sector (Haldane & May, 2010).

Cascade governance is challenging and not yet a capacity or toolset widely available to policymakers around the world. Both predictive abilities regarding complex system behaviour and an understanding of the effectiveness of possible interventions (such as weakening or breaking key links between systems to stop a cascade in progress) are limited at this point. Further, there are psychological tendencies to underestimate and neglect systemic risks (Schweizer et al., 2022). Given these limitations, the primary goal of cascade governance regarding ESTP impacts should be prevention. This can have two dimensions: preventing the transgression of ESTPs as triggers of social-ecological cascades (see Chapter 3.2) and preventing cascading dynamics in social systems by building resilience to environmental pressure due to ESTPs.

Since prevention cannot always be guaranteed, cascade governance requires the development of comprehensive crisis preparedness plans that account for the potential ripple effects of systemic risks. Regular systemic risk assessments are needed to identify potential vulnerabilities and interdependencies within critical systems. Monitoring and early warning systems are valuable in this context (see 3.3.3.3), and should be combined with other tools, such as dynamic network mapping and iterative learning dialogues (Keys et al., 2019). Further, to address the deep uncertainties regarding tipping points and cascading risks, flexible governance approaches perform best where resources can be mobilised rapidly, aims and activities can be adjusted within networks of actors, and communication flows effectively – e.g. between private-sector organisations and government agencies. This should also include the development of redundancy and back-up systems within critical infrastructure and supply chains to ensure that essential functions can continue in the face of severe disruptions.

Cascade governance should therefore be seen as part of transformative responses which simultaneously deconstruct vulnerability, reduce the connectivity through which cascades can be transmitted, and reduce the key drivers of ESTP events (notably GHG emissions). Such responses imply rapid social and cultural changes (see positive social tipping points – Section 4).

3.3.3.5 Justice, equity and distribution of vulnerability

Climate change adaptation and mitigation measures have led to resistance from local social groups in the past, as they are often implemented top-down even where participatory language is used, entailing relocation, privatisation of resources, threats to traditional identities and norms, subordination and norm compliance, further weakening the agency of already-vulnerable groups (Woroniecki et al., 2019; Brink et al., 2023; Rudge, 2023). Any impact governance needs, therefore, to respond to concerns around equity and justice (Rudge, 2023). As Stoddard et al., (2021) write, that "powerful and affluent groups may opt for personal protections, rather than joint responses that secure communal benefit, has already been seen in concerns about exclusive adaptation that protect the privileged at the cost of those who are most vulnerable. The capacity for inequality to concentrate life-threatening harm in marginalised communities appears to have played a central role in social upheaval, including the 2008 financial crisis, as well as in societal collapses".

As we have noted, the distribution of vulnerability to impacts from ESTPs does not necessarily follow the same distribution pattern of vulnerability to climate change, but the capacity to adapt, whether to climate change in general or to ESTPs, is extremely skewed towards rich countries and affluent population groups, which makes impact management an issue of justice and international and national politics.

Moreover, human actions can produce or reinforce vulnerability or exposure, for instance when early warnings fail to reach affected populations or when marginalised groups are denied access to evacuation shelters (Otto & Raju, 2023). Recent trends in privatisation of adaptation, however, seem to only worsen the inequality with respect to adaptation (Nyberg et al., 2022). Many countries in the Global South are currently locked in inadequate adaptation due to constraints under the current international financial mechanisms (see Figure 3.3.5).

To avoid adaptation becoming a mechanism for protecting privileges, strengthened political commitment to transformative, just adaptation is needed. Social movements can play an important role in this context.

They can create pressure on governments through direct action, raise public awareness, and facilitate the monitoring and evaluation of adaptation progress (IPCC AR6 WGII 2022a). Furthermore, looking at potential synergies between mitigation and adaptation efforts that focus on social justice is important in order to not perpetuate inequities and past injustices (Ripple et al., 2019).

Figure 3.3.5: Financial barriers to ESTP preparedness in the Global South. This diagram of financial barriers for building ESTPs response capacity faced by the Global South is an adaptation of a diagram of financial barriers for mitigation and adaptation faced by the Global South, created by Goswami & Rao 2023. It captures various vulnerabilities and inequities linked to financial mechanisms that disadvantage Global South countries in their ability to prepare for ESTPs.

3.3.4 Final remarks

ESTP impact governance is currently underdeveloped, both in research and practice. Research and knowledge co-production on this topic are urgently needed as well as corresponding capacity-building among relevant stakeholders across scales – for example, global, regional and national governance institutions for climate change adaptation. Several distinct characteristics of ESTPs pose formidable challenges for impact governance, including the speed and time horizons of tipping processes, the emergence of new vulnerabilities, and the irreversibility of many impacts. Combined, these characteristics imply that ESTPs could quickly exceed adaptation limits, capacities for dealing with different kinds of migration, and current disaster risk management capabilities.

This chapter begins to develop a framework for multi-scale, multi-phase impact governance that takes these characteristics into account. ESTP impact governance should seek to minimise harms related to tipping processes, including by preventing cascading dynamics in coupled Earth and human systems. Impact governance for ESTPs is relevant across a broad set of issue domains and the corresponding institutions and actor communities, including climate change adaptation, international development, migration, human rights and disaster risk preparedness. Effective governance will require aligning existing institutions at various levels and extending their mandate, but also creating potentially new initiatives and processes.

