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# Social tipping points and adaptation limits in the context of systemic risk: Concepts, models and governance

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Physical tipping points have gained a lot of attention in global and climate change research to understand the conditions for system transitions when it comes to the atmosphere and the biosphere. Social tipping points have been framed as mechanisms in socio-environmental systems, where a small change in the underlying elements or behavior of actors triggers a large non-linear response in the social system. With climate change becoming more acute, it is important to know whether and how societies can adapt. While social tipping points related to climate change have been associated with positive or negative outcomes, overstepping adaptation limits has been linked to adverse outcomes where actors' values and objectives are strongly compromised. Currently, the evidence base is limited, and most of the discussion on social tipping points in climate change adaptation and risk research is conceptual or anecdotal. This paper brings together three strands of literature - social tipping points, climate adaptation limits and systemic risks, which so far have been separate. Furthermore, we discuss methods and models used to illustrate the dynamics of social and adaptation tipping points in the context of cascading risks at different scales beyond adaptation limits. We end with suggesting that further evidence is needed to identify tipping points in social systems, which is crucial for developing appropriate governance approaches.

KEYWORDS

**adaptation limits, social tipping points, non-linear change, systemic risk, governance**

## Introduction

Physical tipping points have received a lot of attention in global change research (Brovkin et al., 2021; Wunderling et al., 2021) to explain complex interconnections between earth system components, and their consequences (Kopp et al., 2017; Franzke et al., 2022) but there has been less attention to social tipping points i.e., at which points societies can or cannot adapt to these changes (Bentley et al., 2014; Mechler et al., 2020; Mechler and Deubelli, 2021).

Social tipping points are framed as points in dynamic systems, where a small change in the underlying elements or actors' behavior triggers an abrupt irreversible change in the social system (Milkoreit et al., 2018; van Ginkel et al., 2020), of which outcome may be both negative and positive (Tàbara et al., 2022). Social systems do not adhere to universal rules and laws as natural systems commonly do; people make choices that are prone to behavioral biases, shaped by cultural contexts, change with new information and social influences (Noll et al., 2021) and are diverse (Hochrainer-Stigler et al., 2020a). Past research on social tipping points focused mainly on climate change mitigation (Tàbara et al., 2018; Otto et al., 2020; Smith et al., 2020) or the physical dimension of climate-related shocks (Kopp et al., 2016; Castilla-Rho et al., 2017).

We argue that there is a need to understand the systemic nature of adaptation and consider social tipping as a chain of adaptation tipping points within a social system (see van Ginkel et al., 2020), as well as identify potential abrupt irreversible changes and their triggers ex-ante. The contribution of this perspective is 2-fold. First, we align relevant literature on social tipping points and adaptation limits taking the systemic risk perspective and identify five key dimensions that connect them. We conceptualize adaptation tipping points as associated with soft adaptation limits, where agency can help to absorb risk. Second, we discuss methods that are used to assess social tipping points. Based on two exemplary cases, we consider the governance of systemic risks associated with social tipping points.

## Connecting social tipping points, adaptation limits and systemic risks

We propose a chain of adaptation limits that constitute social tipping points and manifestations of systemic risks, which can be considered as positive or negative (Figure 1). Stresses associated with sudden-and slow-onset climate change events and processes differentially affect natural and social systems with implications for social tipping point behavior. As climate change risks cascade through social systems, their effects on different agents are uncertain and varied, and the realization of risk may lead to soft limits when implemented adaptation will not suffice to buffer against risks or adaptive capacities are missing, while further (transformational) adaptation is currently not available (center of panel, where A denotes a set of adaptation tipping points).

New adaptation practices need to be adopted that go beyond incremental adjustments toward transformational adaptation involving systems change. If alternative adaptation options are not available at all, agents face hard limits or maladaptation. As a result, a wide-ranging systemic change may take place due to a tipping point being crossed. For example, when conventional flood defenses like dikes or beach nourishments face technological (e.g., upscaling of existing technologies is unfeasible), biophysical (e.g., no space to store pumped water that often accompanies dikes) or socioeconomic (e.g., a large seawall is socially unacceptable or unaffordable) limits to sea-level rise adaptation, people may decide to adapt *via ex situ* out-migration to avoid being trapped *in situ* in climate hotspots.

