# Global Tipping Points

## Summary Report 2023

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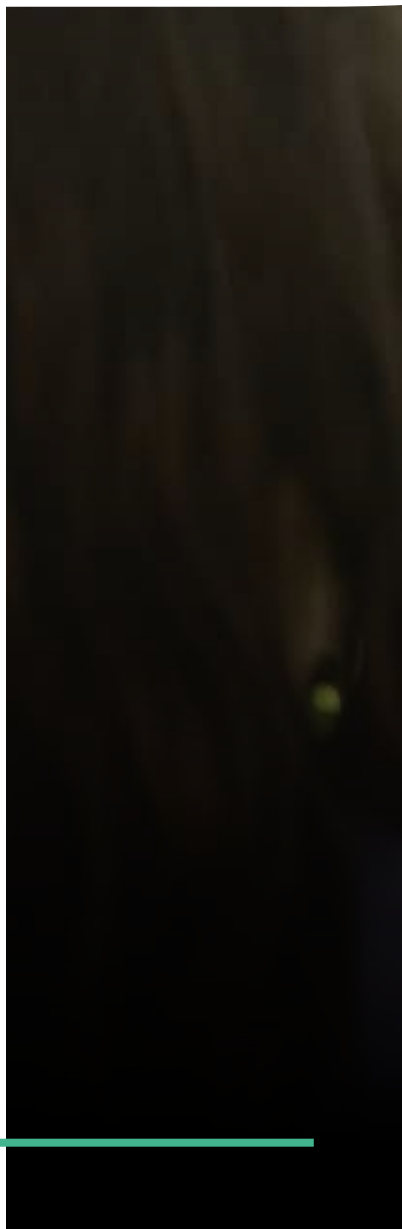



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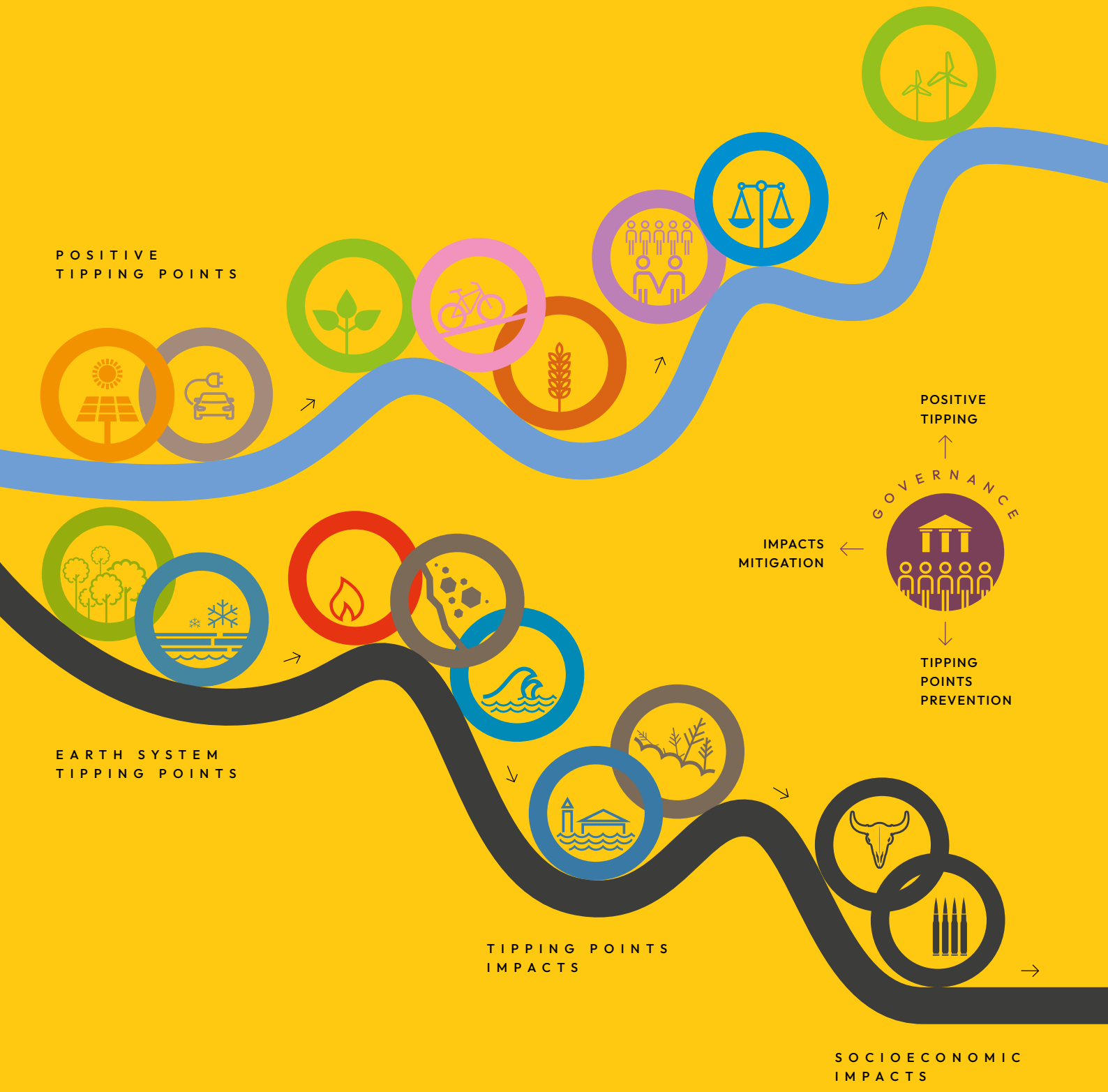
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IMPACTS

# Narrative summary

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Harmful tipping points in the natural world pose some of the gravest threats faced by humanity. Their triggering will severely damage our planet's life-support systems and threaten the stability of our societies.

For example, the collapse of the Atlantic Ocean's great overturning circulation combined with global warming could cause half of the global area for growing wheat and maize to be lost. Five major tipping points are already at risk of being crossed due to warming right now and three more are threatened in the 2030s as the world exceeds 1.5°C global warming.

The full damage caused by negative tipping points will be far greater than their initial impact. The effects will cascade through globalised social and economic systems, and could exceed the ability of some countries to adapt. Negative tipping points show that the threat posed by the climate and ecological crisis is far more severe than is commonly understood and is of a magnitude never before faced by humanity.

Currently, there is no adequate global governance at the scale of the threats posed by negative tipping points. The world is on a disastrous trajectory. Crossing one harmful tipping point could trigger others, causing a domino effect of accelerating and unmanageable change to our life-support systems. Preventing this – and doing so equitably – should become the core goal and logic of a new global governance framework. Prevention is only possible if societies and economic systems are transformed to rapidly reduce emissions and restore nature.

The current approach of linear incremental change favoured by many decision makers is no longer an option. Existing governance institutions and decision-making approaches need to adapt to facilitate transformational change.

Crucial to achieving this transformational change are positive tipping point opportunities, where desirable changes in society become self-propelling. Concerted actions can create the enabling conditions for triggering rapid and large-scale transformation. Human history is flush with examples of abrupt social and technological change. Recent examples include the exponential increases in renewable electricity, the global reach of environmental justice movements, and the accelerating rollout of electric vehicles. Negative tipping point threats could be mitigated if there was a vast effort to trigger other positive tipping point opportunities.

Unfortunately, in the time lag during which appropriate governance and action might be realised, negative tipping points could still be triggered. This means that societies must urgently be made more resilient to minimise the vast and unequal harms. Critically, more resilient societies are also needed to ensure that collective focus on triggering positive tipping point opportunities can be sustained even through a negative tipping event. This resiliency can be achieved with 'no regrets' actions that anyway make societies more sustainable, equitable and prosperous.

The existence of tipping points means that 'business as usual' is now over. Rapid changes to nature and society are occurring, and more are coming. If we don't revise our governance approach, these changes could overwhelm societies as the natural world rapidly comes apart. Alternatively, with emergency global action and appropriate governance, collective interventions could harness the power of positive tipping point opportunities, helping navigate toward a thriving sustainable future.

# Key messages

IRREVERSIBLE CHANGE

KEY MESSAGE 01

## CLIMATE CHANGE AND NATURE LOSS COULD SOON CAUSE 'TIPPING POINTS' IN THE NATURAL WORLD

Environmental stresses could become so severe that large parts of the natural world are unable to maintain their current state, leading to abrupt and/or irreversible changes. These moments are called Earth system 'tipping points'. Five major tipping systems are already at risk of crossing tipping points at the present level of global warming: the Greenland and West Antarctic ice sheets, warm-water coral reefs, North Atlantic Subpolar Gyre circulation, and permafrost regions.