Chapter 3.4 Knowledge co-production and science-policy engagement

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Summary

Knowledge production and learning related to ESTPs face significant challenges, with implications for effective science-policy interactions. Scientific knowledge about ESTPs is increasingly reflected in IPCC assessment reports, but governance actors are not yet using this growing knowledge base sufficiently. Lack of awareness, misconceptions and learning challenges limit the demand for, and use of, existing scientific insights. At the same time, engagement with tipping points in the social sciences and humanities is lagging.

The knowledge needed to understand, assess and support governance efforts related to ESTPs in a polycentric setting must be solutions-oriented, context-specific and actor-relevant. Anticipatory knowledge and related capacities for making sense of and acting with regard to uncertain futures (e.g. complex systems thinking) are essential tools for decision makers. Currently dominant patterns of knowledge co-production and science-policy engagement do not foster learning and anticipatory capacity-building sufficiently to generate robust and actionable knowledge for policy. To effectively support governance efforts related to ESTPs across multiple scales, knowledge production should be inter and transdisciplinary, and increasingly participatory. Developing capacities for anticipation requires expanded use of methods like participatory scenario development, roleplay simulations and storytelling, which combine quantitative and qualitative data, foster participants' ability to deal with uncertainty, and strengthen long-term agency.

Experiments with some of these approaches are currently taking place in global knowledge-generating institutions like the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). However, more profound changes to current science-policy interface institutions and processes will be needed to support effective decision making on ESTPs. The needed knowledge-production and capacity-building processes are more resource intensive and require more time (longer and more frequent engagement) than common science-policy interactions. They are also difficult to include in the scope of international institutions like the IPCC. Regional (e.g. Arctic Monitoring and Assessment Programme) and national scientific organisations (e.g. national academies of science) and policy advisory bodies might be best suited to drive innovation and progress in this domain.

Key messages

- To support effective governance of Earth system tipping processes, solutions-oriented, context-specific, actor-relevant and anticipatory knowledge is needed. Existing international knowledge institutions (e.g. the IPCC) need to be reformed to better support this kind of knowledge production.
- Currently, knowledge gaps are biggest in the social sciences and humanities.
- Learning challenges specific to tipping points are significant and could slow down or impede effective governance and public engagement.
- Anticipatory knowledge and related capacities are weak and require time and resource-intensive knowledge co-production processes.

Recommendations

- International organisations, national governments and science funders should foster urgent international research collaboration, especially in the social sciences and humanities, by promoting open, interdisciplinary, solutions-oriented, networked knowledge co-production systems focusing on ESTPs.
- Regional and national science and knowledge institutions (e.g. national academies of science, EU foresight initiatives) should foster anticipatory capacity building with participatory co-production processes involving policymakers, scientists, other knowledge holders, artists and designers.
- Governments should provide funding to support knowledge co-production and anticipatory capacity building. Individual decision makers and governance institutions should dedicate more time and resources to these processes.
- A core goal of knowledge co-production should be the translation of scientific knowledge regarding the temporal and spatial scales of ESTPs into actionable understanding of feasible options across scales and actor types.
- The IPCC should develop a special report covering climate tipping points and elevate discussions of tipping points in future assessment cycles, including in summaries for policymakers.

3.4.1 Knowledge needs, status quo, and learning challenges

3.4.1.1 Knowledge needs

Responding effectively to the current and future risks associated with Earth system tipping processes requires governance actors to leverage dynamic knowledge production systems for political decision making, policy and institutional design. The mobilisation of the 'best available knowledge' is recognised in the Paris Agreement (Article 7.5), encouraging interactions between different knowledge systems for enhancing climate resilience and effective adaptation.

Governance actors need to develop and frequently update a thorough and actionable understanding of Earth system tipping processes, their characteristics, differences, and likely implications for societies. Such an understanding should be based on, and evolve with, scientific information, but also other forms of knowledge, beliefs and values that contribute to meaning making. The knowledge needed to support future governance efforts should be specific for diverse actors, taking into consideration the scale and context of needed action. Hence, effective science-policy interactions at all of these scales are crucial for the adaptive, multi-scale and anticipatory governance of Earth system tipping processes.

Knowledge and continuous learning are integral to the capacities needed to anticipate and prevent harmful tipping points in the Earth system. Other capacities needed include systems thinking (conceiving of and governing the Earth as a complex interconnected system), imagination (envisioning possible futures, including pathways and solutions to address challenges related to Earth system tipping) and institutional entrepreneurship (creating initiatives within existing institutions or establishing new ones to help anticipate and prevent ESTPs). Science-policy institutions rarely focus on these capacities, and most political and knowledge institutions do not provide incentives to invest in their development.

3.4.1.2 Status quo

Scientific knowledge about ESTPs has expanded significantly over the last 20 years, with most of this research conducted within the natural sciences. This report's scope provides a broader lens than previous work, including additional Earth system tipping elements (Table 1.7.1 & Figure 1.7.1). While modelling efforts are expanding, many Earth system and climate economy models today still lack representations of tipping dynamics, especially couplings between social and biophysical processes (Franzke et al., 2022). At the same time, despite the research summarised in Section 2, there is a significant knowledge gap regarding the social and human dimensions of Earth system tipping, from expected impacts, risks and vulnerabilities to implications for decision making and governance, including framing effects, actor motivations and the role of political power.

Given that this solutions-oriented knowledge is essential to support the development of a governance and policy agenda on ESTPs, its scarcity is a reason for concern.

