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Systemic Risks and Governance of the Global Polycrisis in the Anthropocene: Stability of the Climate-Conflict-Migration-Pandemic Nexus

Jürgen Scheffran*[1]
*juergen.scheffran@uni-hamburg.de, ORCID: 0000-0002-7171-3062
[1] Research Group Climate Change & Security, Institute of Geography, Universität Hamburg, Germany

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Abstract:

Non-technical summary. As human development is colliding with planetary boundaries, the world is facing interconnected crises, disasters and geopolitical conflicts that require and complicate cooperative solutions for navigating the global polycrisis between a collapse of human civilisation and a sustainable transformation of nature-society relationship. When multiple crises are compounding and become "overcritical" beyond tipping points, they may trigger cascading chain reactions that overwhelm efforts to control and contain the dynamics. Understanding the complex dynamic interaction between climate, conflict, migration and pandemic risks offers insights to develop capabilities for effective earth system governance to facilitate a transformation from a negative to a positive nexus.

Technical summary. To assess the complex interplay and stability conditions of multiple risks in the polycrisis, an integrative framework involves interacting changes, sensitivities and pathways in nature-society interaction with natural resources and human security. Results highlight the role of additive compounding and multiplicative cascading events for crisis expansion or containment which can be influenced across thresholds by interventions and governance. The analysis is specified for the climate-conflict-migration-pandemic nexus in which the interactions of climate sensitivity and conflict sensitivity affect internal stability against destabilising external factors. For a risk minimization and containment strategy, desirable is a stable low-risk case compared to unlimited risk escalation, compensated by efforts and investments enabling anticipative governance, adaptive management and cooperative institutional mechanisms, moving from individual to collective action and converting a destabilising vicious circle into a stabilising virtuous circle.

Social media summary. The present polycrisis is unprecedented, increasing the interconnectivity, complexity and intensity of interactions with globalisation, breeding instability, overwhelming adaptation and requiring new anticipative governance and management capacities.

1. Conceptions of the polycrisis and systemic risks

In the Anthropocene humanity is shaping the face of the Earth (Crutzen & Stoermer, 2000; Brauch 2021). The "Great Acceleration" (McNeill & Engelke, 2014) of human development, driven by positive feedbacks of economic growth, debt, and the use for energy and other natural resources, is reaching limits to growth and planetary boundaries, imposing multiple stressors and conflicts over power, territory and resources. Crises and conflicts become disruptive forces that undermine existential living conditions, challenging the Western-dominated world order which started with colonial expansion from Europe and the Industrial Revolution (Scheffran, 2023).

As the world is facing more interconnected crises and disasters, from climate change to the Coronavirus pandemic, nations are entering geopolitical conflicts that preclude cooperative solutions and reduce the freedom for navigating out of the crisis world, implementing the transformation of human-nature relationship, and balancing the available environmental space with an acceptable life for all inhabitants in the common home of Planet Earth. While the need for transition to a sustainable world with efficient use and fair distribution of its natural resources, is more urgent than ever, the capability for effective Earth System Governance is declining, increasing the discrepancy between ambition and reality. When human development collides with planetary boundaries and their counteracting forces, this may have devastating effects on both.

Multiple interacting risks and crises can spread through network structures (Scheffran, 2016), driving the world into a “polycrisis” (Morin & Kern, 1999; Tooze, 2022; Homer-Dixon et al., 2022; Lawrence et al., 2024; Jørgensen et al., 2023). While risk focuses on the likelihood and potential harm of future events affecting individual system parts or components, such as agents and infrastructures, crisis is defined as an ongoing “rupture of normalcy that has fateful consequences and thus requires decisive action”, or as a “sudden (non-linear) event or series of events that significantly harms, in a relatively short period of time, the wellbeing of a large number of people” (Homer-Dixon et al., 2015). A harmful emergency requires urgent response to avoid even greater harm. A global polycrisis has been defined as “the causal entanglement of crises in multiple global systems in ways that significantly degrade humanity's prospects” (Lawrence et al., 2024), which is more than coincidence and connects multiple crises. In the polycrisis cause-effect chains from interactions among multiple crises create systemic complexity and risks through systemic failure and inter-systemic effects (Lawrence et al., 2024) such that limited disruptions can affect entire systems and spread to others. Key properties contribute to polycrisis, such as synergistic interaction of simultaneous multiple causes; non-linearity, multi-stability, disproportionate flipping responses; hysteresis behavior; crossing boundaries across scales and disciplines; or “Black swan” events. Multiple crises can be amplified with increasing intensity, accelerated with higher frequency, and synchronized with events at different locations.

Polycrisis differs from concepts of systemic, catastrophic, and existential risk which may cause complex pathways to potential harm for one or two systems. Systemic risk assessment focuses on “the risk or probability of breakdowns in an entire system”, involving “co-movements (correlations) among most or all parts” (Lawrence et al., 2024). Systemic risks are often complex, transboundary, stochastic, non-linear and show feedbacks that amplify effects of small changes, leading to tipping points, cascading effects and uncertainties (Schweizer et al., 2021). Intra-systemic disruptions can spread from one part of a system to the entire system via contagious cause-effect chains in the system's network, while inter-systemic disruptions spill outside the system boundaries to other systems (Juhola et al., 2022; Schweizer, 2021). One distinction between the risk and crisis concepts is in whether they study the probability of future events (risk studies) or the interaction of presently observed events, possibly extrapolated to the future (crisis studies). Systems and crises can be connected in real events through vectors, such as energy, matter, information and biota (Lawrence et al. 2024).

System dynamics can be represented by system states moving like a ball in a stability landscape, driven by slow-moving *stresses* interacting with fast-moving *trigger* events pushing the system from one stability basin of attraction (disrupting stabilising mechanisms) to another, with a turbulent critical transition (systemic crisis, regime shift) in between. Stresses, triggers and crises can be confined to small spatial, temporal or systemic scales, or interact through inter-systemic pathways and globalised network structures (micro-macro) which are difficult to control.

Integrating climate-conflict and polycrisis research, a main objective of this study is to identify stability conditions of compounding and cascading risk pathways in a framework of polycrisis and systemic risks, assessing the research gap and question how connections between multiple crisis drivers and governance mechanisms influence stability thresholds. In the following, key mechanism and events illustrate the evolving global polycrisis since the end of the Cold War (Section 2), challenging the world order, with the regional case of the Arabic Spring in the Mediterranean region. Section 3 focuses on systemic interactions and governance approaches in the polycrisis. An integrative framework of nature-society interaction in the earth system is developed in Section 4, including sensitivities, pathways and stability conditions, and applied to dynamic multi-risk constellations and governance challenges with a focus on the climate-conflict-migration-pandemic nexus in Section 5.

2. The evolving polycrisis in an interconnected world

While polycrises occurred in earlier times (such as chain of crisis events from the First to the Second World War, the oil crisis of the 1970s connected to the Cold War arms race, related proxy wars and terror attacks in the Middle East, Southern Asia and elsewhere), the present polycrisis is unprecedented, partly because the interconnectivity and intensity of interactions has considerable increased with globalisation. A crucial question is whether growing complexity breeds instability or in the long run contributes to stability, which has been discussed for ecosystems since the 1970s and in the 1980s was expanded to chaos theory, symbolised by the butterfly effect when a system is "on the edge" to disruptive change. Planetary boundaries and other limits to growth impose multiple stressors, including conflict over power, territory and resources, driving the existing world order into multiple complex crises and to the edge of instability and chaos where small causes have big impacts and spread across spatial and temporal scales.

