https://doi.org/10.5194/egusphere-2023-1459
Preprint. Discussion started: 5 July 2023

Derailment risk: A systems analysis that identifies risks which could derail the sustainability transition

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Abstract. The consequences of Earth system destabilisation will impact societies' ability to tackle the causes of this problem. There are extensive agendas of study and action on the risks from the failure to realise rapid sustainability transitions to date ("physical risk") and the risks resulting from these transitions going forward ("transition risk"). Yet there is no established agenda on the risk *to* sustainability transitions from both physical and transition risks and their knock on consequences. In response, we develop a conceptual socioecological systems model that explores how the escalating consequences of Earth system destabilisation impacts the ability of societies to undertake work on environmental action that re-stabilises natural systems. These consequences can act to spur processes of political, economic, and social change that could accelerate the growth in work done. Conversely, increasingly severe direct and indirect consequences could divert work and political support from environmental action, deepening Earth system destabilisation, thereby increasing the chance of passing a planetary threshold over which human agency to re-stabilise the natural world is severely impaired. We term this 'derailment risk': the risk that the path to re-stabilisation of the Earth system is derailed by interacting biophysical and socioeconomic factors. We use a case study of a climate tipping element - the collapse of the Atlantic Meridional Overturning Circulation (AMOC) - to illustrate this derailment risk. A range of policy responses can identify and mitigate derailment risk, including transformational adaptation. Acting on derailment risk is a critical requirement for deepening Earth system re-stabilisation and avoiding catastrophic outcomes.

1 Introduction

How will the effects of climate change, nature loss, and other environmental change impact our ability to tackle the causes of these problems? There is already a high demand on resources to respond to the growing consequences of Earth system destabilisation, including climate shocks and knock-on crises in food production and health (Pörtner et al., 2022). These consequences are expected to accelerate in a warmer future. In turn, even more attention and resources will be needed in response. Meanwhile, an increasingly turbulent world could impact our ability to coordinate responses to escalating crises and to address the underlying causes, including through disrupting international cooperation (Millward-Hopkins 2022). As such, these issues have profound implications for policy strategies formulated in response to the climate and ecological crisis.

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Policymakers currently consider a range of risks resulting from climate change and other environmental destabilisation. For example, frameworks used by government agencies and central banks to explore the financial and economic risks resulting from climate change identify two central risks (FSOC 2021; TFCD 2021). Firstly, the ‘physical risks’ of climate change, which relate to the physical impacts on societies, such as rising temperatures eroding labour productivity. Secondly, the ‘transition risks’ resulting from action to reduce greenhouse gas emissions, like ‘stranded assets’ such as the loss of investments in coal power plants that must be closed prematurely as fossil fuel use is rapidly curtailed. Scenarios using these risk categories explore how a faster transition to net-zero emissions globally will reduce physical risks while increasing transition risks, and vice versa (NGFS 2022). Policymakers, guided by this influential framework, aim to manage these risks, often quantifiable in terms of costs, by optimising strategies that balance physical and transition risks. With assumptions of economic growth and the technological advancements it facilitates, a global solution to these risks seems attainable, enabling Earth system re-stabilization.

However, there remains a dangerous gap when it comes to assessment of risks to the transition itself. These risks emerge from the deepening consequences of Earth system destabilisation, which might act as a drag on economic growth, deter global cooperation, and cause other effects that frustrate our collective ability to deliver rapid re-stabilisation of the Earth system (Franzke et al., 2022). While a cost optimised transition might exist in theory, its implementation in practice could be slowed by the impacts of climate and ecological change. This points to a third category of risk. Not just the risks from the failure to realise a rapid transition to date (physical risk), nor the risks *from* the transition going forward (transition risk), but the risk *to* the transition from both physical and transition risks and their knock on consequences.

The risks to societies that arise as a consequence of a slower transition and so increasing impacts from climate and ecological change are typically considered as exogenous. These impacts are imposed on societies. The risks that arise as a consequence of the transition are considered as endogenous. These impacts are generated by the transition itself. In order to understand the risks *to* the transition consequently requires a complex interaction of exogenous and endogenous factors. We term this as ‘derailment risk’: the risk that the path to re-stabilisation of the Earth system is derailed by interacting biophysical and socioeconomic factors.