The IPCC has addressed climate tipping points since its third assessment report (AR) with varying terminology (see Box 3.4.1). The topic received growing attention in more recent assessment cycles, but has not yet led to active engagement among international or national policymakers, with tipping points not yet part of the UNFCCC negotiation agenda (Milkoreit, 2015; 2019).

Box 3.4.1: Tipping points and the Intergovernmental Panel on Climate Change

The IPCC first addressed climate tipping points in its 3rd Assessment Report (McCarthy et al., 2001), using the terminology of 'large-scale discontinuities' in the report of Working Group II (Impacts, Adaptation and Vulnerability). Tipping points were included in a set of 'reasons for concern', visualised in the 'burning embers' diagram that later motivated the selection of the 2°C temperature goal (Leemans and Vellinga, 2017). At this time, the IPCC concluded that tipping points would only become likely if global average temperatures exceeded 4°C.

The burning embers were not included in AR4 (2007), but scientists independently published an updated figure in 2009 (Smith et al., 2009). It returned in the AR5 WGII Summary for Policymakers (Field et al., 2014), which referred to 'large-scale singular events' as a reason for concern, or RFC. AR5 Working Group I defined tipping points as Earth system components that are 'susceptible to abrupt or irreversible change', focusing on irreversibility and the likelihood of the occurrence of tipping points in the 21st Century (Collins et al., 2013). More than a decade after AR3, the IPCC updated its risk assessment for the transgression of tipping points, stating that they "become moderate between 0-1°C additional warming *[above 1984-2005 average]*, [...]. Risks increase disproportionately as temperature increases between 1-2°C additional warming and become high above 3°C, due to the potential for a large and irreversible sea level rise from ice sheet loss" (Field et al., 2014; Assessment Box SPM.1). AR5 also contained a table listing nine Earth system components that are "susceptible to abrupt or irreversible change" (IPCC AR5 WG I, 2014 Table 12.4, p.1115). These included AMOC, ice sheets, and tropical and boreal forest dieback. Lenton et al., (2019) showed how the IPCC's risk assessment of tipping points had changed over time (Figure 3.4.1).

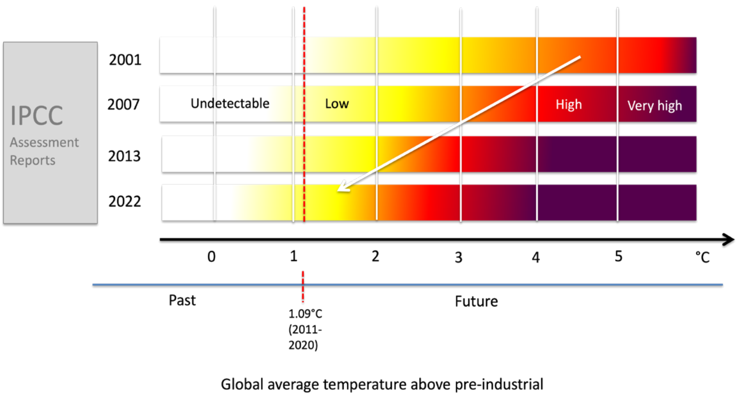

Figure 3.4.1: Changing risk assessment of tipping points in IPCC reports over time. The IPCC has assessed the risk of tipping points ('large-scale singular events') as one of five 'reasons for concern' in a bar graph ('burning embers') to motivate climate action in most of its assessment reports since 2001. Colours indicate levels of risk from white (undetectable) to yellow (low), red (high) and purple (very high). Each AR increased the level of risk expected for a specific level of warming.

AR6 (2021-2023) updated the burning embers diagram (IPCC AR6 WG2, 2023 Fig. SPM.3 a&b), maintaining the language of 'large-scale singular events' (RFC 5). The IPCC's WG I defined a tipping point as "a critical threshold beyond which a system reorganises, often abruptly and/or irreversibly". It also used the related term abrupt climate change, defined as "a large-scale abrupt change in the climate system that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades and causes substantial impacts in human and/or natural systems". (IPCC, 2023). AR6 WGI sometimes uses 'tipping point' to refer to a class of abrupt change in which the subsequent rate of change is independent of the forcing [1.4.4.3 of (AR6 WG1 Ch1). AR6 assessed the risk of tipping point transgression as moderate today (at more than 1°C warming above pre-industrial levels), becoming high around warming of 2°C, and very high beyond 2.5°C.

The IPCC's WG I provided an updated table (4.10) of "components in the Earth system that have been proposed as susceptible to tipping points/abrupt change, irreversibility, projected 21st Century change". This table includes 15 items, including some that do not fall under the definition of a tipping point, e.g. global sea level rise (an outcome of ice sheet melting with no clear threshold for system reorganisation in itself).

Tipping-related knowledge and expertise outside of the academy is still limited, but growing. For example, international organisations like the OECD and World Meteorological Organization (WMO) are developing expertise and programmes with a focus on climate tipping (OECD, 2022), some scientific advisory bodies are building tipping-related capacity (Science Advisory Panel to Member States at the WMO Executive Council). These growing knowledge-production efforts need to be translated into tangible decision-making support for governments and other actors.

At this point, ESTPs only play a minor role in scientific assessments, policy debates and public discourse, and stakeholders are not making good use of available scientific knowledge. Widespread lack of awareness and misconceptions around tipping points (Milkoreit, 2015; 2019) limit the perceived need and corresponding demand for knowledge about ESTPs among policymakers. In this situation, scientific knowledge production also tends to be insufficient (Weichselgartner and Kasperson, 2010).