2.1 The end of the Cold War, complex crises landscapes and geopolitical conflicts

A prominent example for deep systemic change was the end of the Cold War, when from early October to late December 1989 the Eastern European political regimes of the Warsaw Pact were falling like in a domino chain, while the Soviet Union was dissolved in 1991. These momentous tipping events became possible due to a shift from hostile to friendly attitudes and perceptions between 1985 and 1989 when Gorbachev's policy of glasnost and perestroika opened new US-Soviet relationships. Simulations by the author shortly before the fall of the Berlin Wall with the VIABLE model showed a turbulent transition from an arms race to disarmament when perceptions changed from worst-case to mutual trust in security-related variables (Bendor & Scheffran, 2019). Threat perceptions further declined after 1989 and nuclear powers reduced their arsenals, even considered abolition of nuclear weapons. At the same time, the United States continued to push for missile defense and military interventions which provoked hostile reaction from Russia, blocking progress in nuclear disarmament in today's new Cold War period.

The "complexity turn" in international relations after 1990 (Urry, 2005) is characterized by multi-scale interactions, among them crises and conflicts in fractal and fragile landscapes at national, subnational and transnational levels, with growing connectivity, number and diversity of agents and overlapping security dimensions that create instability and surprise. Conflicts in the Balkans, in Africa, the Middle East and other parts of the world triggered foreign military interventions. Nuclear and missile proliferation provoked new arms races including outer space and new technologies. New wars and terrorism contributed to cycles of hatred and violence. Since the terror attacks of September 11, 2001 and the financial crisis of 2008, the world has experienced a sequence of crisis events, including the Greek economic crisis and the Arabic Spring, the wars in Iraq, Afghanistan, Libya, Syria, Gaza and Ukraine, geopolitical conflicts between EU and Russia, US and China, the refugee crisis and terrorist attacks, populist and nationalist movements, the British Brexit and Trump presidency (Scheffran, 2017). Environmental disasters, weather extremes and the Coronavirus pandemic came in addition, among others (Figure 1). Such events are not isolated but globally intertwined through compounding connectors and multipliers (Zscheischler et al., 2018). These include energy and economic growth, climate and environmental changes, resource flows and supply chains, financial and commodity markets, mobility and migration, communication and social networks. When the number or density of interconnected events exceeds a threshold and becomes "overcritical", the devastating dynamics runs and spreads by itself like an uncontrolled chain reaction of systemic risks that drive social-ecological systems and infrastructures beyond thresholds of stability if adaptive management and governance capacities are exceeded or disabled, leading to domino effects and cascading crises (Brosig, 2025).

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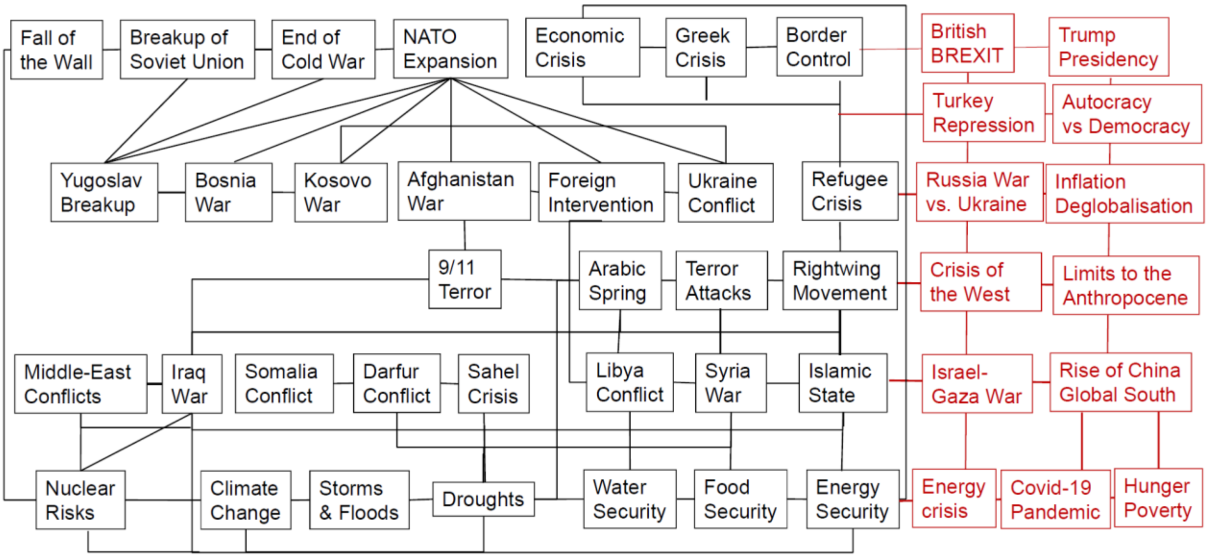

Figure 1. Emerging polycrisis landscape since 1989, connecting events of geopolitical rivalry and globalisation in the upper part with environmental and resource challenges at the bottom and regional conflicts and crises in the middle. Selected linkages between them indicate plausible and relevant connections and relational chains which do not suggest causal or temporal directions, with black events left until 2015, red events after on the right-hand side (modified and updated from Scheffran, 2017).

Failure to contain crises appears as a loss of control for the liberal world order which is under pressure. One possible explanation is that the expansionist development which emerged from Europe since colonial times and generated comparative advantage to other regions, is reaching multiple limits (ecological, economic, social, political). Increasing marginal costs and risks at the boundaries trigger multiple crises, conflicts and disasters (Scheffran, 2023) challenging the globalised world order which is meeting resistance of populist movements, civil society, and other powers in geopolitical struggles (Albert, 2024; Neumann, 2022). Europe is facing challenges in all geographic directions: Putin's Russia in the East, US nationalism and hegemony in the West, destabilisation of the Mediterranean in the South, climate change, resource competition and rivalries in the Arctic North. The U.S. is struggling to maintain its hegemony and forge alliances in the Indo-Pacific (Brands & Gaddis, 2021). The Global South missed the development opportunities of the colonial powers and tries to escape from the spiral of poverty, deprivation, debt, resource exploitation and environmental destruction. Posing an economic, technological and military challenge to the West, China is trying to reshape the international order and expand its global political influence, using the "New Silk Road" to connect East Asia, Europe and Africa. Geopolitical struggles are framing cyber and hybrid war, drone and space warfare, anti-globalisation and energy transition, and environmental and climate change (Zuboff, 2019). Violent conflicts pollute the environment close to ecocide, including CO_2 emissions, destroy the conditions for sustainable peace, distract enormous funds and scarce resources from global problems, and multiply the polycrisis.

In this context, human-environment interactions are associated with tensions, discursive struggles and unequal power relations (Robbins, 2004; Bryant, 1998), critically studied in political ecology which "aims to understand how politics and power influence both social and ecological dynamics" (Büscher et a., 2025). As long as a new stable order is not established, the world remains in an interregnum, as Antonio Gramsci wrote in his Prison Notebooks nearly hundred years ago: "The crisis consists precisely in the fact that the old is dying and the new cannot be born; in this interregnum a great variety of morbid symptoms appear" (English translation cited in: Hoare & Nowell-Smith, 1971; see also Babic, 2020). The morbid symptoms of his time included economic crisis, fascism and war, which today are imminent again, together with climate change, biodiversity loss and other environmental challenges, compounding in a polycrises of Western hegemony, fossil capitalism and the Anthropocene, creating a "climate of complexity" (Rothe, 2015; Scheffran, 2016).

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Analysing the structural roots converging and amplifying in the polycrisis, Albert (2024) suggests an alternative theoretical approach integrating global socioecological relations in a planetary metabolism. In a coevolving landscape of self-organizing systems with competing (counter-) hegemonic projects, crises solutions and possible world futures, frameworks of "planetary systems thinking" are considered as variants of complexity theory, inspired by world-systems theory, ecological Marxism, planetary thinking (Morin & Kern, 1999) and the neo-Gramscian "complex hegemony" approach (Williams, 2020).

