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PERSPECTIVE

An interdisciplinary framework for navigating social–climatic tipping points

Sonia Graham[1,2] | Melanie Wary[1] | Fulvia Calcagni[3] | Mercè Cisneros[4,5] | Claudia de Luca[6] | Santiago Gorostiza[1,7,8] | Ola Stedje Hanserud[1] | Giorgos Kallis[1,9] | Panagiota Kotsila[1] | Sina Leipold[10,11] | Jagoba Malumbres-Olarte[12,13] | Tristan Partridge[1,14] | Anna Petit-Boix[1] | Anke Schaffartzik[1,15] | Galia Shokry[1,16] | Sergio Tirado-Herrero[17] | Jeroen van den Bergh[1,9,18] | Patrizia Ziveri[1,9,19]

[1]Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona, Bellaterra, Spain; [2]School of Geography and Sustainable Communities, University of Wollongong, Wollongong, Australia; [3]Inabita Laboratorio Territoriale, Ripe San Ginesio, Italy; [4]GRC Geociències Marines, Universitat de Barcelona, Barcelona, Spain; [5]Centre for Climate Change (C3), Universitat Rovira i Virgili, Vila-seca, Spain; [6]Department of Architecture, Alma Mater Studiorum, Università di Bologna, Bologna, Italy; [7]Centre for History at Sciences Po (CHSP), Paris, France; [8]Departament de Geografia, Universitat Autònoma de Barcelona, Bellaterra, Spain; [9]ICREA, Barcelona, Spain; [10]Department of Environmental Politics, Helmholtz Centre for Environmental Research–UFZ, Leipzig, Germany; [11]Chair of Environmental Politics, University of Jena, Jena, Germany; [12]cE3c—Centre for Ecology, Evolution and Environmental Changes & CHANGE—Global Change and Sustainability Institute/Azorean Biodiversity Group, Universidade dos Açores, Azores, Portugal; [13]Laboratory for Integrative Biodiversity Research (LIBRe), Finnish Museum of Natural History (Luomus), University of Helsinki, Helsinki, Finland; [14]Department of Global Studies, University of California, Santa Barbara, California, USA; [15]Department of Environmental Sciences and Policy, Central European University (CEU), Vienna, Austria; [16]Department of Environmental and Sustainability Sciences, Kean University, Union, New Jersey, USA; [17]Department of Geography, Universidad Autónoma de Madrid (UAM), Madrid, Spain; [18]School of Business and Economics, and Institute for Environmental Studies, VU University Amsterdam, Amsterdam, The Netherlands and [19]BABVE Department, Universitat Autònoma de Barcelona, Bellaterra, Spain

Correspondence
Sonia Graham
Email: sgraham@uow.edu.au

Melanie Wary
Email: melanie.wary@gmail.com

Present address
Sonia Graham, School of Geography and Sustainable Communities, University of Wollongong, Wollongong, 2522, NSW, Australia

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Abstract

1. To effectively navigate out of the climate crisis, a new interdisciplinary approach is needed to guide and facilitate research that integrates diverse understandings of how transitions evolve in intertwined social–environmental systems.
2. The concept of tipping points, frequently used in the natural sciences and increasingly in the social sciences, can help elucidate processes underlying major social–environmental transitions. We develop the notion of interlinked 'social–climatic tipping points' in which desirability and intentionality are key constitutive features alongside stable states, feedbacks, reversibility and abruptness.
3. We demonstrate the new insights that our interdisciplinary framework can provide by analysing the slowdown of the Atlantic Meridional Overturning Circulation and associated flooding of the Ahr Valley in Germany as a social–climatic tipping point.
4. This framework can enable more sustainable and equitable futures by prioritising social–climatic tipping points for interdisciplinary research, identifying

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opportunities for action, and evaluating the nuanced desirability and acceptability of proposed solutions.