3.4.1.3 Learning challenges

Tipping points present a set of **specific learning challenges that could undermine governance efforts**. Nonlinear state changes are a feature of many complex Earth system components (Young, 2012; 2017), which require complex systems thinking, often involving a fundamental change in decision makers' assumptions about reality and the nature of change (i.e. an ontological shift) from a mechanistic, linear and simple single-cause model to one centring emergence, nonlinearity and multi-causality. As Renn (2022) notes, tipping points are a type of systemic risk that render trial-and-error approaches to learning useless, demanding novel approaches to learning, such as immersive game-based techniques.

ESTPs occur at unusual spatial and temporal scales, for which common governance approaches are unsuitable. Tipping systems, including ocean circulation patterns or transboundary ecosystems, introduce a distinct spatial scale for governance that often cross national and even continental boundaries – for example, the Amazon basin, Atlantic Ocean or Arctic. In the absence of governance institutions or polities representing all relevant actors for this specific scale, knowledge development is challenging. For some tipping systems, such as ocean currents, scale-specific knowledge producers are scarce or disconnected from decision making. The multiple timescales of Earth system tipping, including extremely long time horizons, present profound challenges for learning, assessing and valuing potential future outcomes and for including timescale considerations in present-day decision making and governance.

The production of scientific knowledge involves dealing with uncertainties, some of which cannot be reduced through further research. This applies to ESTPs. We might detect signals that a system is approaching a tipping point, but not be able to predict when and under what specific conditions the threshold will be reached. For 'slow' tipping systems, science might not be able to state whether or not a tipping point has been crossed for decades, and given that there may be no clearly established or observable 'event' indicators at the time the threshold is crossed, tipping points may be passed with no notice. The limitations of scientific knowledge about tipping points in turn have significant implications for governance, dramatically elevating the need for precaution, an expanded toolbox for dealing with uncertainty, and processes to create anticipatory capacities such as decision makers' abilities to engage in long-term thinking. At the same time, there is evidence that this kind of uncertainty inhibits cooperation and collective action (Barrett and Dannenberg, 2012; 2014; Schill, Lindahl, and Crépin, 2015).

Some of the key questions that remain to be clarified when co-producing knowledge about tipping points include:

- How can actors identify critical information?
- What criteria should guide action priorities amidst an increasing number and severity of Earth system tipping processes?
- How can we attend to long-term processes despite short-term political pressures?

3.4.2 Needed knowledges and knowledge production

Much research on tipping points has focused on global and damaging biophysical trends, rather than on the human and social dimensions of Earth system tipping, including likely social impacts, responses, solutions and governance options. Future knowledge production should consider not only the content, but also the characteristics, of the information needed to support decision making. Below we first address key knowledge characteristics (solutions-oriented and actionable, context-specific and actor-relevant, future-oriented/anticipatory, and transformative). We then consider which knowledge-production processes and systems would be needed to support the development of this type of knowledge regarding ESTPs, including co-production and effective sharing in knowledge networks across scales, and to foster imagination and anticipation.

3.4.2.1 Knowledge characteristics

For knowledge related to Earth system tipping to be useful in governance processes, it has to be solutions-focused (O'Brien, 2013), actionable, relevant to the actor in question, and legitimate (Cash et al., 2003). While these criteria apply to knowledge production for sustainability more generally, anticipatory and transformative capacities should be added and emphasised in the context of ESTPs.

Solutions-oriented and actionable: Solutions-oriented knowledge involves a shift from investigating the nature of ESTPs (their causal dynamics and likely impacts) to actively seeking practical solutions such as prevention and adaptation strategies, with the aim to foster agency and help actors identify and evaluate action options (Tengö and Andersson, 2022; Andersson, 2022; Lang and Wiek, 2022). Actionable knowledge emphasises the application of scientific insights to develop strategies, technologies and policies that address specific challenges related to tipping points (e.g. uncertainty regarding their timing) and improves societal outcomes (Mach et al., 2020).

Context-specific and actor-relevant: This kind of knowledge is situated within particular circumstances and takes into account unique contextual factors and place-specific cultural norms. For example, in the case of ESTPs, there is an immediate need to develop information and tools that allow actors in different countries and at different scales to identify which tipping points are relevant for them, because they might be impacted by them or because of their own capacity to reduce tipping risks. By acknowledging and taking into account relevant practitioners' and researchers' diverse perspectives and linking abstract knowledge about tipping processes with case-specific insights, context-sensitive knowledge can be generated that is relevant and meaningful to the actors applying it.

Anticipatory: Future-oriented and anticipatory knowledge involves harnessing both individual and collective imagination to envision a wide range of potential scenarios and future developments. This approach goes beyond extrapolating from current circumstances and uses creative thinking to collectively anticipate diverse future possibilities (Wiek and Iwaniec, 2013; Dufva, Könnölä, and Koivisto, 2015; Iwaniec et al., 2020; Pereira et al., 2021). By combining this with existing knowledge, researchers and stakeholders can better prepare for emerging challenges and opportunities. This forward-looking perspective can enable the development of strategies and solutions that are robust, adaptable and proactive in addressing future needs and uncertainties (Pereira et al., 2021).