2.2. The case of the Arabic Spring and the Mediterranean Region

To demonstrate the complex connections and dynamics of systemic risks in the polycrisis, a specific regional case is discussed. In the Mediterranean region, including Southern Europe as well as Middle East and North Africa (MENA), diverse ecological, socio-economic and political processes are interconnected, including religious movements, violent conflicts, rivalries and military interventions, Arabic Spring, terrorism, forced displacement, and divisions between Global North and South. Major challenges to the Mediterranean are posed by global warming, affecting health, agriculture, forestry and fishery, the water-food-energy nexus, rivers and coastal zones, rural and urban areas. The shrinking resource base undermines living standards and development opportunities, and conflicts with demands of a growing population, economic consumption and irrigation. Climate change contributes to Mediterranean instability, with other vulnerability factors, such as unemployment, poverty, pandemic, economic recession and unstable political regimes. Compared to South Europe, MENA countries are more vulnerable, less able to adapt and mitigate conflict.

In this intricate context, since 2011 a series of protests emerged in the Arab Spring, from Tunisia to Libya, Egypt, Syria and other MENA countries, multiplying dissatisfaction and spreading protest by social media (Scheffran 2017; Juhola et al., 2022). Some studies argued that the political crisis was aggravated by weather events in China and Russia, which affected the international market price of wheat (Sternberg, 2012), together with other drivers of food prices, including oil price, bioenergy use and stock market speculations. This illustrates how in an interconnected world a self-enforcing chain of stressors can trigger international instability and systemic risks, including tipping points (Figure 2).

In the years before the rebellion, Syria suffered devastating droughts hitting the main growing areas, driving people from rural to urban areas (Kelley et al., 2015). This added to multiple conflict drivers, including dissatisfaction with the Assad regime, the US invasion in Iraq, the Arabic Spring and the Islamic State (Selby et al., 2017). While the Syrian civil war became a battleground, millions were driven as refugees into neighboring countries and beyond the region, merging with other migration movements (Figure 2). In the emerging "refugee crisis" reaching the European Union in fall 2015 nationalist and populist movements provoked tensions and authoritarian responses. To govern such events the Mediterranean is lacking effective dialogue and cooperation, e.g. at Euromed, NATO and OSCE levels, despite calls for multilateral climate governance and solar energy development.

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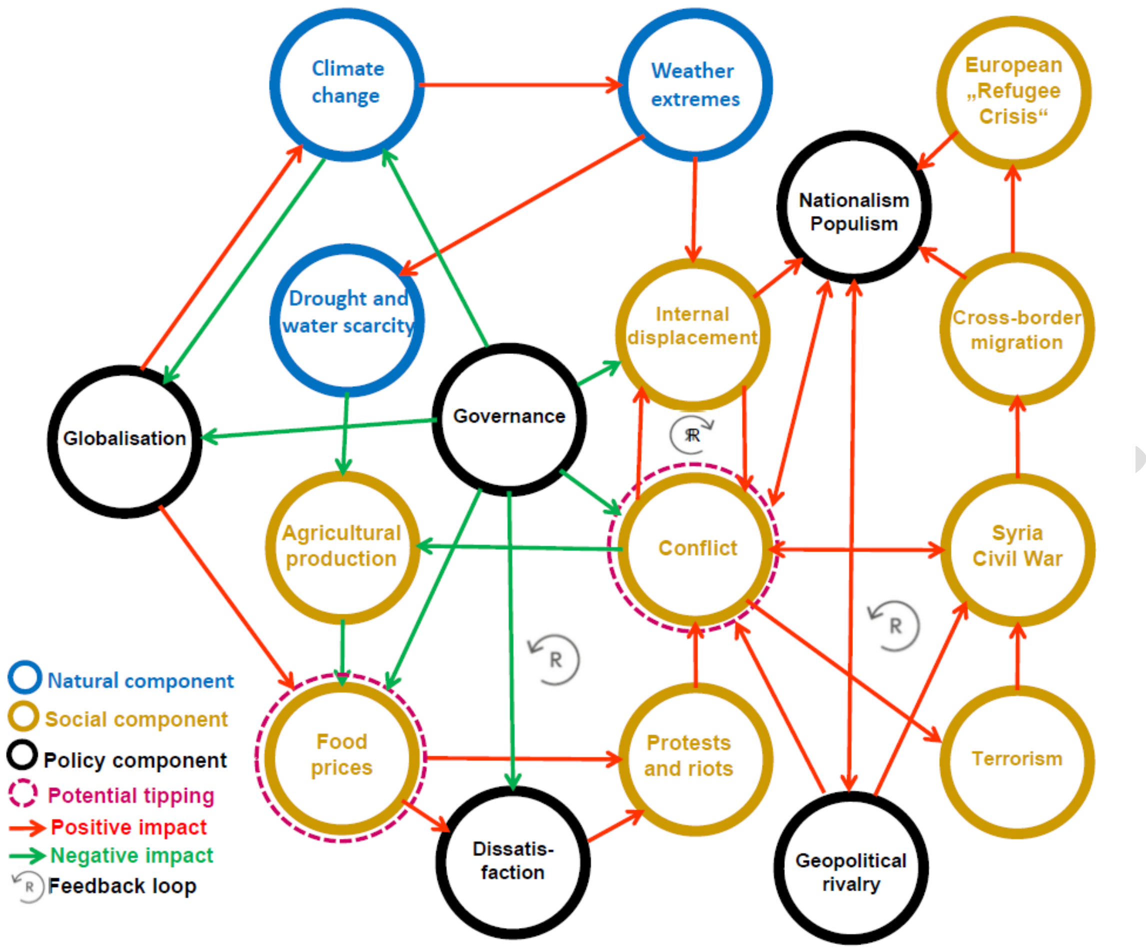

Figure 2. Causal loop diagram of the Arabic Spring and Syrian Civil War, with added policy components in black (Source: Adapted from Lenton et al. 2023: 211, redrawn and revised by author).

3. Systemic interactions and governance in the polycrisis

3.1 The climate-conflict-migration-pandemic nexus

To understand the cascading interactions of systemic risks in the polycrisis, in the following the nexus of climate change, conflict, migration and the Covid-19 pandemic is discussed. Climate change has been described as a risk multiplier for natural resources such as water, food and energy, and critical infrastructures and supply networks for health and wealth, provoking production losses, price increases and financial crises. In fragile regions and hot spots, the nexus of climate-conflict risk can be mutually enforcing with environmental degradation and human insecurity, social and political instability, disease and displacement (Mach et al., 2019; Burrows & Kinney, 2016; Hoffmann et al., 2020). Besides securitising climate policy, "climatising" security policy implies that climate-related practices are introduced into the defense sector, for instance, disaster management, adaptation, mitigation or sustainable development (Aykut & Maertens, 2023). Whether climate stress triggers vicious circles of risk and violence or a positive nexus of governance solutions and synergies in migration, health, peace and climate policies depends on the effectiveness and acceptance of political and legal frameworks (BMZ 2021).

Until today many conflicts are related to the "security dilemma", where threats to the security of one agent provoke reactions threatening security of other agents which contribute to "vicious circles" and "spirals of violence" (Scheffran, Ide & Schilling, 2014; Buhaug & von Uexkull, 2021). For instance, inherently unstable interactions culminated in cascading threats of growing war coalitions before World War 1 (Scheffran, 2016). Today many conflicts have this escalation potential, including the Russia-Ukraine conflict and the Israeli-Palestine conflict, both attracting support from allies. Violence can transform (e.g. from intercommunal conflict to insurgencies or interstate wars) and spread to neighbouring states or regions, e.g. through (cross-border) migration, ethnic links,

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natural resource flows, black markets or arms exports. Societies prone to spirals of violence are in transition or on the edge of instability, such as fragile and failing states with social fragmentation, weak governance and inadequate management capacity, such as Kenya and Sudan (Scheffran, Ide & Schilling, 2014). Once critical thresholds of insecurity and violence have been passed, a self-enforcing spiral of violence perpetuates more violent acts. Similar mechanisms may occur in a self-enforcing cycle of cooperation and peace, once a critical threshold or positive tipping point in the opposite direction has passed (Eker et al., 2024). If not precluded by path-dependence, agents can switch from production to destruction (and vice versa) according to individual or collective actions.