POSING THREATS

KEY MESSAGE 02

## THESE TIPPING POINTS POSE THREATS OF A MAGNITUDE NEVER BEFORE FACED BY HUMANITY

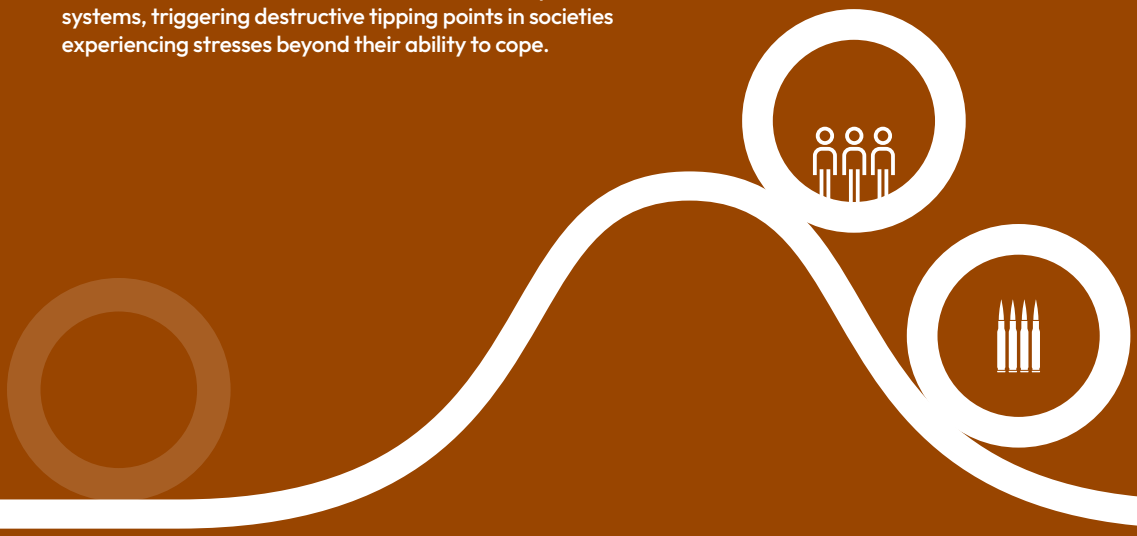
These threats could materialise in the coming decades, and at lower levels of global warming than previously thought. They could be catastrophic, including global-scale loss of capacity to grow major staple crops. Triggering one Earth system tipping point could trigger another, causing a domino effect of accelerating and unmanageable damage. Tipping points show that the overall threat posed by the climate and ecological crisis is far more severe than is commonly understood.

KEY MESSAGE 03

# TRIGGERING DESTRUCTION

## THE EFFECTS OF TIPPING POINTS WILL BE TRANSMITTED AND AMPLIFIED THROUGHOUT OUR GLOBALISED WORLD

This will multiply crises in the same way that the COVID-19 pandemic caused cascading stress to societies and economic systems globally, with unequal and unjust consequences. These impacts could escalate to threaten the breakdown of economic, social and political systems, triggering destructive tipping points in societies experiencing stresses beyond their ability to cope.

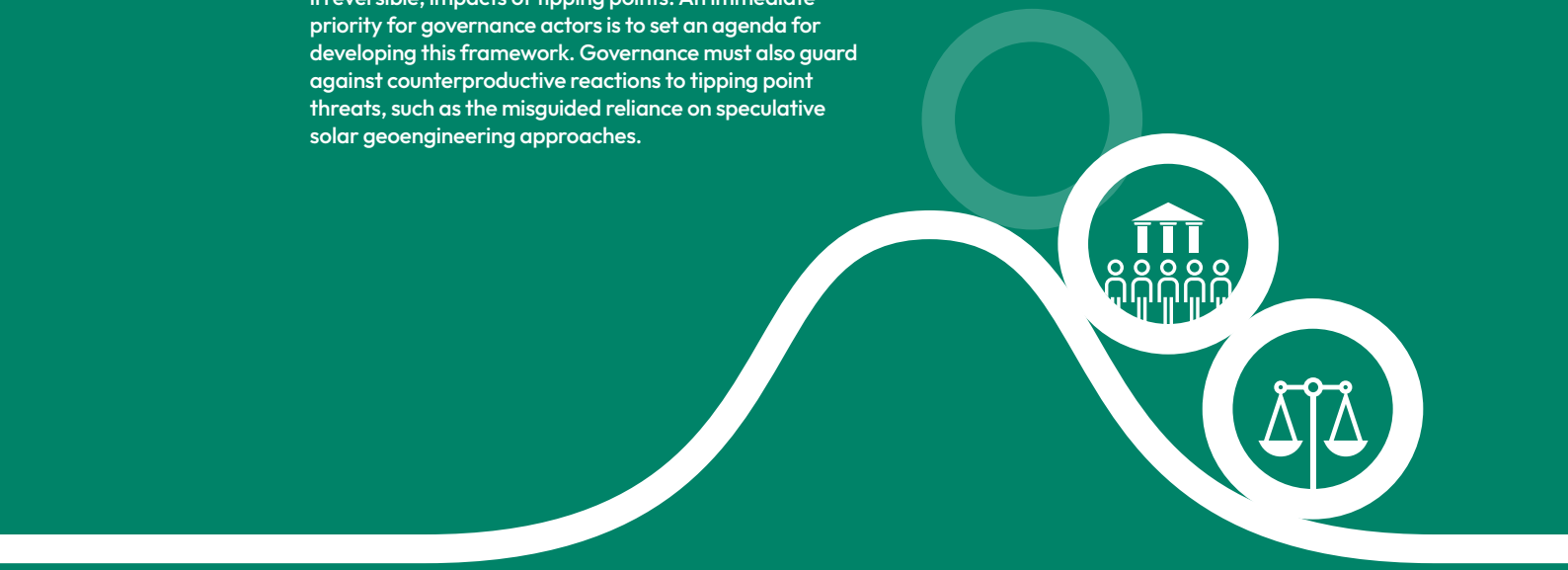


KEY MESSAGE 04

# URGENT ACTION

## STOPPING THESE THREATS IS POSSIBLE BUT REQUIRES URGENT GLOBAL ACTION

Global governance is currently inadequate to minimise tipping point threats and to do so equitably. Governance is needed across multiple scales to address the different drivers, potentially rapid changes, and diverse, often irreversible, impacts of tipping points. An immediate priority for governance actors is to set an agenda for developing this framework. Governance must also guard against counterproductive reactions to tipping point threats, such as the misguided reliance on speculative solar geoengineering approaches.



VICIOUS CYCLES

KEY MESSAGE 05

## EVEN WITH URGENT GLOBAL ACTION, SOME EARTH SYSTEM TIPPING POINTS MAY BE UNAVOIDABLE

Some Earth system tipping points may still be triggered in the time it takes us to undertake global emergency action. Mitigating risk is still possible by reducing vulnerability, and becomes ever more urgent, because each manifestation of a tipping point threat diverts attention and resources to disaster response, eroding away some of our agency to tackle the underlying drivers. This increases the risk of triggering more Earth system tipping points, creating a vicious cycle.

ACCELERATING TRANSFORMATIONS

KEY MESSAGE 06

## 'POSITIVE TIPPING POINTS' CAN ACCELERATE A TRANSFORMATION TOWARDS SUSTAINABILITY

A scale and pace of action necessary to mitigate tipping point threats can be achieved, partly because similar tipping dynamics exist in societies, and can work in our favour. These positive tipping point opportunities can be exploited, whereby coordinated strategic interventions can lead to disproportionately large and rapid benefits that accelerate the transition of societies toward sustainability. This is already happening in some cases. For example, targeted actions by innovators, governments, investors and companies have created economies of scale that are now propelling the exponential uptake of renewable energy worldwide, which has reached or exceeded cost parity with fossil fuel power generation.

POSITIVE CHANGE

KEY MESSAGE 07

## ONE POSITIVE TIPPING POINT CAN TRIGGER OTHERS, CREATING A DOMINO EFFECT OF CHANGE

For example, as electric vehicles pass a positive tipping point towards becoming a dominant form of transport, this reduces the costs of battery technology. Lower-cost batteries in turn provide essential storage capacity to reinforce the positive tipping point to renewable power, which can trigger another tipping point in producing green ammonia for fertilisers, shipping, and so on.