Analytical entry points to characterize social tipping points can be found in systemic risk and complex adaptive systems research. Systemic risks typically feature non-linear cause-effect relationships that often come with tipping points or tipping intervals (Filatova et al., 2016). They rank high in both aleatory and epistemic uncertainty, and often transgress spatial and sectoral boundaries to other systems, sectors and/or geographical regions through cascading effects (Renn et al., 2020). Furthermore, they are often stochastic in their effect structure, with feedbacks that amplify effects of small changes, leading to increased uncertainty that is difficult or impossible to characterize by statistical confidence intervals, and more often socially attenuated than amplified despite their potentially catastrophic impacts (Schweizer and Bovet, 2016; Schweizer et al., 2021).

These characteristics are inherent to complex adaptive systems (Castellani and Gerrits, 2021), among which social systems are especially challenging in terms of identifying tipping points. A social tipping point is a social process that involves drastic changes in both individual and collective behaviors, as well as in institutional settings. The latter can include changes in governance, legal and economic arrangements, as well as long-term effects on social norms and values. Hence, these systems consist of situated, adaptive, and heterogenous agents whose interactions are bound by structures, while simultaneously generating and shaping other structures and social functionalities.

The presence of limits to adaptation has been long recognized (Adger et al., 2009), yet there are few empirical studies addressing this (Ahmed et al., 2018; Mechler et al., 2020; Thomas et al., 2021). An adaptation limit is defined as a point at which an agent can no longer secure valued objectives from intolerable risk through adaptive action (Dow et al., 2013). These points are further divided into biophysical, technological, and socioeconomic limits (Dow et al., 2013).