In the Covid-19 pandemic a virus spread through a globally connected world, infecting and killing millions of people in an exponentially growing chain reaction. An alliance of science and politics reacted in disaster mode, multiplied by interactions between media and public. In short time, far reaching decisions were made under high uncertainty, including partial shutdown of society and economy worldwide. The crisis connected and separated all humans, from private lives to global economy, and interacted with the climate-conflict-migration nexus (Figure 3).

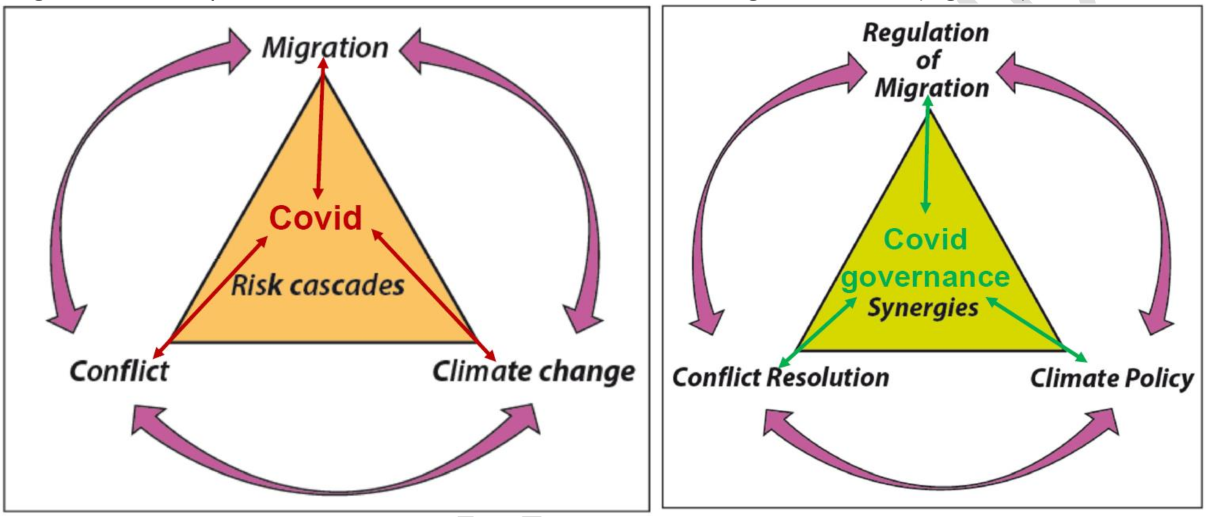

Figure 3. Transformation from the negative to the positive climate-conflict-migration nexus and the interaction with Covid-19 (Source: Adapted and modified from Scheffran, 2023).

3.2 Anticipative and adaptive governance

To address multiple challenges in the climate-conflict-migration-pandemic nexus between collapse and transformation, adequate governance strategies need to maintain stability against complex systemic changes and risks. One approach is to decouple crisis connectors and build synergising connectors. Plausible future pathways consider how stressors, triggers and risks combine with agent perception, anticipation and (inter-)action in critical transitions of crisis patterns and scenarios. To contain vicious circles, opportunities of virtuous circles can induce positive tipping cascades (Lenton et al., 2023). If agents are powerful in capabilities and efficient for action goals, they can withstand, compensate, or counter-act hostility by others, avoiding deviations from stable equilibrium conditions. If the number and intensity of hostile actions exceed critical thresholds, unstable escalation may lead to the breakup of social systems. Stability of social interaction can be maintained if the positive (cooperative) effects of agents exceed their negative (conflicting) effects. Mutual adaptations of actions or institutional control mechanisms can stabilise the interaction and contain conflict.

Humanity can enforce a sustainable transformation, merging solutions and synergies to stabilise human development within available environmental spaces, protecting and preserving the natural resource base. To balance human needs and available natural resources, efficient, sufficient and fair use and distribution of these resources are required.

A key question is whether a transition can be achieved mainly by technical innovations within the existing capitalist economy, catalysed by artificial intelligence to find integrative solutions across different fields of technology, or requires societal innovations and fundamental system change of

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fossil capitalism, replacing its expansive drivers of growth in a sustainable world. Possible futures are shaped by critical thresholds between pathways of disruption and construction, conflict and cooperation, war and peace, risk and resilience, exclusion and coexistence, identity and diversity, trade-offs and synergies. How tensions between different policy fields can be reduced or managed, determines success of social-ecological transformation.

Adaptive, anticipative and cooperative governance and agency of stakeholders, states, networks and institutions use enabling and synergising leverage strategies to contain the polycrisis, establishing conflict-sensitive and resilient climate policies, climate justice and climate matching in North-South cooperation and sustainable energy transition. To integrate innovative concepts in norm-based policies, legal mechanisms and technical solutions involves agents of system change in participatory governance, democratic power distribution, dispute resolution and sustainable peacebuilding. There is an urgent need for effective responses to anticipated, rapid state changes in the Earth system, focused specifically on tipping-point governance (Milkoreit et al., 2024).

4. Integrative framework of climate-society interaction

4.1 Sensitivity to change, pathways and interactions

Expanding the qualitative discussion of the polycrisis, an integrative framework is used to represent the complex interplay of systems, conditions, and actors in the Earth system, including multiple pathways between climate stability *C*, natural resources *N*, human security *H* and societal stability *S* (CNHS) (Scheffran et al., 2012). The linkages are characterised by pairwise sensitivities between variables in each of the four compartments of the Earth system, measuring the change of one variable induced by the change of another variable. Effects may be direct (e.g., change in crop yield in response to temperature change) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise). A prominent example is climate sensitivity, i.e. the global temperature change induced by a doubling of CO_2 concentration in the atmosphere. This narrow definition can be expanded to the sensitivity of climate variables to any other variables of interest, such as sensitivity of climate to natural resources or conflicts. Accordingly, conflict sensitivity could be defined in different ways, for instance how the number of armed conflicts is influenced by global temperature change or precipitation which has been extensively studied with statistical methods, investigated in qualitative field studies, simulated with computer models and estimated in expert assessments (Mach et al. 2019). The same can be done for any other combination of changes in the climate-conflict-migration-pandemic nexus which requires more empirical research beyond this conceptual paper on fundamental structures and processes in the polycrisis.

The following discusses how sensitivities affect instability in a polycrisis, including compound risks, tipping cascades and domino effects. One question is how variable changes proliferate through interconnected pathways, such as movements of resources, people, finance, impacts or market prices, amplifying polycrisis. Models can help to understand these interactions and find governance mechanisms to influence them (Bendor & Scheffran, 2019). The Earth's four subsystems are characterised by general indicators of their viability and interacting changes (Figure 4):

1. *Climate stability C* is based on the objective of the UN Framework Convention on Climate Change (UNFCCC) for "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". Climatic changes *ΔC* concern greenhouse gas (GHG) emission and concentration, temperature, precipitation and weather extremes.
2. *Natural resources N* indicate the quantity and quality of natural systems (soil, water, forests, biodiversity) providing material and energetic services. They are affected by changes *ΔN* negatively (death and loss) or positively (growth and regeneration).
3. *Human security H* protects people from acute threats and facilitates their empowerment and capacity to preserve human life and health, need and well-being, dignity and freedom. Changes *ΔH* impose impacts and responses to stress, depending on human exposure and vulnerability.
4. *Societal stability S* is the ability to maintain basic functions and resilience of societies against

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systemic risks and crises. Changes of societal stability ΔS result from socioeconomic stress, social erosion, tensions and violent conflicts, weakened institutions, and disrupted social networks.