COORDINATED ACTION

KEY MESSAGE 08

## TRIGGERING POSITIVE TIPPING POINTS REQUIRES COORDINATED ACTION THAT CONSIDERS EQUITY AND JUSTICE

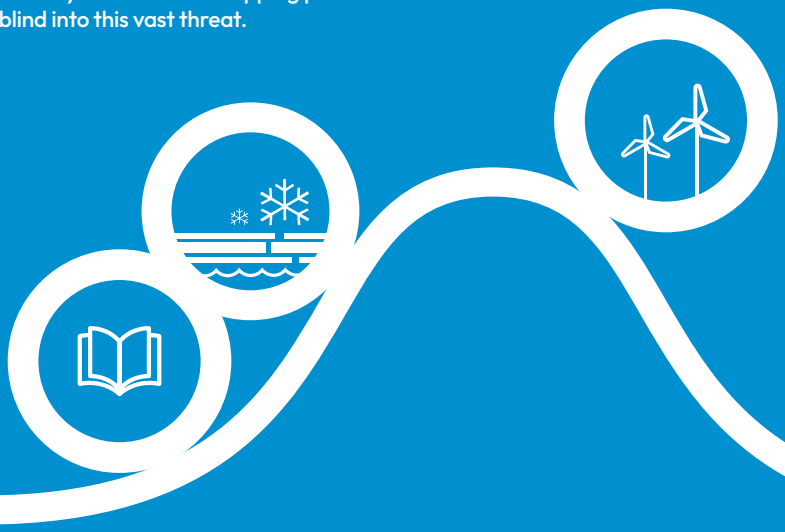
Many areas of society have the potential to be 'tipped', including politics, social norms and mindsets. But these opportunities are not realised on their own. Concerted and coordinated action is usually needed to create the enabling conditions for triggering positive tipping points. Once near a tipping point, it may even be triggered by relatively small groups with targeted action. Appropriate governance can enable this process and is required to equitably manage its knock-on effects, so that all parts of society can engage with and benefit from tipping point opportunities.

KEY MESSAGE 09

# A DEEPER UNDERSTANDING

## WE NEED A DEEPER UNDERSTANDING OF TIPPING POINTS – BUT WITHOUT DELAYING ACTION

Improving understanding of tipping point threats and opportunities in both nature and societies is an urgent priority to support governance and decision making, with the aim to limit harm and support transformations to sustainability. But this quest for knowledge must not delay or slow action. We know enough to identify that the threat of Earth system tipping points demands an urgent response. Indeed, our best models likely underestimate tipping point risks. The world is largely flying blind into this vast threat.

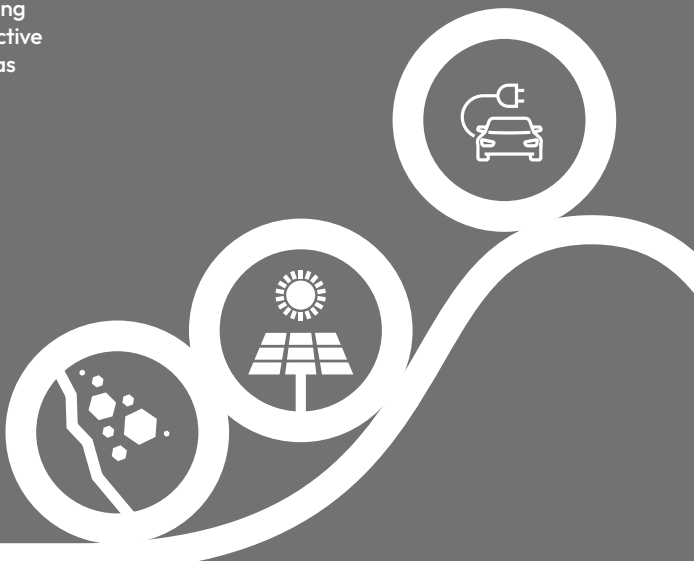


KEY MESSAGE 10

# A POWERFUL COUNTER EFFECT

## POSITIVE TIPPING POINTS CAN CREATE A POWERFUL COUNTER EFFECT TO THE RISK OF EARTH SYSTEM TIPPING POINTS CASCADING OUT OF CONTROL

The ultimate risk presented by Earth system tipping points is that they cascade, creating a growing momentum that undermines our collective ability to deal with the vicious cycle of escalating consequences. But both protecting and enhancing our collective ability to realise positive tipping point opportunities – even as damaging events escalate – can create a powerful counter effect, avoiding spiralling disaster. Doing so means urgently making our societies more resilient to this new era of rapid change and implementing equitable global governance.



# Key recommendations

## 1 PHASE OUT FOSSIL FUELS AND LAND USE EMISSIONS NOW

The scale of threat posed by Earth system tipping points underlines the critical importance of the 1.5°C temperature goal and means that global mitigation should now assume an emergency footing. Fossil fuel emissions should be phased out worldwide before 2050. A rapid end to land use change emissions and shift to worldwide ecological restoration are also needed. Countries should reassess their highest possible ambitions accordingly, particularly wealthy, high-emitting nations.

## 2 STRENGTHEN ADAPTATION AND LOSS-AND-DAMAGE GOVERNANCE

Some Earth system tipping points are now likely to be triggered, causing severe and spatially uneven impacts on societies and interconnected ecological, social and economic systems. Tipping point impacts will be felt worst by the most vulnerable communities within and between nations, with knock-on impacts for global inequality, the stability of the world economy, and geopolitics. This provides an urgent impetus to strengthen adaptation and loss-and -damage governance in the UNFCCC, adjusting existing frameworks and increasing resources to account for tipping point threats.

## 3 INCLUDE TIPPING POINTS IN NDCS AND THE GLOBAL STOCKTAKE

Considerations of Earth system tipping point risks, corresponding action, and positive tipping point opportunities should be included in the Global Stocktake (GST), future revisions of Nationally Determined Contributions (NDCs), and in associated national and sub-national policy measures. Future GSTs should assess collective progress towards preventing Earth system tipping points, addressing potential impacts and fostering positive tipping points. All future NDCs should include national-scale systemic assessments of exposure to tipping point risks, measures that contribute to the prevention of tipping points, plans for managing potential impacts and strategies for fostering positive tipping points

## 4 COORDINATE POLICY EFFORTS TO TRIGGER POSITIVE TIPPING POINTS

Coordinated action by coalitions of state and non-state actors across governance, business and civil society can bring forward positive tipping points in politics, economies, technology, culture, and behaviour. A focus on 'super-leverage points' – for example policy mandates in high-emitting sectors such as power, road transport, green hydrogen/ ammonia and food – could create a cascade of positive changes.

## 5 CONVENE A GLOBAL SUMMIT ON TIPPING POINTS

The UN Secretary General should convene a global summit on the governance agenda for managing Earth system tipping point risks and maximising coordination on triggering positive tipping point opportunities to speed up mitigation and resilience. It should provide a forum for government, industry and civil society. As a matter of urgency, tipping point threats should also feature on the agenda of key international fora, including the 2024 meeting of the G20 in Brazil.

## 6 DEEPEN KNOWLEDGE OF TIPPING POINTS AND ITS TRANSLATION INTO ACTION

The above efforts should be supported by investment in improved scientific knowledge and monitoring of negative and positive tipping points, and a much improved science-policy engagement process to more effectively and rapidly convert knowledge into action. To help stimulate this process, we support calls for an IPCC Special Report on Tipping Points in the current assessment cycle.