Transformative: Transformative knowledge is oriented to address the ultimate systemic causes of unsustainability: the social structural drivers of climate change, such as persistent inequalities in resource consumption and access, or the distribution of rights and responsibilities. This often involves developing systems thinking and questioning deep assumptions about individual or organisational practices and their social and environmental effects. Promoting second-order learning is central in transformative learning: not just doing the same faster and better, but exploring how things could be done differently under a different paradigm or worldview. Correspondingly, there is a focus on solutions in the domain of worldviews, practices and institutional structures, and on capacity building that supports transformational change across scales (Fazey et al., 2020).

Knowledge with these characteristics would empower governance actors to develop and implement scale- and context-specific governance solutions for ESTPs. Corresponding knowledge production – within and beyond science – should foster these characteristics.

3.4.2.2 Knowledge-production processes

Knowledge production to support the governance of Earth system tipping processes should be multi-, inter- and trans-disciplinary to facilitate **knowledge co-production between scientific and non-scientific actors** and provide concrete decision support tools (Thompson et al., 2017; Mach et al., 2020; Latulippe and Klenk 2020; Turnhout et al., 2020; Pohl et al., 2021). Co-production can be defined as "iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future." (Norström et al., 2020). It recognises that scientific ideas evolve together with social identities, political discourses and institutions.

Participatory approaches to knowledge production have a number of benefits regarding tipping point governance. They enable co-production by engaging participants with different expertise (scientists, policymakers and other stakeholders), promoting active learning and anticipatory capacity building (Galende-Sánchez and Sorman 2021). This approach enables relevant frame development, fosters inclusiveness and – depending on the selection and power representativeness of the participants – the use of context-specific expertise (e.g. local knowledge) with actor-relevant outcomes. Second, participatory approaches can mitigate some of the specific learning challenges related to tipping points. For example, dynamic simulation exercises provide opportunities to virtually experience the passing of tipping points, especially their time-related characteristics like nonlinearity, to identify lessons for governance and risk management today.

Building situated and context-specific knowledge for the governance of tipping points at different scales of action entails moving away from linear, flat notions and gap-filling modes of learning. Knowledge development needs to happen in a **distributed** fashion, at different scales of action and taking into account context-specific factors. Multi-scale knowledge-production systems facilitate the generation of solutions-oriented knowledge that can easily be shared in a distributed network and adjusted in different locations.

Rapid and effective knowledge sharing and information flows are essential for polycentric, networked governance approaches to ESTPs. A fundamental concern is the need for transparency and open access to scientific knowledge, especially climate models. Open models and data access allow knowledge users to better understand model results and adapt them to their own context. Open-source platforms like Wikipedia or GitHub have an important role in this context. Further, there is a need to connect and integrate different kinds of knowledge generated in distributed networks of agents who work, learn and share their experiences in managing complex systems' dynamics at different scales of action. This integration work could take the form of transformative boundary organisations (Tàbara et al., 2017), which purposefully integrate multiple sources of knowledge and focus on complex-systems thinking and learning.

There is an increased need for **processes** that can engage governance actors in future thinking and related **capacity building for anticipatory decision making** about ESTPs. This can be facilitated by bringing decision makers into structured conversations with academics as well as artists and storytellers to facilitate structured, transdisciplinary exploration of multiple possible futures (Galafassi et al., 2018; Galafassi, Tàbara, and Heras, 2018). The aims of 'futures' work include widening understanding of plausible and feasible developments based on the anticipation of interactions between a range of environmental, political, economic, technological, scientific and social factors, and challenging the assumptions embedded in conceptualising the future. Such processes help decision makers switch their mode of thinking about the future from predictive to anticipatory and facilitate a reorientation from navigating 'what will be' to thinking through alternative 'what-ifs'. They can also help participants identify policy instruments that may be robust across a range of plausible futures (Gabriel 2014; Pereira et al., 2021).

Fostering complex systems thinking has to be a key component of governance systems for Earth system tipping processes.

Complex systems thinking is fundamental for understanding and effectively addressing tipping dynamics. It provides not only analytic capacities regarding the causes and characteristics of tipping processes, but enables the systemic search for solutions.

Science-policy engagement on tipping points thus requires novel approaches that **involve unconventional mixed methods.** A combination of qualitative scenarios, expert judgements, roleplay simulations and agent-based models, and even fictional narratives and storyline development, should be used more frequently to complement the physical modelling approaches most commonly used to create knowledge about ESTPs (Gambhir et al., 2019; Elsawah et al., 2020; van Beek, Milkoreit, et al., 2022; Pereira et al., 2021; Pereira et al., 2023). This diverse range of approaches can support the search for response strategies that are robust to a broad range of possible future outcomes. Some illustrative examples of such novel methods are outlined below…

Role-playing simulations and 'serious games' can effectively support learning about complex systems, including the temporal dynamics of complex change processes like Earth system tipping dynamics over multiple decades (van Beek et al., 2022). Beyond knowledge, serious games can affect players' risk perceptions and agency, fostering anticipatory decision making. Simulations already play an important role in supporting decision making under uncertainty (Flood et al., 2018; Mangnus et al., 2019; Edwards et al., 2019; Fleming et al., 2020; Galeote et al., 2021).