Each input change Δx in a system variable x (cause) may induce an output change $\Delta y'$ (effect) of another variable y in the following period $\Delta y' = y_x \Delta x$. Here y_x is the sensitivity of changes in y with regard to changes in x (cause-effect relation), which can represent a positive ($y_x > 0$) or negative coupling ($y_x < 0$), if not zero. Thus, sensitivities are the connectors (stressors) in the impact chain of the polycrisis while input changes Δx are the triggers, together inducing the output change $\Delta y'$ which may result in a critical transition (crisis) if the new state $y' = y + \Delta y'$ moves outside of or into a new stability basin. Similarly, a change in x can affect its own dynamics (self-impact x_x) which determines whether an increase Δx leads to growth ($x_x > 0$: exponential growth), or to decline ($x_x < 0$: exponential decay).

For a functional relationship $y = f(x)$ between the variables and sufficiently small variable changes, sensitivity can be approximated by the first-order partial derivative of function f with regard to x; for larger changes higher orders could be included which implies that sensitivities are not necessarily constant for non-linear functions. The product of positive or negative signs of sensitivity and causal change determine the sign of output effect. Whether it leaves the stability basin, depends on the magnitude of induced change and the distance to the stability boundary. For three variables x,y,z the sequential coupling is the product of the sensitivities $\Delta z' = z_y \Delta y = z_y y_x \Delta x$ corresponding to a domino effect which is interrupted if one sensitivity is zero.

Estimates of sign and magnitude of the relationships can be presented by impact graphs which provide a framework for the network of connections and changes between the variables. Since each of these systems is characterized by a vector of variables X and Y, the links can be represented by a sensitivity matrix (X_Y) (small letters x represent scalar variables, capital letters X are vectors). Key sensitivities are the stress induced in natural resources by climate change (N_C), the impact of energy and environmental change on human security (H_N), and the societal consequences of changes in human security and economic growth (S_H). The coupling between climate stress and societal stability (S_C) captures direct connections between climate change and society as well as indirect linkages through environmental and human impacts. Other linkages are also relevant, such as couplings between human security and climate change H_C, societal and environmental change S_N, and reverse couplings (impacts on climate stability) C_N, C_S, C_H, and so on. Since there is an internal dynamics within each of these systems, there are also internal couplings of variables denoted by C_C, N_N, H_H, and S_S (Figure 4). A discussion of sensitivities is given in Table 1. In general, signs are uncertain and conditional on past data or future scenarios and may increase or decline beyond a threshold (such as 1.5°C global temperature rise).

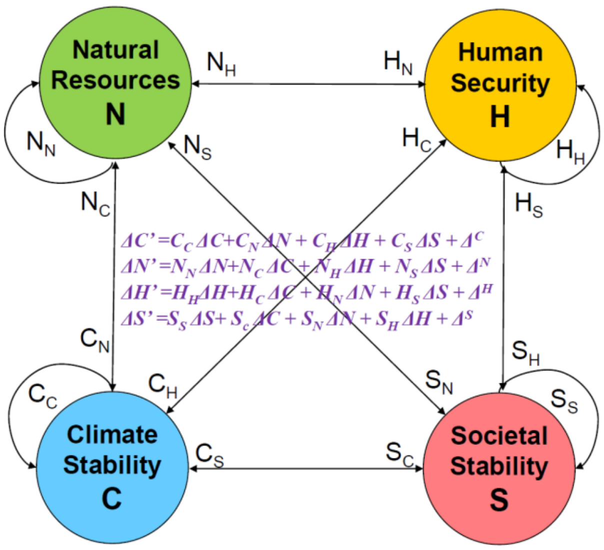

Figure 4: Sensitivities in nature-society interaction and dynamic changes ΔX in a time period inducing changes $\Delta Y'$ in the following period, parallel or sequential (expanding work in Scheffran et al., 2012).

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Cause →Effect	Climate stability ΔC	Natural resources ΔN	Human security ΔH	Societal stability ΔS
Climate stability ΔC	[C_C] A natural removal of carbon from the atmosphere stabilises climate (-), increased carbon emissions can trigger rapid climate change beyond tipping points, both through positive feedbacks (+).	[N_C] To some degree biomass grows better with higher carbon concentration or temperature (-), while climate change reduces productivity and carrying capacity of many natural resources (+).	[H_C] Changing climate negatively affects human wellbeing and security, e.g. through disasters and adverse climatic conditions (+); in some cases benefits are possible (-).	[S_C] Natural disasters and large-scale climate change can weaken societal infrastructures (+) or trigger transformation to the Sustainable Development Goals (SDGs) that ideally stabilise society (-).
Natural resources ΔN	[C_N] Depletion of natural resources can aggravate climate change, e.g. exploiting fossil fuels or biomass loss releasing carbon while climate and resource protection go together (+).	[N_N] Many natural resources grow exponentially (+) or logistically when reaching limits (still +) but may also break down at certain thresholds (-).	[H_N] Since human needs depend on natural resources (+), their decline may lead to a loss of human security.	[S_N] Since various socioeconomic structures depend on the exploitation of natural resources (+), their decline weakens these structures.
Human security ΔH	[C_H] Increase in human security may lead to more emissions or provoke responses such as deforestation that aggravate climate change (-) or support climate policies (+).	[N_H] An increase in human security can lead to an expansion of the exploitation of natural resources (+) or to its decline by support of SDGs (-).	[H_H] Depending on individual responses, a loss in human security can lead to a downward spiral (+) or to countermeasures improving the situation (-).	[S_H] Cooperative and peaceful human security strategies stabilise societies (+), while threats can induce responses for peacebuilding and societal stability (-).
Societal stability ΔS	[C_S] More wealthy and stable societies may increase (-) or reduce emissions (+). Violent conflict and arms race cause additional emissions (+).	[N_S] Development can increase exploitation of natural resources (-) or the sustainable use (+). Conflicts exploit resources and pollute the environment (+).	[H_S] Social instability and conflict undermine human security while more stable societies are better suited to satisfy human needs (+).	[S_S] In a stability range societies tend to self-stabilise (+); beyond the range instability may prevail (-)

Table 1: Typical sensitivities in relationships between causes (vertical) and effects (horizontal) of nature-society interaction (revised and updated from Scheffran et al., 2012)

4.2 Compounding change and cascading chains

The dynamics in the CNHS framework can be represented by a four-dimensional dynamical system of output changes $\Delta y_j'$ in the following period induced by the sum of input changes Δx_j in the previous period plus all other external changes Δ_i^y *(i, j = 1, …, 4).* All changes can combine in a compounding way, either adding in the same positive or negative direction or neutralize each other. Multiple impacts may not only be direct, simultaneous and additive, but also interact in sequential (multiplicative) feedback chains over several time steps, leading to cascading impacts that increase or decay depending on the sign and magnitude of sensitivities.

For instance, temperature increase $\Delta T > 0$ can lead to loss of natural resources $\Delta N' = N_T \Delta T < 0$ for negative sensitivity $N_T < 0$ which can have a negative impact on human security $\Delta H' = H_N \Delta N < 0$ for $H_N > 0$. Human responses to this loss can reduce societal stability $\Delta S' = S_H \Delta H < 0$ for $S_H > 0$. The combined effect of temperature rise ΔT on societal stability along the full pathway $\Delta C \rightarrow \Delta N \rightarrow \Delta H \rightarrow \Delta S$ would be negative $\Delta S' = S_H\ H_N\ N_T\ \Delta T < 0$ (Figure 5). For small sensitivities the product is marginal, indicating minor effects on society (green case in the left graph), but if the sensitivities increase beyond a "tipping threshold", the product can lead to an escalating dynamics (red case in the right graph). If the chain is continued, societal change my induce temperature $\Delta T' = T_S\, S_H\, H_N\, N_T$

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ΔT which is positive for $T_S < 0$ (escalation for $T_S S_H H_N N_T > 1$) and negative for $T_S > 0$ (self-limitation). It is also possible that societal stability is directly affected by climate change via $\Delta C \rightarrow \Delta S$ (e.g. by a disaster or heatwave), and indirectly by pathway $\Delta C \rightarrow \Delta H \rightarrow \Delta S$ and $\Delta S = S_H H_T \Delta T < 0$. Alternatively, a loss of human security may induce counteracting responses that foster collaboration between people to compensate for the loss, in which case societal stability may rather be increased $\Delta S = S_H H_N N_T \Delta T > 0$ for $S_H < 0$, resulting in the opposite effect on temperature $\Delta T < 0$. This shows that adaptive systems are not determined to fail but able to preserve their existence through feedback cycles that maintain stability within viable limits, either by influencing the direction of sensitivities or the direction of change in system variables. Due to non-linear effects, an increase in global temperature above a certain threshold may trigger instabilities, tipping points and cascading sequences that could exceed the adaptive capacity and resilience of natural and social systems (Milkoreit et al., 2018; Lenton et al., 2023).