KEYWORDS
AMOC, climate adaptation, climate impacts, climate mitigation, interventions, transformation, turning points

1 | INTRODUCTION

Millions of youth around the world are calling for urgent climate action, that is, radical societal changes to address dangerous climate change and climate injustices (Lenton et al., 2019; Taylor, 2019). They are concerned and outraged about the negative social–environmental tipping points we are approaching and surpassing because of climate inaction (Antadze, 2020), such as the 2°C human-induced climate tipping point that would have irreversible impacts on livelihoods and biodiversity (Fridays for Future, 2023). Navigating such tipping points requires integrated interdisciplinary knowledge about *interlinked* social–environmental systems (Lenton et al., 2019; Otto et al., 2020; Tàbara et al., 2018). We need a framework that helps to anticipate changes at multiple temporal and spatial scales, design and negotiate *desirable* solutions, and make *intentional* changes that avoid exacerbating injustices (Leal Filho et al., 2018; Russill & Nyssa, 2009; Stafford et al., 2010).

One way to manage interlinked, cross-scale and changing social–environmental systems is through interdisciplinary research on tipping points (Köhler et al., 2019; Milkoreit et al., 2018). In complex systems research, tipping points are understood as sudden shifts in a dynamic regime that are often difficult to predict. More generally, tipping points indicate fundamental and potentially irreversible changes in the structure and function of a system, likely to impact other systems and potentially initiate a 'global cascade' of changes (Lenton et al., 2019; Tàbara et al., 2019). Climate tipping points,[1] such as the disintegration of the Greenland Ice Sheet (Collins et al., 2019), and their related social tipping points, such as the loss of Indigenous relations, knowledge and institutions (Whyte, 2020) and forced relocation of at-risk coastal communities (Huntington et al., 2012; van Ginkel et al., 2020), are intimately interlinked yet rarely studied together. We refer to them as social–climatic tipping points to emphasise their temporal and spatial connectedness and explicitly consider the role of human agency in avoiding undesirable outcomes.

One key challenge of interdisciplinary research on social–climatic tipping points involves expanding on the efforts of closely related disciplines to integrate knowledge from distantly related disciplines that span the social–natural science frontier (Bailey et al., 2015). For example, bringing together social–environmental research fields, such as social and industrial ecology, with diverse social and natural science disciplines, such as history and paleoclimatology, among others. An associated challenge involves establishing a common interdisciplinary terminology of concepts (Milkoreit, 2023; Milkoreit et al., 2018; Rineau et al., 2019) and developing more comprehensive theories (Feola, 2015; Korhonen et al., 2004) of how tipping points in biophysical environments can be simultaneously understood as socio-cultural tipping points and vice versa. Here we focus on developing the concepts of *intentionality* and *desirability* that are emerging as highly salient to understanding social–climatic tipping points and that require further interdisciplinary deliberation (Milkoreit, 2023).

In this perspective, we provide an example of how interdisciplinary researchers may approach social–climatic tipping points. We begin by identifying key learnings about intentionality and desirability from diverse disciplines and then explore how such learnings can provide a fresh perspective on a well-known climate tipping point, the slowdown of the Atlantic Meridional Overturning Circulation (AMOC), by analysing it as a social–climatic tipping point. In sharing these learnings, we hope to inspire future interdisciplinary studies that help achieve a just transition out of the climate crisis.

2 | DEFINING TIPPING POINTS AND RELATED CONCEPTS

To date, much scholarship on tipping points has come from ecological sciences and dynamical systems theory (Russill, 2015). Natural sciences provide foundational insights on tipping points in Earth systems that could support decision-makers in addressing the climate crisis. The natural science perspective elucidates tipping points as changes between *stable states* of the Earth system and associated *feedbacks*, and considers interacting temporal and spatial scales at which changes occur, from local to global. This perspective makes it possible to understand the long-term build-up of what are perceived to be *abrupt* changes and to determine thresholds for the *reversibility* of these changes.

What is often missing in natural science conceptualisations is explicit recognition that social systems co-determine environmental changes (van Ginkel et al., 2020). The need to consider tipping points from an integrated, interdisciplinary perspective has been gaining traction. Franzke et al. (2022, p. 2) argue that in light of the recent social science contributions to the topic an interdisciplinary approach is 'necessary to evaluate the interplay between human society and environmental systems that may lead to the crossing of tipping points'. For a definition of tipping points to be useful in interdisciplinary research and assist decision-makers, the interdependence of Earth and social systems needs to be explicitly recognised, the role of human agency addressed, and due consideration given to how the term 'tipping point' can validly be applied to both the physical and social worlds (Nuttall, 2012).