Participatory, multi-scale scenario development involves creating a range of plausible future scenarios that encompass different trajectories of change. These scenarios can span different scales, and help in understanding how different drivers interact and shape potential outcomes in the short and long term, including cascading effects. This approach draws on knowledge from various disciplines and sectors (environmental science, sociology, economics, politics, and local and Indigenous communities) and integrates both quantitative and qualitative methods. The method can foster learning about the dynamics and impacts of ESTPs across different timeframes and geographical scales, illuminating, for example, how vulnerability to impacts is distributed across space and time. By considering multiple timeframes, researchers and policymakers can identify critical time-sensitive interventions and develop response strategies that will be robust across a range of potential future outcomes, thus linking knowledge development to decision making. The scenario development process should be participatory, enhancing the role of stakeholders to facilitate mutual learning and co-production of actor- and context-relevant knowledge (Biggs et al., 2007; Shaw et al., 2009; Elsawah et al., 2020; Kliskey et al., 2023; Lazurko, Schweizer, and Armitage, 2023).

Combining **multi-scale scenario development** with other forms of **qualitative engagement** can support the assessment of near- and long-term impacts, response capacities and vulnerabilities (i.e. using surveys and online democracy tools with many participants, and small focus group deliberation). This approach can capture diverse perspectives beyond academic expertise, including local or Indigenous knowledge, and contextual insights that can generate a deeper understanding of the social, cultural and ethical dimensions of governing Earth system tipping processes. Iteration is important for this approach, with scenario development and qualitative engagement informing each other (Alcamo, 2008; Trutnevyte et al., 2019; Prehofer et al., 2021; Pereira et al., 2023; Jahel et al., 2023).

3.4.3 Effective science-policy interactions for tipping point governance

Linear models of knowledge transfer from science to policy are outdated and have limited explanatory power (Beck, 2011; Beck and Oomen, 2021), but this conception continues to structure current science-policy interfaces, including the IPCC-UNFCCC relationship. Conceiving of the science-policy interface in terms of knowledge (and governance) co-production (Jasanoff, 2004; Miller, 2004; Bremer and Meisch, 2017) provides a more useful starting point in the domain of ESTPs. This implies that knowledge, understanding and meaning are the result of complex interaction processes in which scientists and policymakers mutually shape each other's perspectives.

3.4.3.1 Building on existing science-policy engagement processes

The full range of existing science-policy engagement processes across multiple scales of governance are relevant for fostering engagement and knowledge building on ESTPs. At the global scale, this places intergovernmental scientific assessment bodies like the IPCC and IPBES and their relationships to political negotiation and decision-making institutions (e.g. UNFCCC, CBD) into the spotlight. Below, we focus on these global-scale institutions, but many other formats of science-policy engagement exist, including parliamentary hearings, science advisory bodies, and expert groups at the national scale and in the European Union.

The IPCC is the central source of authoritative scientific knowledge for the international climate governance process. Despite multiple critiques levelled at the model in recent years (Turnhout et al., 2020; De Pryck and Hulme, 2022), it can and should play an important role in fostering knowledge related to climate (and Earth system) tipping points, elevating this topic on the negotiation agenda of the UNFCCC and possibly political systems at other scales.

However, the seven-year reporting rhythm of the IPCC is moving too slowly to reflect the rapidly evolving scientific knowledge base related to climate (and Earth system) tipping points.

More frequent, shorter learning cycles are needed to ensure the latest understanding of science is available and accessible to a wide range of actors more rapidly (De Pryck and Hulme, 2022). Contributing to this increased frequency is one of the aims of this report. Such an approach requires capacity building both on the side of knowledge provision and communication and with relation to its adoption and use. The format of IPCC special reports provides an important avenue for developing scientific and policy-relevant knowledge regarding ESTPs, but does not fully address this speed deficit. Other scientific assessment processes, including this report, can complement the work of the IPCC, but to the extent they lack the formal relationship with and mandate from a negotiation or decision-making body like the UNFCCC, they lack the authority and perceived legitimacy of the IPCC (Cash et al., 2003) and are less likely to be utilised.

Scholars increasingly recognise that anticipating multi-dimensional, multi-scale and cascading climate impacts are not well served by existing climate risk assessment processes (Simpson et al., 2021). Both Earth system models (WGI, physical science) and integrated assessment models (WGIII, global mitigation pathways) will need to integrate biophysical and social tipping points to a greater extent (McPherson et al., 2023), and connect the implications to locale- and actor-specific vulnerabilities and adaptation capacities (WGII). In this vein, climate tipping points present an opportunity for stronger collaboration across IPCC Working Groups.

Fostering more solutions-oriented knowledge elevates the importance of WGs II and III and the need to expand assessment of relevant knowledge in the social sciences and humanities. Going beyond economic perspectives and technological change, solutions work related to tipping points needs to bring in understandings of how knowledge and beliefs about the future shape future-oriented decision making and agency.

More generally, the IPCC's tendency towards conservatism (Brysse et al., 2013) is particularly problematic in the context of tipping points. This conservatism is a reflection of scientific values such as restraint, rationality, dispassion and moderation, which create a tendency towards caution and underreporting of certain scientific findings, but also results from the desire to provide information that is safe against attack or political misuse. The panel's mandate to be policy relevant but not policy prescriptive further creates a tendency towards information that supports the pursuit of existing political goals, confirming their underlying linear assumptions of change. What is needed is accelerated learning of a kind that enables a shift towards non-incremental and transformative approaches to action. Proposals for IPCC reform are emerging (Asayama et al., 2023), but they do not address the question of how anticipatory and transformative knowledge co-production could be practically enabled in the UNFCCC.

There are limits to what the IPCC can do when it comes to developing anticipatory and transformative capacities among diverse governance actors across multiple scales.

Fostering actor-relevant and context-specific knowledge demands distributed knowledge production with heavy involvement of regional (e.g. AMAP, EU), national (e.g. governmental foresight offices) and sub-national knowledge institutions.
(Hoppe, 2005; Hoppe, Wesselink, and Cairns, 2013).