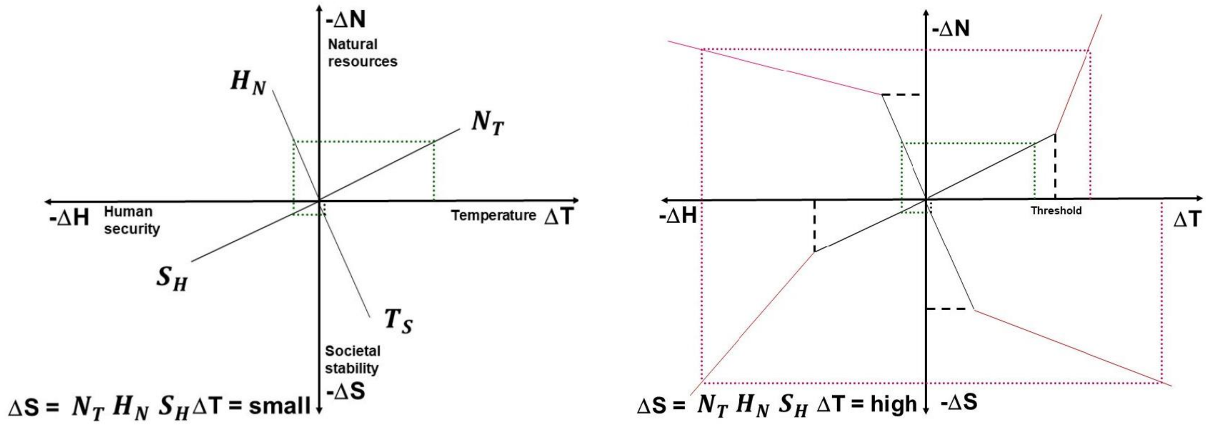

Figure 5. (a) Dampened cascade of moderate temperature rise on chains in the CNHS framework; (b) Escalating tipping cascade beyond critical sensitivity thresholds.

4.3 Stability conditions

System dynamics models are based on equations of the type $\Delta x(t) = F(x,t)$ where $\Delta x = x(t+1) - x(t)$ represents time-discrete change or continuous change $dx(t)/dt$. Equilibria can be calculated by solving $F(x,t) = 0$. Linear systems $F(x) = A\,x$ have constant coefficients in the interaction matrix A or be a linear approximation of the non-linear case where A contains first-order partial derivatives of function F (Jacobi Matrix). Equilibria are stable if all eigenvalues of matrix A have negative real parts, corresponding to exponential decay.[1] For two-dimensional systems, stability is possible for trace $A = (a_{11} + a_{22}) < 0$ and det $A = a_{11} a_{22} - a_{12} a_{21} > 0$, or for trace $A = (a_{11} + a_{22}) > 0$ and det $A = a_{11} a_{22} - a_{12} a_{21} < 0$, thus the product of self-induced sensitivities should compensate the product of external ones. In higher-dimensional dynamical systems the number of eigenvalues increases and thus the likelihood of instability, if the systems were not selected in an evolutionary process that eliminated unstable real-world systems. In the polycrisis stabilising linkages are exceeded by new unstable interactions with positive eigenvalues until new more stable equilibria are evolving adapting to complexity. Instability in one system can induce instability in other system, potentially spreading harmful changes. While tipping is often associated with non-linearity, stability theory can be applied to linearised dynamic systems where positive and negative eigenvalues separate tipping between exponential growth (instability) and exponential decay (stability). Beyond the tipping point the exponential dynamics is often influenced by quadratic (logistic) or other non-linear terms which become relevant when approaching another system state. A well-known example is a chair following

[1] Eigenvalues are solutions of the characteristic equation det $|A - \lambda \mathbf{I}| = 0$ which in the two-dimensional case leads to the quadratic equation $\lambda^2 + p\,\lambda + q = 0$ and solutions $\lambda_{1/2} = -p/2 \pm \mathrm{sqrt}\,((p/2)^2 - q)$ where $p = -(a_{11} + a_{22})$ and $q = a_{11} a_{22} - a_{12} a_{21}$ which for $p < 0$ has at least one unstable positive eigenvalue and for $p>0$ is stable for $q>0$ and unstable for $q<0$. For $n>2$ stability conditions are more difficult to determine, for instance the Hurwitz criteria or the Lyapunov function. Oscillating behavior occurs for $(a_{11}-a_{22})^2 < -4\,a_{12}\,a_{21}$ which is possible for opposite signs of a_{12} and a_{21}.

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gravitational acceleration around the tipping point until it is crashing on the ground in a non-linear way.

5. The nexus of climate, conflict, migration and pandemic

5.1 Multiple risks, equilibria and stability

The described framework of nature-society interactions and sensitivities provide the methodological background for analysing systemic risks in the polycrisis. This can build on system dynamics models, for instance those by Lotka and Volterra on population dynamics and Lewis Fry Richardson on the arms race at the beginning of the 20th century (Gleditsch, 2020).or by Forrester, Meadows and the Club of Rome on the state of the world in the 1970s, based on linear dynamical equations. These approaches were continued in the 1990s with syndromes representing undesirable patterns of the world, including qualitative modeling where the sign of coefficients matters.

In multi-risk environments natural and social systems could reach their limits and capacities of adaptation. This is elaborated for the nexus of climate-conflict-migration-pandemic risks with a focus on Covid-19. In this complex quadrangular relationship (Figure 6) embedded in the larger CNHS framework, individual risks *R* are discussed and pairwise risk interactions, particularly between climate risk R_1 and conflict risk R_2 (Mach et al, 2019; Daoudy, 2021) which are then connected to migration risk R_3 and pandemic risk R_4. Risk is understood as a function of probability and amount of damage, given by proxy variables such as temperature, precipitation and extremes for climate risk, number of conflicts and casualties for conflict risk, displacement numbers for migration risk, and infections for pandemic risk.

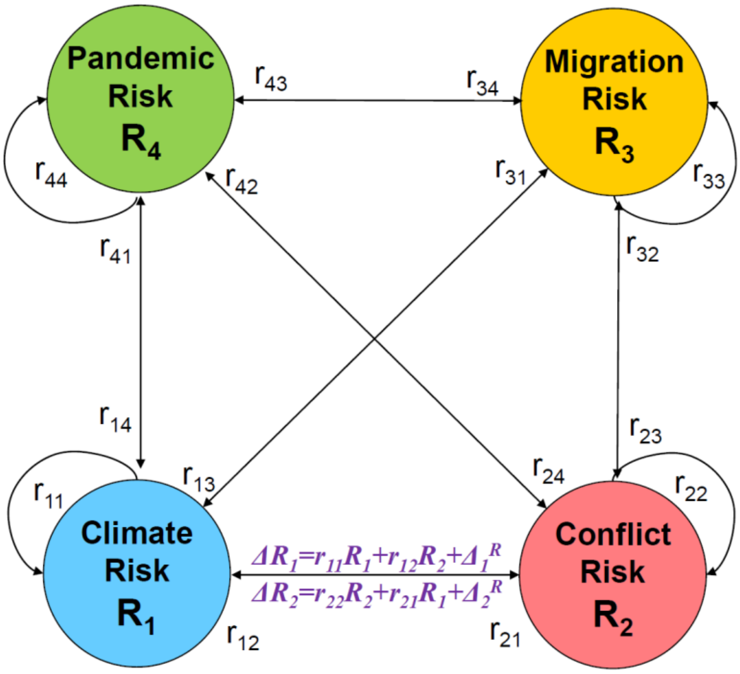

Figure 6. Systemic multi-risk framework of the climate-conflict-migration-pandemic nexus with connecting sensitivities and exemplary pairwise dynamic equations of climate-conflict risk.