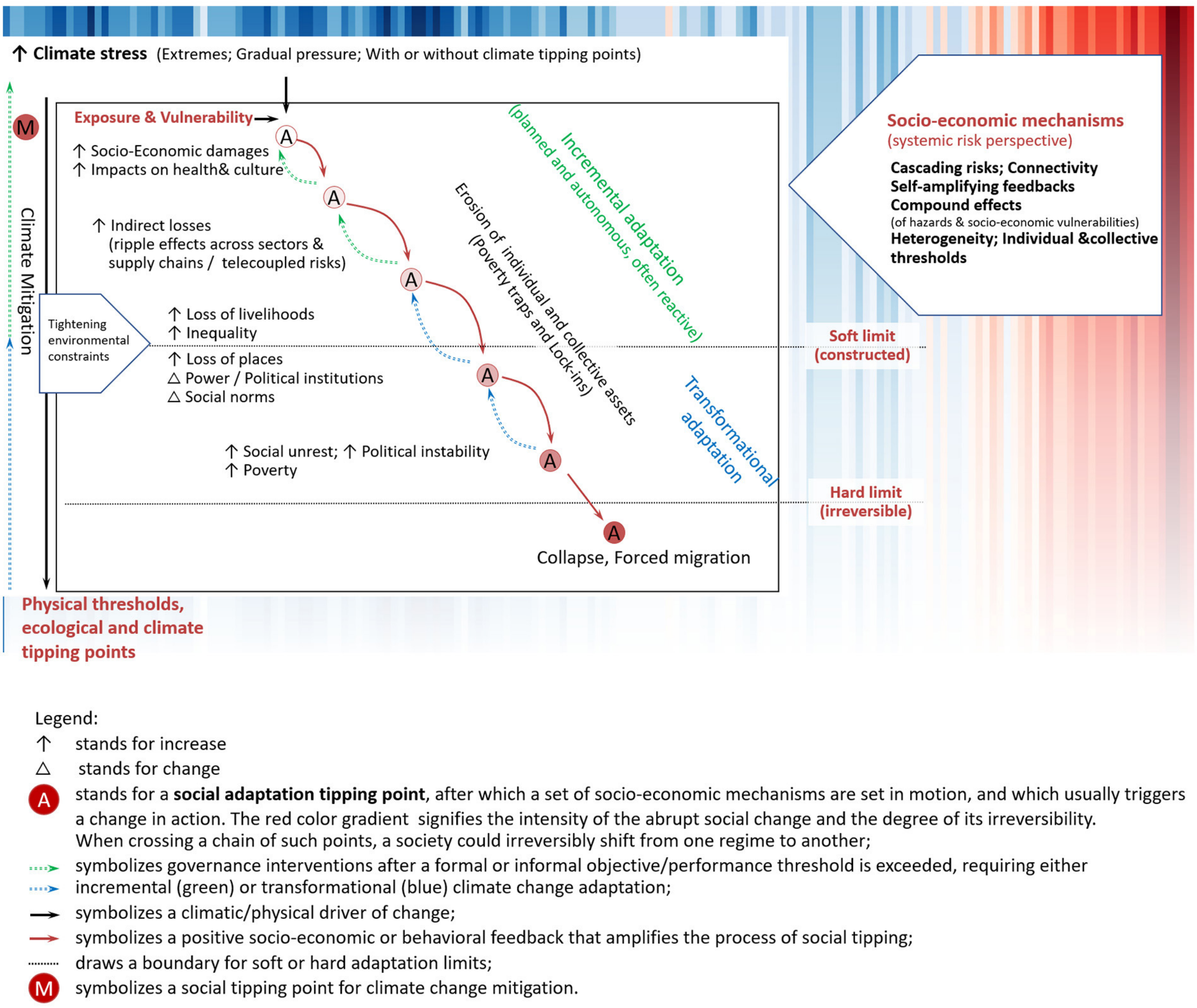


FIGURE 1
Adaptation limits as social tipping points.

The first is considered as hard limits and is associated with the characteristics of socio-environmental systems that cannot be modified by human intervention (McNamara and Jackson, 2019), i.e., physical tipping points. The other two emerge when options are no longer available to adapt at the time, but this may change in the future, i.e., soft limits. Soft limits encompass social institutions, norms, identity, place attachment, worldviews, values, and social support, which place limits on what can be pursued through adaptation (Klein et al., 2015).

Current research lacks an explicit definition of the five key dimensions needed to explore adaptation limits as social tipping points. We propose to identify the following dimensions: *the system under study, the system boundaries, the scales involved, feedbacks within the socio-economic system*, and *agents' responses within the social system*.

## Methods and models to assess social tipping points

As complex adaptive systems (Epstein and Axtell, 1996), social systems consist of contextually situated, adaptive and heterogeneous agents, who by means of interactions give rise to higher-order structures, functionalities, and patterns. Consequently, social tipping points could be analyzed taking the specific properties of such systems explicitly into account. This includes diverse motivations, imperfect information about future climate, learning through experience, social influence, and diffusion of opinions about risks and adaptation practices, and interactions among actors (Hochrainer-Stigler et al., 2020a; Filatova et al. 2016). Contrary to physical systems, people may react differently in identical circumstances, with a broad set of strategies to deal with systemic risks (Page, 2015).

Incorporating social complexities into formal models is non-trivial (Taberna et al., 2020). For example, the Earth System and Integrated Assessment Models (ESMs and IAMs) are key in understanding coupled dynamics of climate and socioeconomic systems on the macro-scale, but they do not include human behavior on the micro-scale (Beckage et al., 2020). They are also criticized for an assumption of representative rational agents with perfect information about the climate-altered future, fixed preferences and lack of social or technological learning, problematic utility or damage functions and simplistic treatment of adaptation (Farmer and Geanakoplos, 2009; Pindyck, 2013; Farmer et al., 2015; Stern, 2016; Stern and Stiglitz, 2021). Furthermore, socio-economic institutions in IAMs are static and non-adaptive, since markets, regulatory, policy and informal institutions remain unchanged, while societies continue to experience previously unprecedented and unanticipated risks. These assumptions are unrealistic and insufficient to understand social tipping points in adaptation.