Actor relevance combined with the time and resource demands of some methods for anticipatory knowledge development further minimises the potential role of the IPCC in its current form, which is already a time-consuming and unfunded commitment for most participants. Instead, it requires distributed efforts by organisations that can play a convening role for trainings and workshops, or technological resources like immersive or virtual reality environments. Major international science organisations or networks like Future Earth could adopt a role in fostering this type of learning at the interface of science and policy.

Looking beyond the IPCC, recent analyses of **global environmental assessments** consistently identify a set of challenges that need to be addressed to support global environmental decision making about the future (Norström et al., 2020; Pereira et al., 2021). These are particularly relevant for knowledge production related to ESTPs and include the need to: (1) anticipate unpredictable and diverse future conditions, (2) create knowledge that is relevant at multiple scales, and (3) include diverse actors, perspectives and contexts, and enhance the role of stakeholders including the public (Elsawah et al., 2020). Increasingly frequent iterations of learning cycles and the ability to respond rapidly to changing and new knowledge will also be needed (Norström et al., 2020). Finally, given the emphasis on distributed knowledge production in multi-scale networks, global assessment processes need to develop stronger relationships to knowledge-production processes at lower scales (e.g. national academies of science or government science advisory bodies), becoming network hubs in knowledge-production systems rather than sitting at the top of knowledge-production hierarchies.

Recently, relevant activities and venues have emerged across global environmental assessments that implement some of these recommendations, and might serve as partial templates for the mode of knowledge production that anticipating tipping points demands. The CBD's advisory body, **IPBES**, to some extent replicates the IPCC model, but with important modifications and dynamics. Through its Nature Futures Framework (Lundquist et al., 2021), the IPBES and the UN Environment Programme's Global Environmental Outlook (UNEP, 2019, chap. 23) both take note of ways to combine regional-to-global systems modelling with imagination-driven, bottom-up stakeholder engagements and perspectives. This generates both a greater range and 'thicker' detail of risks that are relevant to communities and decision makers, as well as creating buy-in around actions needed. Combining natural and social sciences with traditional ecological knowledge, Indigenous knowledge and local knowledge is facilitated by the recent establishment of the Local Communities and Indigenous Peoples Platform by the UNFCCC. The IPBES is also taking a greater interest in anticipatory and transformative knowledge and capacities with its ongoing efforts related to the Transformative Change Assessment.

The processes and impacts of ESTPs would reach across multiple global governance issues, creating often-overlooked interdependencies between them. The challenge of linkages has been increasingly recognised in climate assessment and governance, for example, regarding interactions with multiple efforts to achieve the Sustainable Development Goals (Fuso Nerini et al., 2019). Tipping point assessments and knowledge production might innovate further by building on templates like the multi-issue 'nexus' assessments of climate, biodiversity and pollution (UNEP, 2021), biodiversity, water, food and health (IPBES work programme 2019-2030), or climate change, land-use and food security (IPCC, 2019).

3.4.3.2 Using early warning signals?

Being able to provide and make use of early warning signals (EWS) of approaching ESTPs would be a strong signal for an effective science-policy interface. The main purpose of early warning systems is to alert decision makers to impending changes to enable a rapid adjustment of governance and decision making, e.g. kicking preparations for mitigation and impact adaptation into high gear with extraordinary modes of decision making, prioritisation and resource allocation. Ideally, an early warning system would relate a set of distinct signals to a set of differentiated decision-making procedures and priorities with clear and pre-determined shifts in authority and responsibility. In the case of ESTPs, EWS would indicate that prevention efforts for a specific tipping point (see Chapter 3.2) are currently insufficient and failing, and that impact management (see Chapter 3.3) needs to be ramped up within a short time window in case further mitigation is insufficient.

Successful examples for early warning systems exist in the domain of disaster preparedness (e.g. storms and floods). The International Federation of Red Cross and Red Crescent Societies (IFRC) is developing practices of early warning for climate-related extreme events. Recent assessments display an increasing orientation towards preemptive action, forestalling rather than only reacting to harms. For example, the UN Office of Disaster Risk Reduction has instituted a more prospective and holistic perspective towards disaster management, seeking to anticipate and forestall vulnerabilities through development and capacity building (UNDRR, 2022). This new emphasis supplements the more traditional mode of pinpointing hazards and managing relief and compensation processes.

Advances have been made in the domain of early warning signals for ESTPs, including different measures for identifying a system's proximity to a tipping point and proposals to apply these measures to harmful social-ecological tipping points (see Chapters 1.6 and 2.5). However, the usability of this knowledge in the domain of policy and governance remains unclear, as do processes for communicating early warnings to decision makers. Given the challenges regarding the nature of scientific knowledge about Earth system tipping processes, e.g. assessments of when a tipping point is passed potentially not being available until decades after, and early warning signals may not always be present before tipping or be clear evidence of tipping (Chapter 1.6), the benefits of early warning science for decision making might be limited for now (Galaz, 2014, chap. 4).