In this article we consider all three risks within a conceptual socioecological model that explores the consequences of Earth system destabilisation. This necessarily requires analysis that involves multiple feedback loops. Our primary focus lies in the possibility that destabilising dynamics operating between biophysical and socioeconomic systems creates reinforcing feedback loops that could rapidly erode the ability of global society to accelerate (or even maintain) the sustainability transition. These feedback loops could impact attempts at emissions reductions, nature restoration, and other Earth system re-stabilisation actions. If the pace of the transition were to fall below critical values, then the risk of activating tipping elements in the Earth system would increase. Activating biophysical tipping points would reinforce this feedback loop, creating a catastrophic dynamic in which a cascade of feedback loops between accelerating Earth System destabilisation and socioeconomic consequences becomes effectively irreversible. We use the example of the collapse of the Atlantic Meridional Overturning Circulation (AMOC) as an example of a climate tipping event that could present severe risk to global transition efforts if it were to occur.

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Conversely, it is also possible that the destabilising dynamics operating between biophysical systems and human societies would create opportunities for acceleration of the transition via rapid socioeconomic change. For example, increased awareness of impending destabilising feedback loops and coordinated policy interventions could initiate the activation of ‘positive’ tipping points, reinforcing feedback loops operating in social, economic, and political systems that could produce a step-change in action to re-stabilise the Earth system (Sharpe and Lenton, 2021). This offers a pathway for stewardship of the Earth system into a ‘safe space’ for humanity over the coming decades (Rockström et al., 2023). Anticipating and managing risks to the transition - derailment risk - is therefore of paramount importance.

2 Derailment risk

To conceptualise the process of transition to a safe space for humanity, we can use the physical concept of work within a socioecological systems model, which is illustrated in figure 1. By the end of the 20th century human energy use had reached a magnitude comparable to the biosphere (Lenton et al., 2016). The vast majority of the energy provided to power this work has been provided by fossil fuels. The burning of coal, oil, and gas since the industrial revolution has released 1.5 trillion tons of carbon dioxide into the atmosphere, while to date humans have affected three quarters of the Earth’s total land surface (Arneth et al 2019). The net result of this prodigious energy and material consumption is dangerous interference in the Earth system (Rockström et al., 2023). The planetary boundaries framework identifies climate change, biodiversity loss, and biogeochemical cycle disruption as the most at risk of nine Earth system functions (Steffen et al., 2015).

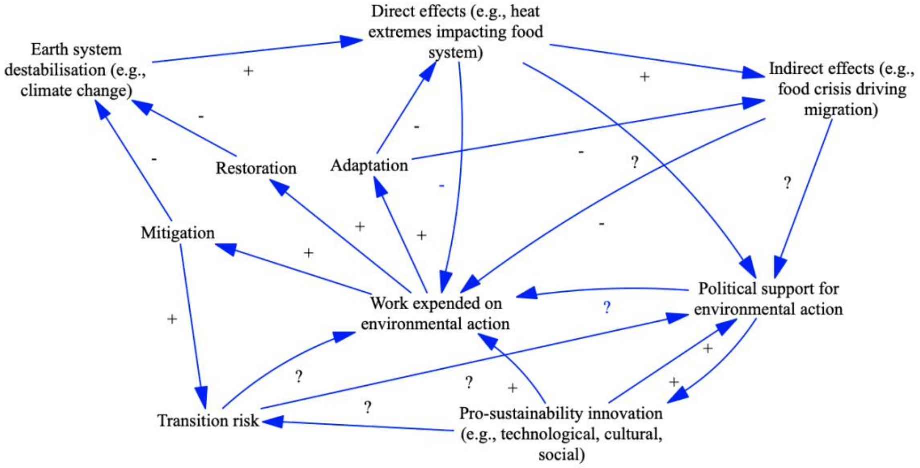

Figure 1: Illustration of derailment risk using the feedback mechanisms between the work done by societies to re-stabilise the Earth system and how these are impacted by the direct and indirect effects of Earth system destabilisation. Positive polarities - where two variables move in the same direction - are illustrated with a + sign. Negative polarities - where two variables move in the opposite direction - are illustrated with a - sign. Ambiguous polarities are illustrated with a question mark.