To do this, models must include a diversity of actors, their motivation, rationale, ability to learn, change in preferences and risk perceptions, all of which are subject to change *via* opinion dynamics, feedbacks in social systems, structural shifts in markets and social norms, and emergence of transformative policies. Reviews of modeling approaches reveal system dynamics and agent-based models are the most suitable, since they explicitly model cross-scale feedbacks and interactions, integrate thresholds and non-linear processes (Filatova et al., 2016). Other complex systems modeling approaches designed to study cascading effects, such as dynamic networks, are also well suited for analyzing systemic risks (Helbing, 2012; Brockmann, 2013). However, important questions related to human agency, such as indetermination, mutual uncertainty and culpability are poorly addressed in dynamic networks (Hochrainer-Stigler et al., 2020a), hence limiting their applicability.

Agent-based models (ABMs) are specifically designed to capture macro-scale phenomena in non-linear systems emerging from social interactions among many heterogeneous adaptive and boundedly-rational learning agents (Filatova et al., 2013). ABMs can identify self-reinforcing chain reactions that could e.g., increase conflicting and antisocial behavior triggering systemic risks (BenDor and Scheffran, 2019), and trace effects of seemingly minor events that provoke major qualitative changes in social systems, such as the Arab Spring (see Section Case examples of adaptation tipping points). With respect to adaptation, a cycle of environmental degradation and intensifying hazards could lead to a new regime of economic decline, possibly causing social unrest, and disruption of political institutions destabilizing affected societies (BenDor and Scheffran, 2019). Worst-case scenarios may exceed adaptive capacities even in the wealthiest countries, as demonstrated by the 2003 heat wave in Europe, or by recent Hurricanes in the United States. ABMs are increasingly applied to study agents' adaptation behavior to various climate hazards, including floods (Yang et al., 2018; Taberna et al., 2020), droughts (Barreteau et al., 2014), wildfires (Spies et al., 2017), and climate-driven migration (Entwisle et al., 2016). Furthermore, ABMs go beyond modeling the behavior of individual actors to capture changes in social institutions in response to climate-driven hazards (Abebe et al., 2019; de Koning and Filatova, 2020).

Social tipping points are shaped not only by human agency but also by cross-scale feedbacks in social systems (Cash et al., 2006). Having an ensemble of models exploring social tipping points enables the quantitative analysis of complex nature, including the existence of multiple entry points for abrupt changes (Hochrainer-Stigler et al., 2020b; Niamir et al., 2020). This could also shift the emphasis from technology-focused and isolated means of analysis to an understanding of the multifaceted nature of such problems, which require governance-related approaches and methodologies.

## Case examples of adaptation tipping points

A focus on the *system boundaries and scales*, *agent characteristics*, *feedbacks in the social system* and the *agents' responses* can be used to illustrate adaptation tipping points with the help of two examples (Table 1).

### Example 1: Systemic risks, tipping points and governance limits in the Arab Spring

In the global supply crises of 2008 and 2011, multiple systemic factors affected world food prices, including high oil prices, weather extremes, land investments, bioenergy demand and speculation on the globalized food markets which resulted in food insecurity, protests, and riots in the Arab World (Arab Spring). The contribution of climate change as a risk multiplier in the Arab Spring has been debated (Werrell and Femia, 2013) as droughts in major wheat producing regions in 2010 and 2011, including China and Eastern European countries, led to export restraints and pressure on the international market price of wheat (Johnstone and Mazo, 2011). In 2010, the Russian Federation, Kazakhstan, and Ukraine (all among the world's top-10 wheat exporters) were affected by severe weather anomalies, such as droughts, heatwaves, wildfires, and air pollution, while the Republic of Moldova was struck by floods and hailstorms, causing significant losses of grain yield (Giulioni et al., 2019).