One of the most recent efforts to develop an interdisciplinary definition of tipping points in social–environmental systems is provided by Milkoreit et al. (2018). The authors reviewed over 9000 natural, environmental and social science articles that addressed tipping points or associated phenomena, such as regime shifts and critical transitions. They developed the following general definition, which incorporates four constitutive features—non-linear change, feedback, stable states and irreversibility—used most frequently across disciplines and determined to be necessary for identifying a tipping point.

> a tipping point is a threshold at which small quantitative changes in the system trigger a *non-linear change* process that is driven by system-internal *feedback mechanisms* and inevitably leads to a qualitatively different *state of the system*, which is often *irreversible*. (p. 9, emphases added to indicate constitutive features)

While this definition was intended to be interdisciplinary, it is deeply influenced by natural science understandings of tipping points. Indeed, Milkoreit et al. (2018) recognised that this definition required additional specifications if it were to apply to social tipping phenomena. In 2023, Milkoreit identified *intentionality* and *desirability* as key characteristics of social tipping points yet did not elaborate on what these concepts mean. Similarly, Winkelmann et al. (2022) recognised that agency, encompassing intentionality and desirability, is a main driver of social tipping processes, but used it as a concept for distinguishing between social and climate processes, rather than studying them together. While Milkoreit (2023) focused on social tipping points, she welcomed a 'flip in the script' that the concepts of desirability and intentionality bring to social tipping points within climate action debates because if 'desirable' change can be intentionally induced, then 'we no longer looked at tipping points only as threatening, potentially even catastrophic events in nature that appear largely unstoppable … Instead we look for them as much-needed policy tools at our disposal to speed up our responses to climate change and move along the transformations demanded by publics and decision-makers' (Milkoreit, 2023, p. 3). Yet she warns against uncritically embracing these concepts because '[t]hey imply a possibly false sense of control and agency with regard to highly complex processes in social-environmental systems that are likely characterized by emergence and surprise' (Milkoreit, 2023, p. 4).

Here we seek to further operationalise and critically reflect on the social dimensions—desirability and intentionality—of social–climatic tipping points. We consider contributions from a broad, though non exhaustive, range of social and social–environmental research fields in which concepts such as critical junctures, turning points, social and planetary boundaries, or societal transformations are developed and applied, while recognising the diverse and epistemologically different ways in which such concepts are applied in these different fields. We then propose a more expansive interdisciplinary definition of social–climatic tipping points, which incorporates the notions of desirability and intentionality, to guide future research on climate change.

2.1 | Conceptualisations of tipping points across diverse disciplines

The genealogy of the tipping point concept in social sciences can be traced to the 1950s when it was used to understand and describe *unintentional* social transitions (Nuttall, 2012). Political scientist Morton Grodzins (1957) originally described the process of 'tipping' and the 'tip points' at which 14 large cities in the United States experienced *rapid* and largely *irreversible* changes in their racial composition (for a critique of the racist origins of the 'tipping point' concept, see Nerlich, 2022). In contrast, the re-emergence of the notion of social tipping points in the 2000s involved a decided opening as to whether what came after the tipping point was positive or negative (desirable or not; Franzke et al., 2022): the term 'social tipping points' was used to reflect on deliberative social and political transformations related to climate tipping points (Milkoreit et al., 2018; Skrimshire, 2008).

In considering social–climatic tipping points, social research goes beyond trying to predict the timing and nature of tipping points, as occurs in the natural sciences, to identifying what social changes have the potential to affect the dynamics of the whole system. This involves focusing on 'conscious interventions of human agency' (Otto et al., 2020, p. 2356) informed by collective understandings on what *desirable* social–environmental states entail, where collective includes the perspectives of those who are often marginalised, such as Indigenous communities or youth (Christensen & Krogman, 2012). Such *intentional* tipping interventions may include the spreading of technologies, behaviours and social norms, and the creation of new institutions that contribute to the achievement of more just and equitable carbon-neutral societies (Fünfgeld, 2017; Otto et al., 2020; Whyte, 2020; Winkelmann et al., 2022). Yet, social research is not only concerned with possible interventions, but also how they are implemented and experienced, which actors are instrumental in mobilising and resisting change and the (unequal) impacts they might have (e.g. Pelling & Dill, 2010). In the following, we explore the contributions of different (interdisciplinary) research fields to the understanding of the elements of *desirability* and *intentionality* in social–climatic tipping points.