As figure 1 shows, we consider that societies seek to address Earth system destabilisation and its consequences through three broad categories of work. Firstly, mitigation of environmental harms, including rapidly reducing greenhouse gas emissions and halting biodiversity loss. Secondly, adaptation to the inevitable consequences of current and future Earth system destabilisation. Thirdly, the restoration of the biosphere through repairing harms to nature and reducing atmospheric concentrations of carbon dioxide. Together, these three areas of work - mitigation, adaptation, and restoration - constitute the process of an overall sustainability transition whereby societies seek the progressive re-stabilisation of the Earth system.

Restoration is often assumed within mitigation. For example, the UNFCCC recognises the role ecosystems such as forests have in sequestering carbon dioxide (UNFCCC, 2023). We have separated out mitigation and restoration in our analysis in recognition of the sheer scale of restoration needed to re-stabilise Earth system elements. For example, policy trajectories for climate action assume a large and increasing burden of carbon dioxide removal from the atmosphere, which will require younger and future generations to undertake significant work to meet (Hansen et al., 2017). This will need to be done at the same time as meeting all other mitigation and adaptation requirements. There will be limits to the amount of work that current and future generations will be able to commit to the transition. In figure 1, we identify a total amount of work available for mitigation, adaptation, and restoration - ‘work expended on environmental action’. This is mediated in four ways.

2.1 Interactions that affect the work expended on environmental action

Firstly, we assume that the direct and indirect consequences of Earth system destabilisation will affect the amount of work available. For example, direct effects such as periods of extreme heat and humidity will reduce the amount of work available to be expended on environmental action by eroding labour productivity (Dasgupta et al., 2021). Indirect effects that encompass the socioeconomic consequences of environmental change can also decrease the work available for environmental action. For example, prolonged periods of extreme heat can lead to food production losses (Zhao et al., 2017). The socioeconomic impacts can include poverty and increased migration, which in turn cause economic disruption and political destabilisation (Chatham House, 2021). Such effects can be transmitted around the world through globalised socioeconomic systems. These destabilising dynamics interact with and exacerbate existing social, economic, and political challenges (Keys et al., 2019). In this way, we can see how the initial direct impacts of environmental change can produce reinforcing feedback loops that serve to draw finite resources away from working directly on responding to the climate and ecological crisis. Work done to adapt societies to direct and indirect impacts should lead to more resilience in societies’ abilities to continue to work on the sustainability transition.

Secondly, we assume that direct and indirect effects of Earth system destabilisation will affect political support for environmental action. In our model, political support is one of the major determinants of the work available for environmental action. This support or ‘political will’ is the result of the complex dynamics inherent in political, social, and economic systems. Varying political support will result in changes over a wide range of scales: from simple regulatory policies to deeper shifts in mindsets and paradigms in policymaking, all of which can unlock greater or lesser work on mitigation, adaptation, and restoration (Chan et al., 2020). The direct and indirect effects of Earth system destabilisation could erode political support for environmental action. For example, one response to significant environmental change can be increased migration. This can increase socioeconomic inequality and conflict risk, factors that are known to drive authoritarian nationalism, which could, in turn, increase barriers to cooperative mitigation (Millward-Hopkins, 2022). Conversely, worsening direct effects, such as extreme weather events, could increase political will to act by serving as 'focusing events' for policy making, increasing awareness of the threat and spurring greater political activism that manifests in policy change for environmental action (Baccini and Leemann, 2021; Groff, 2021). The net effect of these connections is ambiguous, as represented by a question mark in figure 1.

The third way that the work available to act on the transition varies arises from the innovations that support sustainability objectives. These partly occur as a consequence of development and innovation in economies, where penetration of technologies is accelerated by interactions between research and development, learning by doing, economies of scale, and the spread of new social norms, all of which progressively reduce costs and increase acceptability (Smith, Stirling and Berkhout, 2005). This innovation is partly mediated by developments in politics and policymaking. For example, tax, subsidy, and regulation policies have been used in some countries to make electric vehicles cheaper and increase uptake (Sharpe and Lenton, 2021). In turn, these policy approaches can trigger 'positive' tipping points whereby new technologies, societal norms, mindsets, and other innovations can rapidly out-compete incumbents (University of Exeter et al., 2023). Crossing such a tipping point creates reinforcing feedback loops that accelerate uptake of the new approach or technology and that weaken resistance to change and support for incumbents. In the case of electric vehicles, reaching cost parity without tax or subsidy support can trigger reinforcing feedbacks of increasing returns to scale, with costs falling as production rises, increasing consumer demand for cheaper alternatives, which also increase manufacturing and investment (Sharpe and Lenton, 2021). Such feedback mechanisms and the potential for positive tipping points exist across technological and energy systems, political mobilisation, financial markets, and sociocultural norms and behaviours, among other areas (Winkelmann et al., 2022). Consequently, the rate of change of the transition may be surprisingly large as it exceeds the expected capacity of social, economic, and political to undergo transformations.