This affected much of the Middle East and North Africa (MENA), a dry region with little agriculture, and subsequently one of the world's largest food importers and highly vulnerable to market fluctuations (Schilling et al., 2012), and low incomes and sharply rising food prices together affected food security (Sternberg, 2013). This was one of multiple stressors that magnified the political crisis, in addition to the dissatisfaction

TABLE 1 Examples of tipping point cases.

| | System, type of tipping point and shocks | System boundaries, scale | Agency/agent characteristics | Feedbacks in the social system (also cross-scale) | Agent's responses within the social system |
|---|---|---|---|---|---|
| **Example 1** | External drivers such as rising world food market prices and weather extremes affecting grain production contributed to socio-economic conditions and political dissatisfaction with governments that triggered social tipping points leading to the Arab Spring and its multiple consequences. | Climate-related and other compound events overwhelmed adaptive and governance capacities in parts of the Arab World, triggering unrest, regime change, civil war, and migration, moving from local and national to regional and global scales. | Protesters in Arabic countries triggered cascading dynamics of collective group behavior in social networks, where multiplier effects contribute to mass movement. Collective actions attract people, strengthen social networks, and raise media attention, leading to swarming or herding behavior. | Path dependencies and social media enforced feedback mechanisms spreading the movement across the region and to global level, e.g., through cycles of violence in Syria and refugee movements. | Correlation of individual and collective action led to rapid switching between alternative modes of social interaction, from mass demonstrations to repression and breakdown. Stabilization can be based on regional cooperation and multi-level governance in climate mitigation, adaptation, and transformation to sustainable peace. |
| **Example 2** | Coastal livelihoods (south Asia)-adaptation tipping point-soft and adaptation limits | Subsistence based farming villages, some limited state and international assistance essentially climate adaptation/risk governance at community scales | Smallholder villagers largely pursuing incremental livelihood strategies forced at adaptation tipping point to consider transformational adaptation to overcome soft adaptation limits | Aggravating feedbacks pushing system and smallholders beyond adaptation limits *ex situ*, positive transformation would imply significant livelihood diversification *in situ*. | Farming unprofitable/ infeasible forcing households to transform livelihoods or finally relocate to cities for other opportunities |
| | Compound climate-related risks worsening with further global warming demand enhanced adaptation decision-making as effectiveness of incremental adaptation becomes insufficient | | | | |

of the people with autocratic governments and poor levels of democracy, and the lack of well-being, which made actors respond. The unrest started with the self-immolation of Mohamed Bouazizi in Tunisia on December 17, 2010. A seemingly minor event triggered a tipping point, which provoked major qualitative changes and initiated uprisings in the Arab world (Pollack et al., 2011), accelerated by the Internet and social media (Kominek and Scheffran, 2012; Lang and de Sterck, 2012). No protests took place in MENA countries with high per capita incomes because of adequate food security and sufficient adaptive capacities, while political and economic responses in Tunisia, Egypt and Libya were inadequate to contain the movement and regime change (Sternberg, 2013). The Arab Spring and the Syrian civil war (possibly aggravated by a severe drought), together with other developments triggered a cycle of violence and the "refugee crisis" of 2015 when hundreds of thousands of refugees moved from MENA to Europe, demonstrating how overlapping stressors triggered multiple crises that overwhelmed adaptive capacities and stability of several countries (Werz and Hoffman, 2013), an example for tightly coupled hotspots spiraling out of control (Scheffran, 2015, 2016).

### Example 2: Adaptation tipping points and systemic risk forcing deliberate transformation in Tamil Nadu, India

Millions of people in coastal regions in Asia, as well as in Pacific and Caribbean small island states are confronted face with the climate-compounded risks (Allen et al., 2018) while at the same time are also key innovators regarding climate resilient development. Exposed communities are at risk of losing their livelihoods due to sea level rise, salinity, wave run-up, storms and other hazards aggravated by climate change; yet the processes of how such negative transformations may unfold and interact are currently not well understood. A case study explored how smallholder villagers in Tamil Nadu, India, are managing systemic livelihood risk (Mechler et al., 2019). Key drivers are salinisation in the wake of sea level rise and coastal inundation, as well as droughts (as slow-onset types of events) and flooding brought about by cyclonic storms (sudden-onset event) in a region that has been subject to various flood and drought episodes over the recent years (Adelphi GIZ, 2015; Mechler et al., 2019).