# Executive summary

## Section 1

# Earth system tipping points

# Current state of knowledge

**A.1. More than 25 Earth system tipping points have been identified from evidence of past changes, observational records and computer models. (Chapters 1.2, 1.3, 1.4)**

A.1.1. In the cryosphere, six Earth system tipping points are identified, including large-scale tipping points for the Greenland and Antarctic ice sheets. Localised tipping points likely exist for glaciers and permafrost thaw. Evidence for large-scale tipping dynamics in sea ice and permafrost is limited. (Chapter 1.2.2)

A.1.2. In the biosphere, 16 Earth system tipping points are identified, including forest dieback (e.g. in the Amazon), savanna and dryland degradation, lake eutrophication, die-off of coral reefs, mangroves, and seagrass meadows, and fishery collapse. (Chapter 1.3.2)

A.1.3. In ocean and atmosphere circulations, four Earth system tipping points are identified, in the Atlantic Meridional Overturning Circulation (AMOC), the North Atlantic Subpolar Gyre (SPG), the Southern Ocean Overturning Circulation and the West African monsoon. (Chapter 1.4.2)

**A.2. Some Earth system tipping points are no longer high-impact, low-likelihood events, they are rapidly becoming high-impact, high-likelihood events. (Chapters 1.2, 1.3, 1.4)**

A.2.1. Multiple drivers are destabilising tipping systems, including climate change for most as well as habitat loss (e.g. deforestation), nutrient pollution and air pollution for some. Multiple drivers, interactions and feedback loops can make tipping thresholds difficult to assess. (Chapters 1.2.2, 1.3.2, 1.4.2)

A.2.2. Already, at today's 1.2°C global warming, tipping of warm-water coral reefs is likely and we cannot rule out that four other systems may pass tipping points: the ice sheets of Greenland and West Antarctica, the North Atlantics Subpolar Gyre circulation, and parts of the permafrost subject to abrupt thaw. (Chapters 1.2.2, 1.3.2, 1.4.2)

A.2.3. Passing 1.5°C global warming, widespread mortality in warm-water coral reefs becomes very likely, and another three potential tipping systems start to become vulnerable: boreal forest, mangroves and seagrass meadows. (Chapter 1.3.2)

A.2.4. At 2°C global warming and beyond, several more systems could tip, including the Amazon rainforest and subglacial basins in East Antarctica, and irreversible collapse of the Greenland and West Antarctic ice sheets is likely to become locked in. (Chapters 1.2.2, 1.3.2)

A.2.5. Some systems can cross tipping points due to other drivers, or have their warming thresholds reduced by other human pressures, with for example Amazon dieback possible at lower warming if deforestation continues. (Chapters 1.3.2, 1.4.2)

**A.3. Earth's tipping systems can interact in ways that destabilise one another, making tipping 'cascades' possible. (Chapter 1.5)**

A.3.1. Tipping systems in the climate are closely coupled together. Hence a tipping point in one system can have significant implications for other systems. (Chapter 1.5.1)

A.3.2. Most interactions between climate tipping systems are destabilising, tending to destabilise the Earth system beyond the effects of climate change on individual systems. (Chapter 1.5.2)

A.3.3. Global warming is rapidly approaching levels that could trigger individual tipping points in systems that can interact with and destabilise other tipping systems. (Chapters 1.2.2, 1.3.2, 1.4.2, 1.5.2)

A.3.4. Tipping 'cascades', where tipping one system causes another tipping point to be passed, and so on, are possible but currently highly uncertain. (Chapters 1.5.3, 1.5.4)

**A.4. Early warning signals have been detected that are consistent with the Greenland Ice Sheet, AMOC, and Amazon rainforest heading towards tipping points. (Chapter 1.6)**

A.4.1. Loss of resilience (the ability to recover from perturbations) is expected before reaching a tipping point, but does not directly reveal how close a tipping point is. (Chapters 1.3.1, 1.6.1)

A.4.2. Loss of resilience can occur in systems without tipping points, hence independent evidence that a system is prone to tipping is needed before interpreting loss of resilience as a tipping point early warning signal. (Chapters 1.6.1, 1.6.3)

A.4.3. The central western Greenland ice sheet, AMOC, and Amazon rainforest all have independent evidence of being prone to tipping and show observational evidence of loss of resilience consistent with moving towards tipping points. (Chapter 1.6.2)

**A.5. The risks of crossing Earth system tipping points can be minimised through rapidly reducing anthropogenic drivers of global change. (Chapters 1.2, 1.3, 1.4)**

A.5.1. Urgently and ambitiously reducing greenhouse gas emissions can limit the risks of crossing tipping points in the cryosphere, biosphere, ocean and atmosphere circulation. (Chapters 1.2.2, 1.3.2, 1.4.2)

A.5.2. Rapidly reducing other climate forcing agents, such as black carbon for the cryosphere, and aerosols for the monsoons, can further limit the risk of crossing specific tipping points. (Chapters 1.2.2, 1.4.2.3)

A.5.3. The risk of crossing biosphere tipping points can be minimised through a combined approach of rapidly reducing climate forcing and other interacting drivers such as deforestation, habitat loss and pollution, together with ecological restoration, inclusive conservation, and supporting sustainable livelihoods. (Chapter 1.3.2)

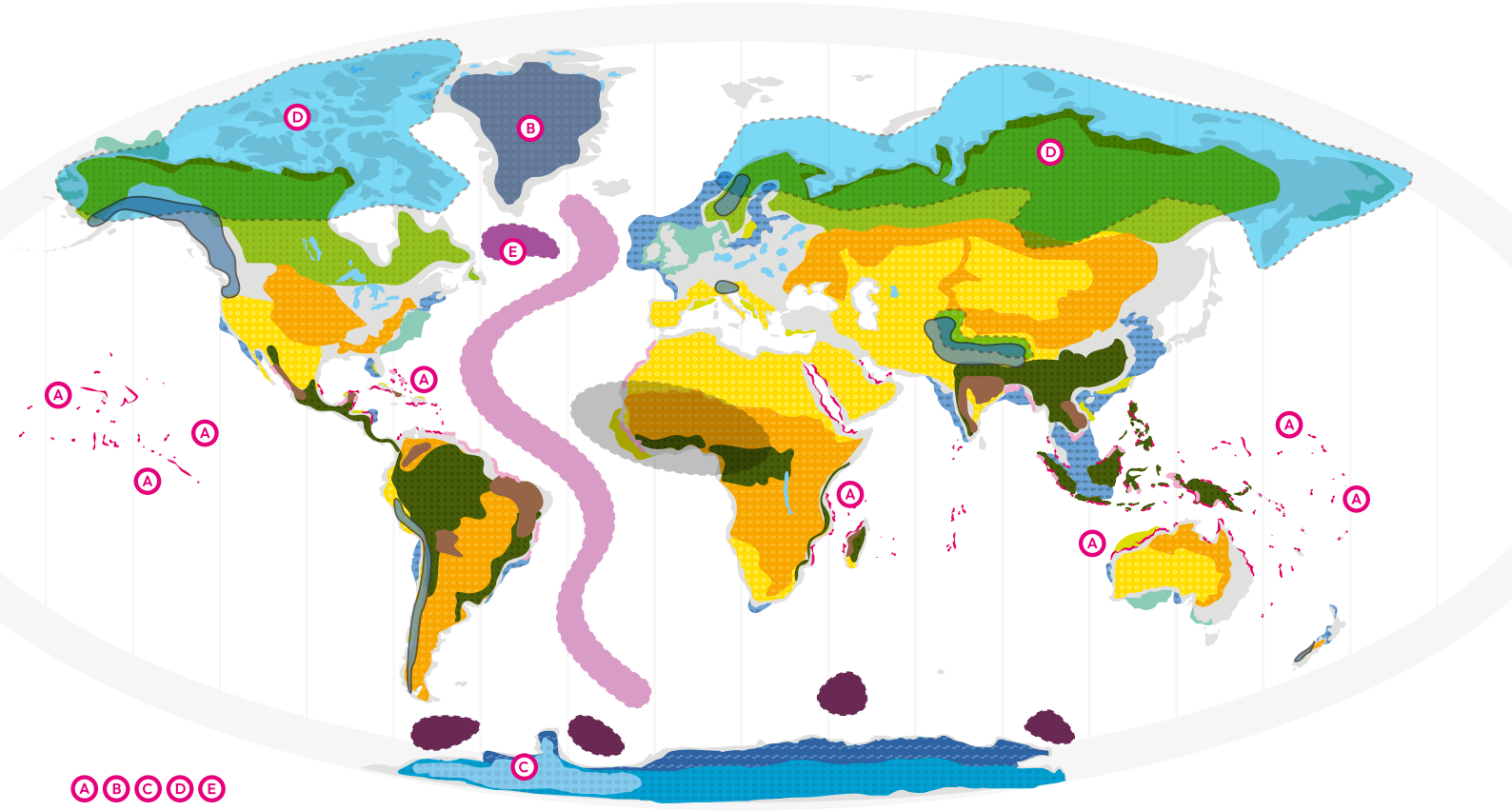



**Figure 1:** Parts of the Earth system identified in this report as featuring tipping points.

# Priorities to advance knowledge

**A.6. Deep uncertainties about Earth system tipping points can be reduced. (Chapters 1.2, 1.3, 1.4)**

A.6.1. Short observational records and limited resolution of important feedback processes in models make assessing the existence and likelihood of tipping points difficult for many systems. (Chapters 1.2.2, 1.3.2, 1.4.2)