3.4.4 Knowledge politics

Knowledge co-production and mobilisation at the science-policy interface is never a-political, but shaped by power relations, social contexts, existing political interests, and values. Political interests often affect what kind of knowledge is produced, for example through public research funding, explicit invitations for reports (such as the IPCC's Special Report on 1.5°C) or scientific advice, as do scientists' perceptions of what is useful information to achieve political objectives – i.e. what is believed to be 'policy relevant' (van Beek et al., 2022). Other factors within the domain of science also play a role, as well as institutional co-production dynamics (e.g. the process for adopting an IPCC summary for policymakers or issuing a proposal for an IPCC special report), and knowledge mobilisation by political actors (e.g. political leaders speaking at COP sessions referring to a climate tipping process).

We can expect varying knowledge and meanings related to tipping points to emerge in different political and social contexts, and actors with competing political interests to offer competing knowledge claims (for example, using uncertainty regarding a tipping threshold value to argue for and against rapid prevention measures). Depending on their interests, and those of their constituencies, political actors are likely to develop different risk perceptions regarding ESTPs, assign varying levels of importance to them, and develop different preferences for solutions. Actors can and often do use scientific information strategically to further their pre-existing political interests and political positions (Grundmann, 2007), sometimes widening existing cleavages (Sarewitz, 2004) and reinforcing contestations. The 'same' scientific information can be used by different actors to justify very different positions (Schenuit, 2023). This can be particularly challenging for cascading shocks (Galaz et al., 2011). For example, political representatives of small island states assessing the importance of cryosphere tipping processes will likely consider the prospect of nonlinear ice sheet loss to reinforce their existing beliefs about the severe risks of sea level rise, and will use the science of tipping points to highlight island states' vulnerability and strengthen their arguments for urgent international mitigation action. At the same time, actors reluctant to engage in mitigation or curtailment of the fossil fuel industry might use tipping point science, especially related to nonlinearity and irreversibility, to build a case for their desired form of climate intervention (geoengineering), to the extent of arguing that this is the only viable option for averting catastrophe.

Scientific knowledge is only one source of **input into meaning-making processes**. One of the most important – politically relevant – aspects of meaning making at this point is the formation of national and sectoral interests related to ESTPs (see 3.1.4). Interest formation is tied to multiple factors, including the actor's identity and values (Wendt, 1992; Finnemore, 1996), institutional mandate or power positions.

Related to the strategic mobilisation of knowledge about tipping points, we must also be aware of the risk of the strategic denial of scientific knowledge. The strategic organisation of science denial involves orchestrated efforts by groups or individuals to cast doubt on established scientific consensus, often by cherry-picking data, manufacturing controversies, promoting false experts, propagating conspiracy theories, manipulating media coverage, funding questionable research, appealing to personal beliefs, attacking scientists, leveraging political influence and exploiting cognitive biases (Cook, 2020b; Dunlap and Brulle, 2020; Cook, 2020a). These tactics aim to create the appearance of uncertainty and debate around scientific issues, potentially serving the agendas or interests of those behind the denial efforts (Schmid and Betsch, 2019; Hornsey and Lewandowsky, 2022; Björnberg et al., 2017), for example fossil fuel companies, elected officials from fossil-fuel producing regions, or conservative think tanks in the US (Ekberg et al., 2022). Research indicates that engaging with rather than ignoring such dynamics is the most promising strategy for dealing with them (Cook, Lewandowsky, and Ecker, 2017; van der Linden et al., 2017; Lewandowsky and van der Linden, 2021; Compton et al., 2021).

While knowledge politics is an unavoidable component of environmental governance, it is important to make power relations explicit and transparent "to allow for pluralism, create scope to highlight differences, and enable the contestation of interests, views, and knowledge claims" (Matuk et al., 2020; Turnhout et al. 2020, 21).

3.4.5 Final remarks

This chapter has addressed knowledge production challenges related to ESTPs and their implications for effective science-policy interactions. Tipping processes are features of complex systems that present profound learning challenges that can undermine the development of actionable knowledge among decision makers and slow down urgently needed governance efforts. Attention to tipping points has grown in recent IPCC assessment reports, with the assessed risks of tipping point transgression increasing at lower levels of global warming. However, so far this has had limited effect on policy making processes. There are also significant knowledge gaps regarding ESTPs in the social sciences and humanities, which are most relevant to support governance. This context calls for concerted efforts to expand knowledge production related to ESTPs and corresponding science-policy interactions to foster learning and capacity building.

For it to be useful for governance, knowledge about tipping points needs to be solutions-oriented, actionable, context-specific and actor-relevant. Importantly, the multiple time horizons of tipping processes – from years to millennia – require anticipatory forms of knowing and meaning-making. In a polycentric governance framework, it is important to understand where, by whom, and at what scale relevant knowledge is produced, how knowledge producers and users can be connected, and how different kinds of knowledge can empower governance actors to devise, implement and upscale solutions.

Identifying significant limits to the way knowledge is currently developed at the science-policy interface, we have put forward suggestions for improving future knowledge co-production related to ESTPs with a focus on the international scale. Scientific and non-scientific actors should actively participate in knowledge co-production in distributed networks that enable effective multi-scale information sharing. Novel designs of knowledge-production approaches such as participatory scenario development and roleplay simulations are needed, as well as incentives for developing anticipatory and transformative capacities. These approaches tend to combine qualitative and quantitative information, diverse expertise, and even immersive and game-based processes that leverage art and storytelling to provide multi-modal and multi-sensorial learning.

This type of capacity building at the science-policy interface requires more time investment, openness to active learning (rather than reading or listening), and more frequent (iterative) engagement by decision makers than current approaches. Finally, we outlined the importance of grappling with political contestation around the production and mobilisation of knowledge at the science-policy interface.

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Chapter 3.3

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