Risk $R \geq 0$ is represented by linear dynamics $\Delta R = r\,R + \Delta^R = r\,(R - R^*)$ with equilibrium $R^* = -\Delta^R/r$ where *r* is the growth rate and Δ^R are external drivers of risk change. Four cases are considered in

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Table 2.

	(1) r < 0	**(2) r > 0**
$\Delta^R < 0$ **(a)**	R*<0, stable R > 0: risk moves to R = 0 > R*	R*>0, unstable R<R*: risk decays exponentially to R = 0 R>R*: risk grows exponentially (no upper limit)
$\Delta^R > 0$ **(b)**	R*>0, stable R<R*: risk increases asymptotically to R = R* R>R*: risk decays asymptotically to R = R*	R*<0, unstable R>0: risk grows exponentially (no upper limit)

Table 2. Equilibria and stability conditions in single risk R dynamics for possible combinations of growth rate r and external risk change Δ^R.

From a risk minimization and containment strategy, most desirable is case (1a) of a stable negative equilibrium when risk stays at zero, most undesirable is (2b) when there is no chance to avoid unlimited risk escalation. Mixed case (1b) implies a stable risk equilibrium R = R* > 0 while in (2a) R=R*> 0 is a threshold separating a stable low risk area (R<R*) and an unstable high risk area. Implications for governance in a polycrisis are to avoid positive risk growth rates r > 0 and externally induced risk increase $\Delta^R > 0$. More realistic than a purely linear approach is a non-linear dynamics where growth rate r is multiplied with a logistic term $R\ (R^+ - R)$ such that risk cannot move below lower limit $R=0$ and above upper limit $R=R^+$ while tipping is determined by stability around $R = R^*$. It is important to keep induced risk change as negative as possible and actual risk as low as possible which in a multi-risk world may be increasingly difficult to achieve.

This can be specified for two risk types (climate risk R_l and conflict risk R_2) with the dynamic equations:

$$\Delta R_1 = r_{11}\, R_1 + r_{12}\, R_2 + \Delta_1^R = r_{11}\,(R_1 - R_1^*) \qquad (1)$$

$$\Delta R_2 = r_{22}\, R_2 + r_{21}\, R_1 + \Delta_2^R = r_{22}\,(R_2 - R_2^*)$$

where r_{ii} and r_{ij} are the internal and external risk sensitivities and Δ_i^R includes all other (external) drivers of risk change ΔR_i. (i = 1, 2) The fixed point conditions $\Delta R_i = 0$ lead to the mutual equilibria :

$$R_1^* = (-\Delta_1^R - r_{12}\, R_2) / r_{11} \qquad (2)$$

$$R_2^* = (-\Delta_2^R - r_{21}\, R_1) / r_{22}$$

Both linear curves intersect for the risk balance:

$$R_1^{\#} = (r_{12}\, \Delta_2^R - r_{22}\, \Delta_1^R) / Z \qquad (3)$$

$$R_2^{\#} = (r_{21}\, \Delta_1^R - r_{11}\, \Delta_2^R) / Z$$

where $Z = r_{11}\, r_{22} - r_{12}\, r_{21}$ is the determinant of the sensitivity matrix. Possible interaction dynamics can use the four individual cases as starting points which first of all depend on whether $r_{ii} < 0$ (self stabilising containment of climate change and conflict) or are positive ($r_{ii} > 0$), (self-escalating climate change and conflict beyond a tipping point). If the mutual risk forcings are negative ($r_{ij} < 0$), climate risk and conflict risk can contain each below a risk threshold, if they are positive ($r_{ij} > 0$) they are mutually escalating either with or without limits (climate change is a stressor to conflict and vice versa in a vicious circle). A qualitative change occurs when Z > 0 (self-effects $r_{11}\, r_{22}$ dominate) switches to Z < 0 (mutual-effects $r_{12}\, r_{21}$ dominate) while at $Z=0$ ($r_{11}\, r_{22} = r_{12}\, r_{21}$) equilibria are infinite. For symmetric cases (same sign for r_{ii} and both r_{ij}) and $Z>0$ the possible combinations are shown in Table 3. For Z< 0 the equilibria and stability conditions are reversed. Asymmetric cases in which r_{11} and r_{22} have opposite signs as well as r_{12} and r_{21} correspond to periodic stability conditions which are not explicitly highlighted here.

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(r_{ii}, r_{ij}) (Δ_1^R, Δ_2^R)	(+,+)	(+, -)	(-,+)	(-, -)
(+,+)	(R_l^*, R_2^*)= (-, -) EV (+,+)	(-, -) (+, +)	(+,+) (-, -)	(-+,-+) (-, -)
(+, -)	(-, +) (+,+)	(+-,-+) (+, +)	(-+,+-) (-, -)	(+, -) (-, -)
(-,+)	(+, -) (+,+)	(-+, +-) (+,+)	(+-,-+) (- , -)	(-,+) (-, -)
(-, -)	(+, +) (+,+)	(+, +) (+,+)	(--,--) (-, -)	(+-,+-) (-, -)

Table 3. Equilibria and stability conditions (eigenvalues EV) in interactions between climate risk R_1 and conflict risk R_2 for possible combinations of symmetric cases of r_{ii} and r_{ij} , external risk change Δ_i^R and *Z>0 (i, j = 1,2).*

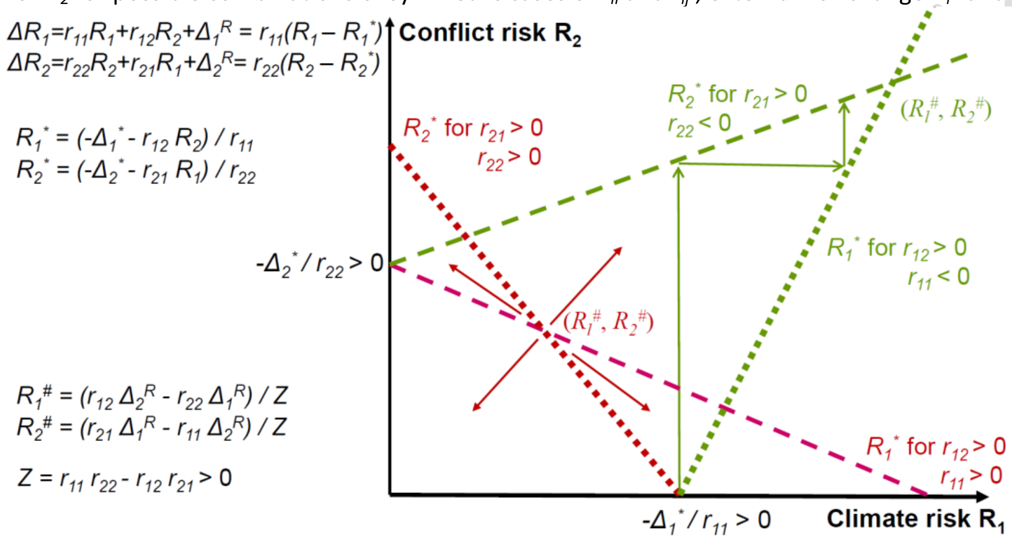

Figure 7: Two selected cases of equilibria and stability are presented: An unstable saddle point (red) and a stable fixed point (green).