A.6.2. Key process uncertainties include: in the cryosphere, the potential for a marine ice cliff instability; in the biosphere, the complex interactions between ecohydrological and fire feedbacks; and in ocean and atmosphere circulation, the resolution of small-scale processes such as ocean mixing. (Chapters 1.2.2, 1.3.2, 1.4.2)

**Recommendation:**

**A.6.3. Research funders, knowledge institutions and scientists should invest in reducing uncertainties surrounding the existence and likelihood of specific Earth system tipping points through targeted palaeo-data gathering, Earth observations, model development, knowledge sharing across disciplines, and a systematic model intercomparison project.**

**A.7. Assessment of Earth system tipping point interactions and possible cascades can be improved. (Chapter 1.5)**

A.7.1. Earth system models can be improved to represent more tipping system interactions. Large ensembles of model runs can be used to detect less common but potentially important interactions. Direct causal interactions and indirect feedbacks – e.g. via changes in temperature – can be better quantified. (Chapter 1.5.5)

A.7.2. Palaeoclimate records of past abrupt changes can help identify and understand tipping point interactions and possible cascades. Methods of inferring causality can be applied to observational data to detect tipping system interactions. (Chapters 1.5.3, 1.5.5)

A.7.3. A fresh elicitation of expert knowledge could help identify potential tipping system interactions. (Chapter 1.5.5)

**Recommendation:**

**A.7.4. Research funders, knowledge institutions and scientists should invest in improving assessment of tipping point interactions and possible cascades through the development and use of Earth system models, causal analysis of palaeoclimate and observation data, and expert elicitation.**

**A.8. Early warning of Earth system tipping points can be improved. (Chapter 1.6)**

A.8.1. Model experiments can be designed and used to identify which observable variables and associated statistics are most promising to provide early warning signals of specific tipping points, and thus guide monitoring efforts. (Chapter 1.6.3)

A.8.2. Tipping point detection and early warning methods can be improved, with the application of machine learning showing promise. (Chapter 1.6.3)

A.8.3. For slow-tipping systems, such as ocean overturning circulations, investment in palaeo-data reconstructions can improve the potential to detect tipping point early warning signals. (Chapters 1.6.2, 1.6.3)

A.8.4. For fast-tipping systems, such as ecosystems, the reliability of early warning signals can be improved by reducing biases in satellite remote sensing data caused by missing data and by merging of data. (Chapter 1.6.3)

**Recommendation:**

**A.8.5. Research funders, knowledge institutions and scientists should invest in improving early warning of Earth system tipping points through refining methods, use of models to guide monitoring efforts, palaeo-data gathering and improving remotely sensed datasets.**

## Section 2

# Tipping point impacts

# Current state of knowledge

**B.1. Crossing Earth system tipping points would have severe impacts on people and biodiversity. (Chapter 2.2)**

B.1.1. Amazon dieback, ice sheet collapse, permafrost thawing and collapse of the AMOC have the potential for severe impacts on water, food and energy security, health, ecosystem services, communities and economies. (Chapter 2.2)

B.1.2. Amazon dieback would be a catastrophe for biodiversity, would add to global and regional warming, could put 6 million people at direct risk from extreme heat stress and cause between US$1 trillion and US$3.5 trillion in economic damages. (Chapter 2.2.3.1)

B.1.3. Antarctic ice sheet instability leading to a potential sea level rise of two metres by 2100 would expose 480 million people to annual coastal flooding events. (Chapter 2.2.2.1)

B.1.4. Permafrost thawing would add significantly to global warming, it already damages property and infrastructure, and 70% of current infrastructure in permafrost regions is in areas with high potential for thaw by 2050. (Chapter 2.2.2.4)

B.1.5. An AMOC collapse could substantially reduce crop productivity across large areas of the world, with profound implications for food security. (Chapters 2.2.4.1, 2.2.6.2)

**B.2. Negative social tipping points triggered by climate change and Earth system tipping could have catastrophic impacts on human societies. (Chapter 2.3)**

B.2.1. Escalating Earth system destabilisation threatens to disrupt societal cohesion, increase mental disorders and amplify radicalisation and polarisation. It has the potential to escalate violent conflicts, mass displacement and financial instability. (Chapter 2.3)

B.2.2. Negative social tipping points would hamper collective mitigation efforts and capacities to respond effectively to Earth system destabilisation, thus impeding the realisation of positive futures. (Chapter 2.3)

B.2.3. If societies fail to re-stabilise the Earth system we will not stay in a business-as-usual state. Instead, negative social tipping will bring about another social system state, likely characterised by greater authoritarianism, hostility, discord and alienation. (Chapter 2.3).

**B.3. Negative social tipping points could cascade to create systemic risk. (Chapter 2.4)**

B.3.1. Although empirical evidence is currently scarce, extrapolating known feedbacks in complex human-natural systems suggests that tipping points in social and natural systems could plausibly cascade, with catastrophic risks for human wellbeing. (Chapter 2.4)

B.3.2. Less is known about cascades from Earth's tipping systems to socio-economic systems than those between Earth's tipping systems. This is due to limited experience, and time lags between crossing Earth system tipping points and the reaction of social systems. (Chapters 2.3, 2.4)

B.3.3. Research on tipping cascades in human systems thus far has focused on accelerating mitigation action, rather than preparing for potential consequences of physical climate risks. (Chapters 2.2, 2.3, 2.4)

**B.4. Early warning signals can be used to anticipate impact tipping points. (Chapter 2.5)**

B.4.1. Methods used to detect tipping points and loss of resilience in Earth's tipping systems (e.g. the Amazon rainforest) can be applied to anticipate tipping points in socio-economic impacts. (Chapter 2.5)

B.4.2. Recent applications of these methods have shown valuable early warning information of changes in food insecurity, and of land degradation in managed vegetation systems. (Chapter 2.5)

B.4.3. New datasets such as social media data and new technologies like deep learning have the potential to enhance the ability to anticipate tipping points in socio-economic impacts. (Chapter 2.5)

# Priorities to advance knowledge

**B.5. Improved assessments of the impacts of Earth system tipping points and negative social tipping points are urgently needed. (Chapters 2.2, 2.3)**

B.5.1. There is uneven and incomplete assessment of the impacts of Earth system tipping points on people, social systems and ecosystems, with almost no work on understanding the vast range of potential human and social impacts. (Chapters 2.2, 2.3)

B.5.2. Existing assessments of the economic impacts of crossing Earth system tipping points often systematically underestimate the risks. (Chapters 2.2, 2.3)

B.5.3. Assessments need to go beyond economic damages to broader human, social and cultural impacts of crossing Earth system tipping points. (Chapters 2.2, 2.3)

**Recommendations:**

**B.5.4. Research funders should invest in improving assessment of the impacts of Earth system tipping points, starting with systematic application of existing Earth system models and impact models to tipping point scenarios. (Chapter 2.2)**

**B.5.5. Research funders and knowledge institutions should foster interdisciplinary collaboration between natural and social scientists to improve assessment of the economic, social and cultural impacts of tipping points. (Chapters 2.2, 2.3)**

**B.6. Assessment of the interactions of impact tipping points and possible cascades can be improved. (Chapter 2.4)**

B.6.1. Knowledge of negative social tipping points and their impacts needs to be coupled to knowledge of Earth system tipping points through the interdisciplinary consideration of potential causal chains of propagation of systemic risk. (Chapters 2.3, 2.4)

B.6.2. Focused research is needed on the mechanisms and consequences of tipping interactions, including identifying distinct feedbacks fuelled by policy, economic, financial and behavioural dynamics that can potentially lead to cascades. (Chapter 2.4)

B.6.3. Monitoring programmes are needed to systematically gather data about potential tipping point interactions over long periods of time, founded on research into which variables to monitor. (Chapter 2.4)

**Recommendation:**

**B.6.4. Knowledge institutions and research funders should support coordinated, interdisciplinary research programmes focused on building understanding of interactions between climate and social tipping points and their role in the emergence of systemic risk. (Chapter 2.4)**

**B.7. Improving capacity to anticipate negative tipping points can provide increased opportunity to pre-emptively adapt and reduce vulnerability to their impacts. (Chapter 2.5)**

B.7.1. Existing knowledge of negative tipping points should serve as enough 'early warning' to motivate urgent action, but could be augmented by more formal early warning of specific Earth system tipping points (A.4) to aid impact management. (Chapter 2.5)