Fourthly, the amount of work available for mitigation, adaptation, and restoration can be impacted by the effects of the transition itself. This is typically called transition risk in the context of risks to economic performance as a consequence of pro-environment policies and action. We interpret transition risks as dynamics that can directly act to either increase or decrease the work available for further environmental action. For example, rapid changes in climate policy provide opportunities for renewable energy incumbents, reinforcing mitigation action (Mealy and Teytelboym, 2022). But this rapid action could also have the effect of disrupting financial stability, leading to credit rationing and falls in confidence and consumption (Semieniuk et al., 2020). The spillover impacts could generally curtail investment, including in mitigation action. The impact of transition risk on work available for environmental action can also be indirect through its impact on political will. For example, acceptance of transitions in energy systems is related to perceptions of distributive and procedural justice (Evensen et al., 2018). Changes resulting from mitigation action that are perceived as unjust might curtail support, slowing the pace of decarbonisation. Conversely, greater understanding and experience of the co-benefits of environmental action can reinforce support for further action (Cohen et al., 2021). Pro-sustainability

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innovation has an impact on transition risk, such as when changing behavioural norms in wider impact reputational risk for a given firm, economic activity, or sector. The overall impact of transition risks and their interaction with innovation are ambiguous and are therefore illustrated with a question mark in figure 1.

2.2 Derailment risk grows when work done is not sufficiently increasing

The dynamics in figure 1 can be used to explore the overall impact on Earth re-stabilisation of its destabilising consequences and how these affect the transition. We can identify two broad, opposing scenarios. In the first the reaction to the direct and indirect consequences of Earth system destabilisation act to increase work expended on environmental action and reinforce political support (and so all respective connections are positive polarities in figure 1). This is partly driven by higher levels of adaptation. Transition risks have a net effect of increasing opportunities for environmental action. Pro-sustainability innovation and political support create a reinforcing feedback of societal and economic change that accelerates the transition. In reference to the framework of Steffen et al. 2018, this scenario sees cascading and reinforcing positive tipping points that enable societies to achieve Earth system stewardship sufficient to avoid crossing a planetary threshold of cascading biophysical feedbacks and tipping points (Steffen et al, 2018; Lenton et al., 2022).

The second scenario is one in which the reaction to the direct and indirect consequences of Earth system destabilisation limit or even reduce the amount of work done. Adaptation is insufficient to protect socioeconomic systems from escalating impacts, which sap ever greater attention and resources from environmental action, and cause wider destabilisation that erodes political support. Transition risks, such as financial instability from rapid mitigation responses impacting investment decisions, have a net effect of further eroding work done. This is ‘derailment risk’ in full effect: an overall feedback loop is created in which the destabilising ‘symptoms’ of Earth system destabilisation increasingly erode work done on tackling root causes (IPPR, 2023). Crucially, derailment risk occurs if work done is not accelerating - as well as if it is declining - as ever greater amounts of work are needed to re-stabilise the Earth system from the current low baseline. In this scenario, growing Earth system feedback loops will exacerbate derailment risk by the direct and indirect impacts of climate and ecological change more severe. For example, climate feedbacks - such as forest dieback, wildfires, and permafrost thaw - can increase warming due to greenhouse gas emissions, requiring more work to be done on Earth system re-stabilisation (Ripple et al., 2023). In this way, we can see derailment risk as representing a set of socioeconomic feedbacks that interact with a set of intrinsic biophysical feedbacks identified in Steffen et al., 2018 that could push the Earth system over a planetary threshold beyond which spiralling requirements on work are needed to arrest an accelerating descent into a catastrophic ‘Hothouse Earth’ state.