5.2 Interactions between climate, conflict, migration and pandemic risks

The following Table 4 provides a qualitative discussion of the interactions between climate, conflict, migration and pandemic risks.

j=1,…,4	**Climate risk change** $\Delta R_1 = r_{11} R_1 + r_{1j} R_j + \Delta_1^R$	**Conflict risk change** $\Delta R_2 = r_{22} R_2 + r_{2j} R_j + \Delta_2^R$	**Migration risk change** $\Delta R_3 = r_{33} R_3 + r_{3j} R_j + \Delta_3^R$	**Pandemic risk change** $\Delta R_4 = r_{44} R_4 + r_{4j} R_j + \Delta_4^R$
Climate risk R_1	Climate self-stabilisation is possible below threshold ($r_{11}<0$), destabilisation beyond tipping points ($r_{11}>0$) escalating climate risk (weather extremes, loss of ecosystems and resources, societal instability). Risk reduction ($\Delta R_1 < 0$) for external risk loss $\Delta_1^R< 0$ below threshold $R_1 < R_1*$ and mechanisms for self-stabilisation ($r_{11}<0$), e.g. vulnerability reduction, adaptation, synergies in water-energy-food nexus, infrastructure	In fragile hot spots, climate risk can multiply conflict drivers ($r_{21}>0$) in vicious circles, e.g. loss of income & livelihood, injustice, human insecurity, political instability. Move from negative to positive climate-conflict nexus of solutions and synergies in governance for risk reduction ($\Delta R_2 < 0$) by reduced sensitivity ($r_{21}<0$) and external risk ($\Delta_2^R<0$), e.g. cooperation in resilience, disaster	Climate risk can drive displacement ($r_{31}>0$) for climate vulnerability and mobility which can be reduced by governance reverting sensitivity ($r_{31}<0$) and external risk reduction ($\Delta_3^R<0$), *e.g.* contained displacement, protection of those exposed to climate risk and vulnerability, better adaptation, integration, less linkages between low development and poverty, oppression and persecution, armed	People in climate-affected regions are more sensitive to Covid infection ($r_{41}>0$) and less protected by countermeasures (social distancing, etc.) and governance mechanisms to strengthen resilience and stability to contain the spread of the virus with medical care such as vaccines ($\Delta_4^R<0$).

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	protection, mitigation & sequestration, energy efficiency, decarbonisation	management, North-South transfer, environmental peacebuilding.	conflict and violence, environmental degradation and resource depletion.	
Conflict risk R_2	Conflict regions tend to be more climate vulnerable ($r_{12}>0$) and have less adaptive capacity, induce climate impact of war, military and arms race, significantly increasing climate risk beyond adaptation limits. Governance can reduce sensitivity ($r_{12}<0$) and build active climate risk reduction ($\Delta_1^R < 0$).	Conflict can escalate ($r_{22}>0$) or reach limits towards stability ($r_{22}<0$). External interventions can feed conflict, e.g. through arms imports ($\Delta_2^R >0$), or contain it ($\Delta_2^R < 0$) via conflict governance and resolution, negotiation and arms control, prevention of physical and structural violence.	Conflict risk can drive displacement ($r_{32}>0$) in fragile regions with high mobility which can be reduced by governance reducing sensitivity ($r_{32}<0$) and external displacement ($\Delta_3^R <0$), e.g. support for conflict-sensitive people and risk reduction, protection or integration, discouraging displacement.	People in conflict may have more interaction and less protection, against pandemic risk ($r_{42}>0$). Governance prevents conflict, contains pandemic risk ($\Delta_3^R<0$) of conflict parties and reduces pandemic sensitivity to conflict risk ($r_{42} < 0$).
Migration risk R_3	Displacement and mobility can escape or diminish climate risk in origins or destinations via migration networks and remittances ($r_{13}<0$) but can expose people to new climate risk ($r_{13}>0$), e.g. in urban or coastal destination areas; or increase climate risk elsewhere by increasing CO_2 emissions & resource depletion or disputes at origin and destination. Migration networks can diminish climate risk in origins, e.g. through remittances ($\Delta_1^R<0$).	Displacement can help escape conflict risk ($r_{23}<0$) but during migration people are exposed to new conflict risk in conflict-prone regions or increase it by resistance along migration pathways, in some cases also support conflict parties ($r_{23}>0$). Governance can reduce conflict and migration risk, support vulnerable people, build integration and peace pathways from local to global levels ($\Delta_2^R<0$).	Self-enforcing migration risk may attract more displacement ($r_{33}>0$) through migration networks which could also be self-limiting ($r_{33}<0$) by unsuccessful migration (deterrence and overcrowding) or successful migration (remittances to home countries). Incentives affect migration as adaptation, improved rights, capacities, livelihoods of affected communities in origins ($\Delta_2^R<0$).	Displacement can expose people to high Covid risk and low protection in virus spread ($r_{43}>0$) along mobility pathways. Active governance provides support through migration networks and protection by vaccination in origins and destinations can diminish pandemic risk ($\Delta_4^R <0$).
Pandemic risk R_4	Some Covid responses (less social interaction and economic production) reduce climate risk ($r_{14} < 0$) by less CO_2 emissions but may also increase climate sensitivity ($r_{14} > 0$), e.g. for those in climate risk hotspots where Covid prevents climate adaptation and protection. Governance can actively trigger external climate risk reduction by better mitigation and adaptation ($\Delta_1^R <0$).	Covid responses could reduce conflict risk ($r_{24}<0$) by less social interactions and cease fire, or induce conflict between Covid causes and responses, humans and nature, North-South, social groups and generations, healthcare and democracy, spread in conflict zones, and bio-warfare ($r_{24}> 0$). Governance can reduce conflict risk (human security, resolution, peacebuilding) ($\Delta_2^R <0$).	Covid risk can increase migration risk (income loss, injustice, hunger, human insecurity, infection of refugee camps, etc.) to the displaced ($r_{34} > 0$) by less social interactions but less likely may also reduce mobility from high to low-Covid areas ($r_{34} < 0$). Governance can actively reduce external migration risk ($\Delta_3^R <0$) and help migrants against Covid.	Covid risk is spreading exponentially through virus infection in global networks, killing millions ($r_{44} > 0$), until significant part of population is immune. Self-stabilsation ($r_{44}<0$) through contact reduction (social distancing, shutdown), active suppression and protection against infection with vaccines. ($\Delta_4^R <0$).

Table 4: Interactions between climate, conflict, migration and pandemic risks, using Covid-19 as an example.

6. Conclusions and Outlook

Over the last two decades multiple crises emerged and combined into a global polycrisis where

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systemic risks are spreading across scales through connectors and feedbacks as crisis multipliers. Natural and social systems are driven towards stability thresholds and tipping points, triggering cacades and domino effects. Anticipative and adaptive governance can enable strategies synergizing sustainable development, human security, conflict transformation and environmental peacebuilding to contain the polycrisis, leveraging a transition from vicious circles in fragile societies and hot spots such as the Mediterranean region to virtuous circles and positive tipping cascades.

To analyse and govern conditions for the global polycrisis, an integrative framework of nature-society interaction is developed, involving interacting changes, sensitivities and pathways between the climate and social system as well as natural resources and human security, with additive and multiplicative combinations across space and time. Plausible conditions for equilibria and stability are explored which show that threshold conditions on the balance of self-induced vs. externally-induced changes significantly matter for crisis expansion or containment which can be influenced across thresholds by internal and external interventions, including stabilising governance mechanisms. The general framework is specified for the climate-conflict-migration-pandemic nexus which assesses the interactions within and between each risk dimension. Results show the limits of maintaining internal stability against a growingly complex world with numerous destabilising external factors, unless compensated by efforts and investments enabling anticipative governance, adaptive management and cooperative institutional mechanisms to convert a destabilising vicious circle into a stabilising virtuous circle. To understand the role of agents in the framework of nature-society interaction it is promising to integrate multi-agent modeling such as the VIABLE model, where agents can use their capabilities and adapt their action priorities to stabilise or destabilise the dynamic interaction, moving from individual to collective action and interaction (Bendor & Scheffran, 2019).

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