B.7.2. While there is considerable room for further development (A.8) it is timely for interdisciplinary research to consider how, where and when early warning systems for Earth system tipping points should be developed. (Chapter 2.5)

B.7.3. Further research is needed into early warning of negative tipping points in socio-economic systems (B.4), particularly to determine appropriate data sources, their relevant characteristics, and the types of statistics that can provide robust early warning information. (Chapter 2.5)

B.7.4. There is considerable potential for research on negative tipping points, and early warning thereof, to contribute to wider initiatives to accelerate systemic risk assessment. (Chapter 2.5)

**Recommendation:**

**B.7.5. Knowledge institutions and research funders should invest in interdisciplinary early warning systems research to identify indicators and techniques that empower decision makers to anticipate tipping points and take preemptive, resilience-building actions. (Chapter 2.5)**

## Section 3

# Governance of Earth system tipping points

**C.1. Governance of Earth system tipping points is lacking. (Chapter 3.1)**

C.1.1. Governance efforts need to cover multiple domains, including prevention and impact management, and carefully consider the diversity of tipping processes – each tipping system requires a distinct governance approach. (Chapter 3.1)

C.1.2. Governance of Earth system tipping points should be polycentric and networked, crossing multiple scales and institutions, including the scale of the tipping system. (Chapter 3.1)

C.1.3. Existing sustainability governance institutions across multiple scales, especially those related to the international climate change regime complex, should consider including Earth system tipping points in their mandates and action agendas. (Chapters 3.1, 3.2, 3.2)

C.1.4. Governance of Earth system tipping points should include redundancies to avoid governance failure, and be flexible/adaptive to enable rapid shifts in attention and resources towards emerging problems. (Chapter 3.1)

C.1.5. Short-term decisions have consequences on multiple time horizons (years to millennia) that require anticipatory governance and new risk assessment approaches for Earth system tipping points. (Chapter 3.1)

C.1.6. Actors and institutions across multiple scales and domains (state, industry, civil society) require long-term governance capacities, especially future thinking (anticipation/imagination), complex-systems thinking and long-term agency. (Chapter 3.1)

**Recommendation:**

**C.1.7. Now is the time for governance actors, including UN bodies, international organisations, national governments and non-state actors, to engage in setting the agenda for the governance of Earth system tipping points. (Chapter 3.1)**

**C.2. Preventing the passing of Earth system tipping points should become the core goal and logic of a new and urgently needed governance framework to address the risks they pose. (Chapters 3.1, 3.2)**

C.2.1. Given that Earth system tipping point risks are already moderate at current levels of warming and increase substantially above 1.5°C above pre-industrial levels, a short window for preventive action is open now and will close at different points in time for each tipping system – for some, potentially as early as the 2030s. (Chapter 3.2)

C.2.2. Preventing Earth system tipping requires addressing multiple drivers of tipping at different scales, especially rapidly strengthening current climate mitigation efforts to minimise temperature overshoot (both peak temperature and duration). (Chapter 3.2)

C.2.3. Speculative solar geoengineering approaches to preventing Earth system tipping points face deep ethical, technical and political uncertainties, and should not be considered technically available to use safely and swiftly at present.

**Recommendations:**

**C.2.4. Countries need to rapidly and dramatically reduce greenhouse gas emissions, phasing out fossil fuels and bringing forward their decarbonisation timelines, to minimise the risk of crossing Earth system tipping points. (Chapter 3.2)**

**C.2.5. This must include reducing both long-lived – especially carbon dioxide ($CO_2$) – and short-lived – especially methane ($CH_4$) – greenhouse gas emissions to limit the magnitude and rate of warming, and to minimise peak temperature and the duration of overshooting 1.5°C. (Chapter 3.2)**

**C.2.6. 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. (Chapter 3.2)**

**C.3. Managing the impacts of tipping points has diverse and immediate governance implications.**

C.3.1. Governance of climate change adaptation needs to significantly expand anticipatory work and adopt a multi-temporal perspective tied to the dynamics of specific tipping systems. (Chapter 3.3)

C.3.2. The loss and damage framework needs rapid development, including consideration of the loss of entire biomes. (Chapter 3.3)

C.3.3. Vulnerability to tipping point impacts can be reduced by building resilience, fostering sustainable development and just transformations to sustainability. (Chapter 3.3)

C.3.4. In some locations, existing response mechanisms, including adaptation, could be overwhelmed by the impacts of Earth system tipping processes. Planned relocation in close collaboration with affected communities will become increasingly necessary. (Chapter 3.3)

**C.4. There are relevant institutions and expertise that can contribute to governance of Earth system tipping points, but these need significant adjustments to be effective.**

C.4.1. Mitigating climate tipping points should be addressed within the Paris Agreement framework, including considering tipping points in the interpretation of global goals and narrowing acceptable mitigation pathways to prevent tipping (i.e. minimising peak temperature and overshoot duration). (Chapter 3.2)

C.4.2. Carbon removal strategies need to be aligned with building resilience to tipping points and nature-based solutions need to be resilient to the passing of tipping points if that cannot be avoided. (Chapter 3.2)

C.4.3. Innovation is needed to address a lack of meaningful governance capacities at the scale of the tipping system – for example, the tropical coral reefs or major ocean currents. (Chapters 3.1, 3.2)

**Recommendations:**

**C.4.4. 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. (Chapter 3.2)**

**C.4.5. Parties to the Paris Agreement should include a discussion of Earth system tipping points in future revisions of their Nationally Determined Contributions (NDCs) and mid-century decarbonisation strategies, including an assessment of how the country contributes to tipping point risks, how it will be affected by their impacts, and national measures and plans to prevent their transgression and to prepare for their impacts. (Chapter 3.2)**

**C.4.6. 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. (Chapter 3.3)**

**C.4.7. Countries within the geographic scope of a specific Earth system tipping element (e.g. all countries with tropical coral reefs, Amazon rainforest, or around the North Atlantic) should consider launching new initiatives for collective impact governance, including the development of knowledge and early warning systems specific to the tipping system, fostering adaptation, addressing potential losses and damages, and mutual learning/sharing of experience. (Chapters 3.1, 3.3)**

**C.5. Improved knowledge production and science-policy engagement processes are needed to support governance of Earth system tipping processes.**

C.5.1. Scientific knowledge, especially regarding the temporal and spatial scales, of Earth system tipping processes must be translated into actionable, actor-relevant understanding, across scales and actor types, to support governance of Earth system tipping processes. (Chapter 3.4)

C.5.2. Existing international knowledge institutions need to be reformed to better support this kind of knowledge production. (Chapter 3.4)

C.5.3. Learning challenges specific to tipping points are significant and could slow down or impede effective governance and public engagement. (Chapter 3.4)

C.5.4. Currently, knowledge gaps are biggest in the social sciences and humanities. (Chapter 3.4)

C.5.5. Novel knowledge co-production processes that can engage scientists, policymakers and stakeholders in systems and future thinking are needed to foster anticipatory capacities. (Chapter 3.4)

**Recommendations:**

**C.5.6. International organisations, national governments and science funders should foster urgent international research collaboration, especially in the social sciences and humanities, by promoting open, transdisciplinary and interdisciplinary, solutions-oriented, networked knowledge systems focusing on Earth system tipping points.**

**C.5.7. Regional and national science and knowledge institutions (e.g. national academies of science, EU foresight initiatives) and boundary organisations should foster anticipatory capacity building with participatory co-production processes involving policy-makers, scientists, other knowledge holders, artists, and designers.**

## Section 4

# Positive tipping points in technology, economy and society

**D.1. Positive tipping points offer the prospect that coordinated, strategic interventions can lead to disproportionately large and rapid beneficial results that mitigate existential climate risk and help redirect humanity along more sustainable pathways.**

D.1.1. We are now so close to Earth system tipping points that positive tipping points to accelerate social change are the only realistic systemic risk governance option. (Chapter 4.2)

D.1.2. Positive tipping points don't just happen, they need to be actively enabled. Most positive tipping points require interventions – technological innovation, political and social action, behaviour/norm change, and financial investment – that create the enabling conditions and alter the balance of feedback for tipping to occur. (Chapter 4.2)

D.1.3. Changemakers could benefit from more diverse perspectives to open up the solution space, leveraging a shift in worldviews as well as reconfiguring systems, technologies, markets and materials. (Chapters 4.2, 4.3, 4.4, 4.6)