3 Case study: AMOC collapse

To illustrate our theoretical framework, we explore a stylised scenario in which the activation of a climate tipping element - the collapse of the Atlantic Meridional Overturning Circulation (AMOC) - impacts work expended on environmental action, creating significant derailment risk. This scenario is illustrated in figure 2. The AMOC is an oceanic current system in the Atlantic Ocean driven by temperature and salinity differences that brings heat from the southern hemisphere to northern latitudes. It is an important component of the regional and global climate system.

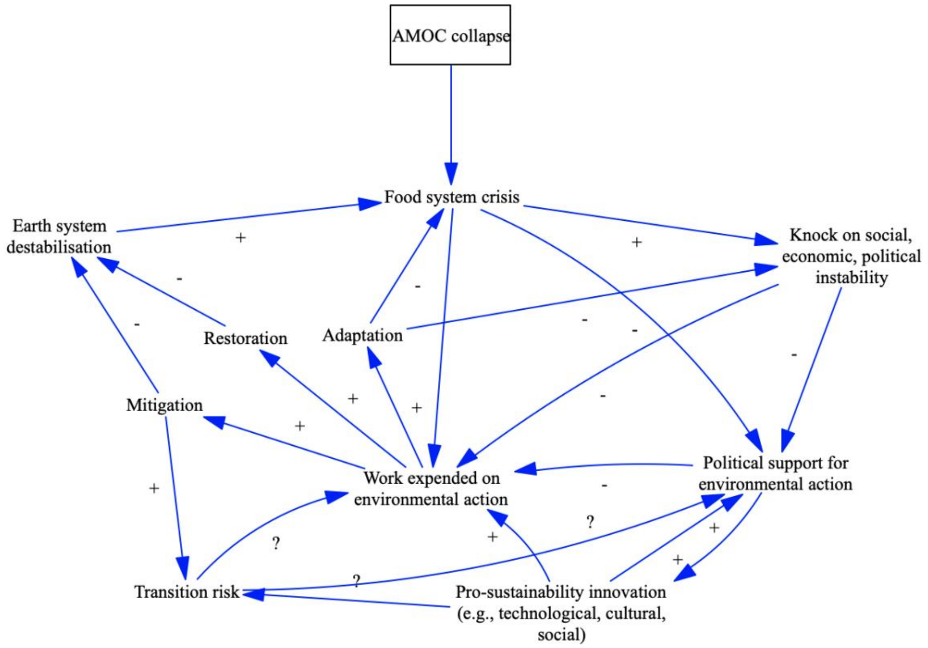

Figure 2: Illustration of derailment risk affecting work expended on tackling climate change resulting from the stylised scenario of the collapse of the Atlantic Meridional Overturning Circulation (AMOC).

Collapse of the AMOC is an example of a subsystem of the Earth's climate system (called "tipping elements") that could pass a tipping point this century as a result of climate change (Armstrong McKay et al., 2022). Tipping points are, according to the IPCC, irreversible levels of "change in system properties beyond which a system reorganises, often in a non-linear manner, and does not return to the initial state even if the drivers of the change are abated. For the climate system, the term refers to a critical threshold at which global or regional climate changes from one stable state to another stable state" (Babiker et al., 2018). Other examples include shrinkage of ice sheets, dieback of the Amazon rainforest, and disruption of monsoon systems (Armstrong McKay et al,. 2022).

The IPCC has concluded that there is only "medium confidence that the Atlantic Meridional Overturning Circulation (AMOC) will not experience an abrupt collapse before 2100" and that the probability increases with higher global warming levels (Arias et al., 2021). If it were to occur, AMOC collapse "would very likely cause abrupt shifts in regional weather patterns and water cycle" (ibid). The effects of these shifts are explored in OECD, 2021, which considers the possibility of AMOC collapse without underlying warming and at 2.5°C above the pre-industrial level as a significant risk befitting an assessment.