The study used risk analysis and impacts chain assessment to trace risks, as well as surveys and participatory engagement with farming and non-farming households and public sector institutions (Mechler et al., 2019). The survey and engagement identified a spectrum of risk management actions and under consideration by farming households to secure their livelihoods, which are largely derived from the cultivation of rice. These include incremental, *in-situ* adjustments to the relevant system (farming), such as a sea dike to contain flooding and freshwater tanks to contain salinity, as well as actions around adaptation tipping points pointing toward deliberate transformational change including the usage of salt-tolerant paddy seeds and setting up ponds elsewhere. Faced with strongly reduced returns from their fields and multiple flood events to recover from, farmers have started to adopt ex-situ responses, including increasing the income share derived from non-farming labor, leaving their lands uncultivated or giving up farming altogether, while some have moved to urban centers attracted by pull factors, such as higher wages and opportunities for schooling.

## Governing tipping points and systemic risk

Our examples illustrate the complexities involved when social tipping points are reached, but the question remains how they can be governed. Despite the unique ability of human agency to adapt, social tipping points pose challenges to established governance arrangements. For systemic risks, especially those combining risk drivers and risk bearers from environmental, societal, and technological domains, a tipping point is an issue for the respective scale of decision-making, from micro to macro scales, which may not always be connected. These governance arrangements must differ significantly from the traditional risk-based, sector-specific approaches.

Systemic risk governance strategies need to address the identification, assessment, management, and communication of risks. The challenges for risk governance are 3-fold. *First*, risk governance should be informed by an in-depth analysis of feedback mechanisms and cascading effects between systems and subsystems by means of formal complex adaptive systems models that elicit structural interdependencies, and emergent behavior caused by system dynamics. *Second*, governance needs to be adaptive toward rapidly shifting societal contexts and demands, as our Example 1 demonstrates. This requires governance to be able to pivot and be anticipatory with regards to early warnings for a cascade of tipping (Figure 1) and target institutional settings, regulatory regimes, actor networks, and social perceptions of risks. Early warning systems can facilitate engagement with stakeholders and the affected public before breaching an adaptation limit. *Third*, stakeholder inclusive approaches can be used for governance arrangements that are problem-oriented and responsive to societal needs (Renn and Schweizer, 2009, 2020; Schweizer and Bovet, 2016).

Social tipping points demonstrate asymmetric trigger-response relationships (Example 1) across the social system (e.g., economic, health, social cohesion), and across scales (household, regional, country to global levels), and governance approaches need to rely on interdisciplinary expertise and transdisciplinary approaches (Schweizer, 2021). For example, the Arab Spring case provides relevant insights to understand the current conflict-related food crisis. To contain the main drivers and their interconnection, such as climate change, globalization and major power interventions, various governance mechanisms can help to strengthen adaptive capacities (Venturi and Dessi, 2021).

As systemic risks are associated with major scientific uncertainties and societal ambiguities with regards to equitable solutions, we propose iterative and transdisciplinary-deliberative approaches that engage stakeholders and can enable adaptive learning. If limits to adaptation cannot be reduced to acceptable levels within current anticipated future pathways, a more fundamental reconsideration of the current approaches are required.

## Concluding remarks

With climate change becoming increasingly acute, it is important to understand non-linear behavior and feedback dynamics associated with social tipping points. We propose five key dimensions to consider connecting social tipping points for the examination of adaptation limits that help to identify the system, its characteristics, and dynamics. We call for further development of modeling and analytical approaches and collection of empirical data for their testing and use. The development of governance approaches can enable the avoidance of reaching dangerous tipping points or drive a system in an undesirable steady state toward a tipping point onto a more favorably trajectory and steady state. Governance to avoid adaptation limits requires an in-depth analysis of feedback mechanisms between the systems, the governance approaches need to be adaptive to early warning signals, and finally, governance arrangements need to be problem-oriented and responsive.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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