**Recommendation:**

**D.1.4. Science funders and knowledge institutions should urgently foster a comprehensive, systematic and transdisciplinary programme of research and development of positive tipping points concepts, theory, methods and applications.**

**D.2. Positive tipping points provide new opportunities and challenges for decision makers. (Chapter 4.2)**

D.2.1. Human systems are complex. Decision makers need reliable information and frameworks to assess the effects, opportunities and risks of interventions. (Chapter 4.2)

D.2.2. An avoid-shift-improve logic can be used in many sectors to decide which form of intervention is most effective. (Chapter 4.3)

D.2.3. High-emitting sectors need coordinated supply-side and demand-side approaches. There are key feedbacks between them that can lead to positive tipping points. (Chapter 4.3)

D.2.4. Small-group coalitions of state and non-state actors (e.g. cities) may be more effective in accelerating ambitious climate leadership than larger groups. (Chapter 4.4)

D.2.5. Rapid systemic change usually creates losers as well as winners. The required scale and speed of change will only be possible with sufficient public consent. (Chapter 4.6)

D.2.6. The public must be involved in relevant decision making and equipped with a clear understanding of the enormous opportunities (lives saved, improved health/wellbeing, better jobs, clean and cheap energy) as well as the risks of rapid change. (Chapter 4.4.2)

**Recommendations:**

**D.2.7. National and regional policymakers need a systems-thinking approach and coordinated strategies across all sectors, departments and levels of government. Both supply-side and demand-side interventions are needed to maximise the potential of positive tipping points. (Chapters 4.2 and 4.3)**

**D.2.8. Countries and relevant non-state actors should form small-group coalitions (climate clubs) of shared interests that can enable positive tipping points. For example, a global tipping point for electric vehicles could be brought forward if China, EU and US introduce future bans on the sale of internal combustion engine vehicles. (Chapter 4.4.2)**

**D.2.9. Governments, cooperating with relevant industries and trade unions, must ensure that those who might otherwise be losers from positive tipping points – e.g. livestock farmers, workers in fossil-fuel industries, or exploited workers mining rare-earth metals for the new economy – are given the support needed for a just transition. (Chapter 4.6)**

**D.3. Positive tipping points are starting to occur in energy systems and can be brought forward by demand-side interventions. (Chapter 4.3.1)**

D.3.1. The power sector in many countries recently passed a tipping point of cost parity for renewable power generation. Declining prices of renewable electricity below cost parity with fossil-fuelled power generation further reinforce exponential growth. Over 80% of new electricity generation in 2022 was solar and wind. (Chapter 4.3.1)

D 3.2. Affordable renewable electricity supply is driving tipping points across systems and technologies such as EVs and heat pumps. (Chapter 4.3.1)

D.3.3. Reducing energy demand by avoiding energy-intensive activities, shifting to less energy-intensive activities and improving energy service efficiency can accelerate decarbonising the energy system. (Chapter 4.3.1)

**Recommendations:**

**D.3.4. Investors, policymakers and technology providers need to focus on clean energy technology development, the achievement of cost parity with 'sunset' technologies, and exponential diffusion worldwide, especially in emerging markets. (Chapter 4.3.1)**

**D.3.5. Policymakers need to introduce strong regulations, such as minimum efficiency levels for buildings and appliances, that incentivise demand reductions through the adoption of low-carbon technologies and behaviours. (Chapters 4.3.1, 4.3.2)**

**D.3.6. Policy to support both supply-side and demand-side reductions should be designed to support sustainable and durable changes. (Chapter 4.3.1)**

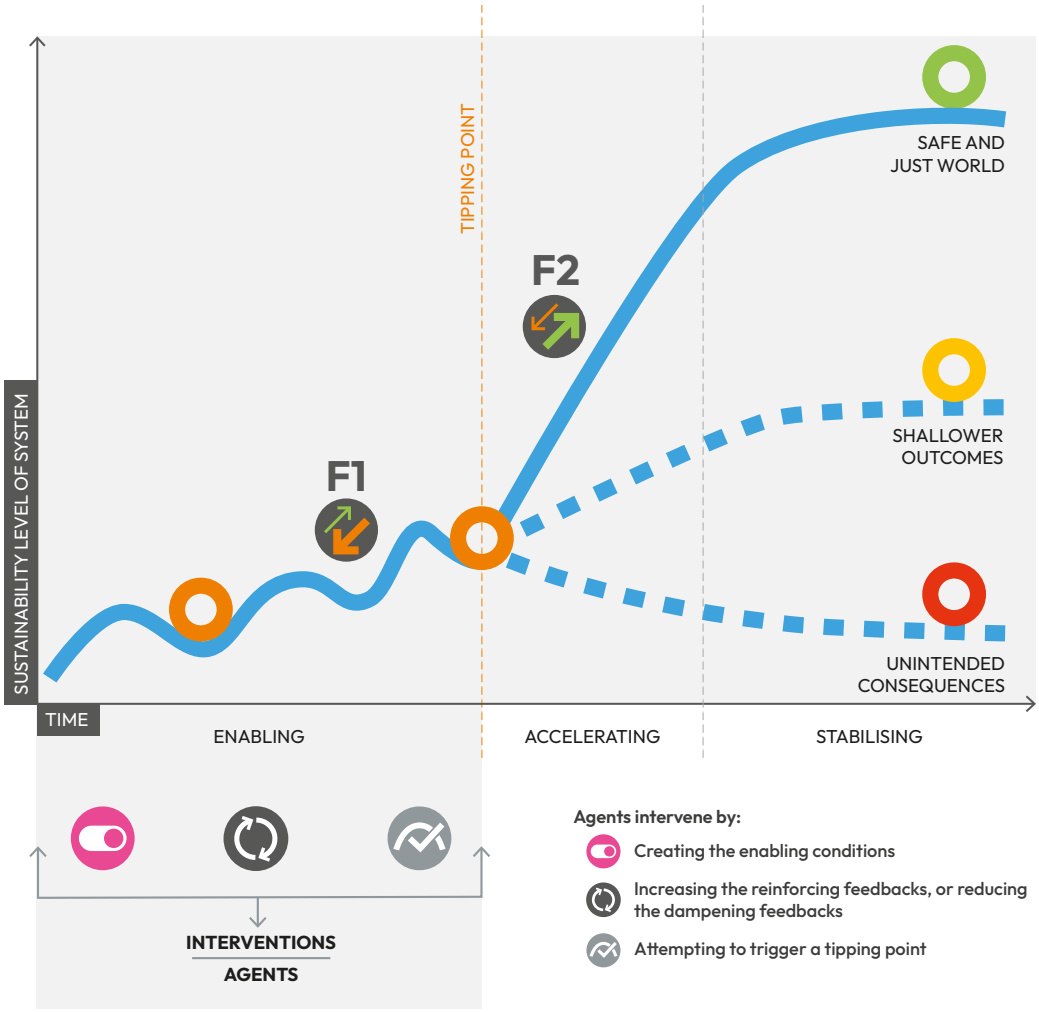



**Figure 2.** Visual summary of the concept of positive tipping points. The current state of the target system is unsustainable. The desired outcome is consistent with a safe and just world. The process of positive tipping typically entails three different phases of enabling, accelerating and stabilising. To encourage the desired outcome, agents can strategically intervene to leverage change during the enabling phase in three ways, by: 1) Creating the enabling conditions; 2) Increasing the amplifying feedbacks that increase instability/decreasing the dampening feedbacks that maintain stability; or 3) Attempting to trigger the positive tipping point. Once the tipping point has been crossed, the system enters an accelerating phase of nonlinear change dominated by amplifying feedbacks, then stabilises again in a qualitatively different state. The primary characteristic of a tipping point is a shift in the balance of feedbacks: at point F1, prior to the tipping point, dampening feedbacks are dominant and system stability is maintained; at point F2, beyond the tipping point, amplifying feedbacks are temporarily dominant and change accelerates exponentially. Other outcomes are also possible, including 'shallower', less sustainable outcomes, and unintended consequences.