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The induced shift in climatic conditions of an AMOC collapse in either scenario would have profound impacts on agriculture across the world, posing a critical threat to food security globally (OECD, 2022). An AMOC collapse occurring alongside warming would substantially reduce the growing suitability of three major staple crops - wheat, maize, and rise - which provide the majority of global calories (OECD, 2021). Without underlying warming, nearly a quarter of the current area for wheat is lost, 16% for maize, with a smaller change for rice. With 2.5°C of warming, approximately half of the remaining suitable land for wheat and for maize is lost, while there is a small increase in suitable area for rice. As the authors concluded, "AMOC collapse would clearly pose a critical challenge to food security. Such a collapse combined with climate change would have a catastrophic impact" (ibid). These effects mainly impact the northern hemisphere and Europe especially, where the current effect of the AMOC renders the region wetter and warmer than would be the case if the AMOC were to collapse. In our stylised scenario, we posit that the food system crisis caused by AMOC collapse (in either scenario) acts to erode environmental action by directly redirecting work into emergency response to protect populations from food insecurity and handle wider destabilising consequences. This also occurs indirectly as political support for environmental action is crowded out by the imperative of emergency response.

Additional effects of AMOC collapse include disruptions to monsoon systems, reducing the "suitability" of parts of the world for human habitation (the 'human climate niche', as described by Xu et al., 2020, and destruction of boreal forests, which constitutes a cascading impact on other parts of the climate system (OECD, 2021). These along with the severe impacts on food security would have considerable and far-ranging indirect consequences, including on economic, social, and political stability (OECD, 2022). In our stylised scenario, we posit that the net effect of these indirect consequences decreases work available for environmental action by crowding out political attention. While the reinforcing feedback loops between pro-sustainability innovations and political support continue, their effect is insufficient to compensate for the direct and indirect reductions of work done on mitigation, adaptation, and restoration. This pushes the world into a state of growing derailment risk. The resultant reduction in work expended on Earth system re-stabilisation combined with the impact on biophysical feedbacks from AMOC collapse would cause escalating direct and indirect effects, further exacerbating derailment risk. We posit that this dynamic would make it progressively more difficult to rally political support and expend the work needed to establish a trajectory to Earth system re-stabilisation. Instead, interacting socioeconomic and biophysical feedbacks would create a cascade of direct and indirect impacts. One end point for such reinforcing feedback would be continued warming of the climate putting the Earth on a course towards a "hothouse" state.

4. Implications for policy strategies

Five 'Shared Socioeconomic Pathways' (SSPs) now serve as the main scenarios exploring interactions between human societies and the natural environment over the 21st century (O'Neill et al., 2017). As a result, they are a major guide to policy responses. The SSPs consider projected global socioeconomic changes up to 2100 - including population, urbanisation, and GDP - and the subsequent challenges to mitigation and adaptation, enabling an integrated analysis of many factors determining climate action (Riahi et al., 2017). (There are no SSPs that consider Earth system destabilisation in the round). For example, SSP1 ("Sustainability: Taking the green road") sees rapid technological change, more globally equal development, and a greater focus on

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environmental sustainability, all resulting in low challenges to mitigation and adaptation. In contrast, SSP4 ("Inequality: A road divided") has low challenges to mitigation resulting from high but unequally distributed technological development and large challenges to adaptation due to inequality and persistent poverty in some parts of the world.

However, the SSPs do not directly consider the connection between the consequences of Earth system destabilisation and work available for re-stabilisation. A major consequence of our model of derailment risk is that this omission could be a dangerous blind spot in how the SSPs are guiding policymaking on re-stabilisation. It cannot be assumed that collective work on the Earth system - and societies' ability to muster growing amounts of work - will inevitably grow, both directly, through more technological capacity and resources, and indirectly through more political will. This is the case whether or not it is assumed that continued growth in material production and consumption is compatible with planetary boundaries. Overall, the work done to re-stabilise the Earth system in order to avoid passing a planetary threshold will be impacted by a more complex set of feedbacks than are considered in the SSPs. A failure to capture these feedbacks can lead to a significant underestimation of the societal risks of Earth system destabilisation and a misinterpretation of the collective ability to restabilise and the simultaneous ability to effectively manage the consequences of destabilisation.