**D.4. Positive tipping points are starting to occur in electric vehicle markets which need to be complemented by systemic changes in transport and mobility systems. (Chapter 4.3.2)**

D.4.1. Electric vehicles show evidence of passing or approaching tipping points in major markets including China and Europe. (Chapter 4.3.2)

D.4.2. There is an urgent need for tipping points in transport demand as freight and personal transport continue to increase with diverse negative impacts. (Chapter 4.3.2)

D.4.3. There are encouraging localised examples of tipping points in urban mobility, with a decrease in individual motorised transport and a shift to more active transport modes which can be upscaled. (Chapter 4.3.2)

**Recommendations:**

**D.4.4. Policymakers need to prioritise integrated planning to enable tipping in transport, foremost regional planning for public transport and active travel infrastructure to avoid material-intensive individual mobility. (Chapter 4.3.2)**

**D.4.5. Policymakers need to steer the transition of the transport sector with tools such as zero emission vehicle mandates, which can induce EV tipping points across markets.**

**D.5. Positive tipping points have yet to occur at scale in food systems, but there are a range of interventions that can create enabling conditions. (Chapter 4.3.3)**

D.5.1. Shifting to more plant-based diets, avoiding food loss and waste, and improving farming practice have synergistic benefits for meeting the Paris targets, biodiversity protection goals and Sustainable Development Goals. (Chapter 4.3.3)

D.5.2. Potential positive tipping points can be enabled in the uptake of alternatives to livestock products, spread of sustainable agriculture, and green ammonia production for fertiliser. (Chapter 4.3.3)

**Recommendations:**

**D.5.3. Policymakers should focus on designing and sequencing policies strategically to incentivise production shifts away from livestock. Adaptive and deliberative governance can help ensure positive outcomes for potential 'losers' (e.g. livestock farmers). (Chapter 4.3.3)**

**D.5.4. Policymakers should enable diversified income opportunities for farmers, to make agroecological or sustainable landuse practices economically attractive (e.g. through carbon markets, agri-photovoltaics). (Chapter 4.3.3)**

**D.5.5. New emission-pricing (e.g. for methane and nitrogen), especially focused on large producers, could generate revenues to support most affected regions and low-income groups, foster innovation (e.g. via reducing VAT rates on plant-based food), and create additional income sources for farmers. (Chapter 4.3.3)**

**D.5.6. Policymakers, retailers and public cafeterias should use nudging and public procurement of more plant-based and sustainable food to accelerate the adoption of new sustainable, healthy diets. (Chapter 4.3.3)**

**D.5.7. Policymakers, investors, NGOs and food retailers should support innovation, health and sustainability transparency criteria, accessibility, and certification to facilitate market penetration of sustainable and healthy alternative proteins. (Chapter 4.3.3)**

**D.6. Social behaviour and politics can enable positive tipping in other key systems and can themselves be viewed as systems with tipping points. (Chapter 4.4)**

D.6.1. Changes in social-behavioural systems often precede and fuel wider changes and can exhibit tipping dynamics through social contagion processes. (Chapter 4.4)

D.6.2. Elements of civil society, including social movements, tend to be at the vanguard of radical social change. However, to successfully disrupt and replace an incumbent regime, they also need to cultivate a broad coalition of public, business and political support. (Chapter 4.4)

D.6.3. 'Free social spaces' are places where social movements and other alternative communities of practice can gestate, experiment and build their networks, partly protected from more powerful mainstream influences. (Chapters 4.2, 4.4.1)

D.6.4. New social norms that could help transform society include anti-fossil fuel norms and sufficiency norms. However, replacing deeply entrenched norms around consumerism in favour of sustainable sufficiency would be challenging. (Chapter 4.4.1)

**Recommendations:**

**D.6.5. Governments should pursue policies such as fossil-fuel phase-out and post-carbon infrastructure investment in ways that make the desired behaviours the most affordable and convenient options. (Chapter 4.4.1)**

**D.6.6. Policymakers should design policies to create increasing returns for shifts towards sustainable behaviours, compensate for losses, and ensure the autonomy and capacity of key actors. (Chapter 4.4.2)**

**D.7. The financial system can play a key role in enabling positive tipping points if it is appropriately regulated. (Chapter 4.4.3)**

D.7.1. Policy interventions can enable transformative shifts within and beyond the financial sector, capitalising on nonlinear dynamics. (Chapter 4.4.3)

D.7.2. Public finance can mitigate market uncertainty and encourage private investment, helping to trigger positive tipping points (e.g. in offshore wind). Premature withdrawal of public finance (e.g. subsidies) can delay or jeopardise positive tipping points. (Chapter 4.4.3)

D.7.3. Promoting alignment of investors' expectations regarding the timing and pace of the transition can help to scale sustainable investment. (Chapter 4.4.3)

D.7.4. Policy mixes that combine command-and-control and market-based instruments can initiate virtuous cycles, driving technological development and reducing the overall need for public investment. (Chapter 4.4.3)

**Recommendations:**

**D.7.5. Governments and development finance institutions need to provide support to overcome climate investment traps in developing countries by reducing capital costs and establishing an investment track record. (Chapter 4.4.3)**

**D.7.6. Governments and financial regulators should provide prudential regulation and financial supervision tools to facilitate a managed decline in fossil fuel lending, together with coordinated transition plans to enhance their collective impact on debt markets (e.g. through the Net Zero Banking Alliance). (Chapter 4.4.3)**

**D.8. Digital technologies can be key enablers of positive tipping across sectors if appropriately governed and supported. (Chapter 4.4.4)**

D.8.1. Digital technologies are already enabling positive tipping points in renewable electricity and light road transport and will likely do so in other sectors. (Chapter 4.4.4)

D.8.2. The potential of digitalisation as an enabler of positive tipping points can be best realised in a public policy framework that prohibits or limits environmental degradation while promoting the purposeful use of digital technologies towards climate mitigation and sustainable development. (Chapter 4.4.4)

**Recommendations:**

**D.8.3. Governments need to implement regulations to ensure the benefits of digitalisation are universal and not limited to specific groups. (Chapter 4.4.4)**

**D.8.4. Public sector actors need to invest in capacity building and the granting of access to appropriate digital hardware, software and infrastructure. (Chapter 4.4.4)**

**D.9. 'Early opportunity indicators' of positive tipping points could be used to maximise the leveraging effect of targeted interentions. (Chapter 4.4.5)**

D.9.1. 'Early opportunity indicators' of approaching tipping points in electric vehicle markets have been detected in country-level data. (Chapter 4.4.5)

D.9.2. These generic indicators could provide early indication of opportunities for interventions to accelerate positive tipping points in other sectors and could be used to assess the impact of previous interventions. (Chapter 4.4.5)

**Recommendation:**

**D.9.3. Research funders and investors should support efforts to develop early opportunity indicators of positive tipping points in other systems, including indicators that capture more than one domain of systemic change (e.g. market data and public attitudes).(Chapter 4.4.5)**

**D.10. 'Super-leverage points' can be identified with the potential to trigger positive tipping cascades. (Chapter 4.5)**

D.10.1. Cascading effects involve multiple systems, for example when one sector drives down the cost of a shared technology or when the output from one sector provides a low-cost input to another.

D.10.2. Cascading effects can also occur within and between social, political and financial systems, potentially leading to rapid changes in social norms, values and policies. (Chapter 4.5)

**Recommendation:**

**D.10.3. Government, business, finance and research sectors need to develop a coordinated, international, systems-thinking approach to super-leverage points and tipping cascades. For example, mandates for green ammonia for fertiliser manufacturing could trigger a tipping point in demand for hydrogen electrolysers, reducing the cost of green hydrogen and increasing the viability of green hydrogen-based solutions in other sectors, including steel and shipping. (Chapter 4.5)**

**D.11. The prevention of Earth system tipping points and the promotion of positive tipping points must ensure just and equitable outcomes. (Chapter 4.6)**

D.11.1. Considerations of what needs to change, who is being asked to change, where the change and its impacts will be felt, and by whom, require reflexivity, inclusiveness and cooperation between all actors in all branches of society. (Chapter 4.6)

D.11.2. Supportive and inclusive financial investment is needed for equitable interventions. (Chapter 4.6)

**Recommendations:**

**D.11.3. All sectors of society should increase pressure on governments to provide the resources and regulations needed for a just and equitable transition to a sustainable future. Consistency is key: conflicting standards and policy backtracking delay progress and investment. (Chapter 4.6)**

**D.11.4. All commentators, particularly media organisations, need to be aware of the politics of language and power dynamics in framing their content and key messages. (Chapter 4.6)**

**D.11.5. Researchers and practitioners need to engage with diversity and employ inclusive approaches from the earliest stages of project design. (Chapter 4.6)**

**D.11.6. Public engagement and education on the opportunities, risks and ethical complexities of a just transition must be at the heart of an international climate action plan. (Chapter 4.6)**

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