It is imperative that these feedbacks are acted on. Our model is an attempt to identify areas for the mitigation of derailment risk. These correspond to the connections on the systems diagrams in figures 1 and 2. A primary means to respond to derailment risk is to increase work done on Earth system re-stabilisation to attenuate conditions from which the risk arises. This can be driven by greater political support for action and the interaction between innovations in, say, social and political movements which can drive this support, or using policies that target rapid changes in the rollout of clean technologies and behaviours (Winkelmann et al., 2022). A large range of these positive tipping points have now been identified (Sharpe and Lenton 2021; Systemiq, 2021; Systemiq, 2023).

However, the processes by which these positive tipping points can occur will have to be made robust to derailment risk. For example, the severe impacts on food security considered in the AMOC case study could create chaotic conditions that crowd out political support for policies that drive positive tipping points. In response, the processes by which positive tipping points are triggered should be made more robust in withstanding the direct and indirect impacts of Earth system destabilisation. This can be done directly through adaptation that reduces the effects of these impacts on work available for environmental action. It can also occur indirectly, by ensuring the drivers of political support for environmental action and that drive innovations that trigger positive tipping points are made more resilient. In this regard, we should see adaptation as an enabler of mitigation under conditions of deepening Earth system destabilisation: the sustainability transition itself needs to be made more resilient. In this way, derailment risk bolsters the case for "transformational adaptation". This is adaptation that fundamentally changes the characteristics of human and natural systems so that their capacity to cope with hazards is increased (IPCC 2022). This is in distinction to "incremental adaptation", which refers to adaptations to specific system components to protect against given climate risks, such as modifying infrastructure to handle sea level rise (Kates, Travis and Wilbanks, 2012). Because of the connection between direct and indirect consequences of Earth system destabilisation and political support, concepts of resilience in this regard need to extend to concepts of justice, fairness, trust, and participation, all of which are factors

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impacting acceptance of the transition (Gölz and Wedderhoff, 2018; Mundaca et al., 2018; Evensen et al., 2018), ensuring political support is maintained and deepened even as incentives for protectionism and competition might grow. Resilience also extends to psychological and emotional factors. Studies of anxiety over climate change report that these feelings have negatively impacted day-to-day functioning and that anxiety and distress are correlated with perceptions of inadequacy and betrayal on the part of governments and leaders (Hinkman et al., 2021). Being wise to the emotional and psychological consequences of escalating impacts is an important factor affecting perceptions and action (Brosch, 2021).

5. Conclusion

There is now a considerable and growing body of research that explores the risks to societies that arise from Earth system destabilisation, and the transition risks that result from re-stabilisation actions. However, there is limited exploration of how the effects of Earth system destabilisation will present challenges to societies' ability to undertake the work necessary to re-stabilise natural systems. This is a dangerous gap. In this paper we introduced a conceptual socioecological systems model that explores this area and applied it to a scenario of the activation of a climate tipping element. This serves as a case study in which the escalating consequences of the collapse divert work and political support away from environmental action, thus amplifying Earth system destabilisation. This further increases the chance of passing a planetary threshold over which human agency to re-stabilisation the natural world is severely impaired. We present this scenario as an example of the risk that the sustainability transition could be increasingly derailed by the worsening impacts of climate and ecological change, which we call derailment risk.

Our model provides a simple mapping of the dynamics of this risk by identifying potential feedback loops. Further work in this area is urgently needed. This should build on emerging methods for understanding and mapping cascading and systemic risks within socioeconomic systems resulting from Earth system destabilisation (UNDRR, 2021) and similar areas of study and early warning systems for feedbacks and non-linear dynamics in the Earth system, including tipping points (Bury et al., 2021). Mapping of derailment risk should pay particular attention to concepts of fairness and equality, which are currently assumed within the political dynamics within our simple model, but are crucial factors determining cooperation on environmental action.

Our analysis leads us to conclude that it is essential that sustainability transition policies are made more resilient to potentially large-scale turbulence in biophysical and socioeconomic systems. Optimal strategies are not necessarily the most resilient. Failure to provide sufficient work for the sustainability transition risks its complete derailment. This would be an outcome that could tip societies into a much more turbulent and dangerous world.

Code and data availability

The model was developed using Vensim. Original files can be made available on request.

Author contributions

LL developed the model, JD advised on development. All authors drafted the manuscript.

Competing interests

At least one of the (co-)authors is a member of the editorial board of Earth System Dynamics.

Financial support

None of the authors had any financial support in the development and writing of this manuscript.

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