Within **human geography** are studies on climate adaptation tipping points or adaptation limits, that is conditions under which an adaptation solution ceases to be effective (van Ginkel et al., 2020). Within this discipline, it is often assumed that there exists a set of social and environmental conditions that meet local social values and needs (Barnett et al., 2014; Juhola et al., 2022), that is, a *desirable* stable state or status quo (Fünfgeld, 2017). Changes in the desirable stable state occur as a result of global anthropogenic climate change, for example, increased coastal flooding resulting in salinisation of farming lands (Juhola et al., 2022) or inundation of essential infrastructure (Barnett et al., 2014). While such local impacts may be addressed incrementally through adaptation, such as building new protective infrastructure, at some point no new adaptation options will be available and social reorganisation is required, for example, abandonment of farm land or relocation of inundated coastal towns. Some geography scholars therefore make a distinction between incremental adaptation and transformative adaptation. Transformative adaptation assumes that it is possible for social actors to identify alternative desirable stable states, which are not achievable through incremental adaptation, and then intentionally mobilise to shift social values, expectations and behaviours towards those transformative solutions through institutional tipping points. For example, feed-in tariffs may aim to move to a different energy regime by changing individual behaviours and market incentives (Fünfgeld, 2017). Where incremental adaptation is assumed to involve a smooth and linear transition that operates within tolerable limits (Dow et al., 2013; Garschagen & Soletzki, 2017), transformational adaptation is recognised as being a non-linear process that involves negotiating conflict among diverse actors at multiple scales (O'Brien & Sygna, 2013), often challenging concentrations of elite power and the status quo.

Critical human geography and environmental justice studies highlight how the *desirability* of alternative stable states, and the *intentionality* of actions that might prevent, maintain or establish certain social–climatic states, are not uncontested but rather the result of ongoing conflict and struggle in society (Cote & Nightingale, 2012; Whyte, 2020). Different value systems are not equally represented in decision-making processes, depending on power/knowledge dynamics in society. Not everyone has the same agency to have their values, beliefs and interests reflected in mainstream or hegemonic discourses about what is desirable action, or with what intentionality. For example, Pelling and Dill (2010) discuss how disasters can provide opportunities for social tipping points. Post-disaster responses often create new resource flows and social networks that can change relations between citizens and the state resulting in political regime changes where the state and elites are unable to maintain power and uphold their legitimacy. However, the likelihood for such transformative change is strongly related to pre-disaster power relations and inequalities based on class, ethnicity, etc. (Pelling & Dill, 2010). Thus, desirability and intentionality of transformative adaptation raises questions about whose values and vulnerabilities are included in scoping desirable stable states, which actors are able to exert influence at various scales, how existing social relations can be disrupted and the consequences of such radical change (Cote & Nightingale, 2012; Fünfgeld, 2017; Juhola et al., 2022).

To our conceptualisation of social–climatic tipping points, **social ecology** contributes an understanding of societies which lends itself to the integration of knowledge across disciplinary boundaries: societies are socio-cultural and biophysical hybrids, subject to both natural and cultural spheres of causation (Fischer-Kowalski & Weisz, 1999). In studying social metabolism—the material and energy inputs, transformation and outputs required for societal reproduction—socio-ecological research has long been conducted in the tipping-point neighbourhood. Socio-metabolic transitions, regime shifts or metabolic reconfigurations (Schindler & Demaria, 2019) occur when a society's material and energetic basis changes fundamentally (e.g. from solar energy and biomass to fossil energy) and coincides with an equally fundamental change in societal organisation and power relations. These large-scale shifts are, in and of themselves, not intentional. However, the far-reaching change in the societal resource base that they require is only achievable through what social ecology refers to as colonisation, that is, 'the *intended* and sustained transformation of natural processes, by means of organized social interventions, for the purpose of improving their *utility* for society' (Fischer-Kowalski & Weisz, 1999, 234, emphases added).

From deforestation and tillage to the construction of roads or dams, these interventions render the environment more useful to specific social actors (Hausknost et al., 2016) but they also require labour and energy and generally have (*unintended*) consequences such as erosion, habitat loss, pollution, etc. The linking of socio-metabolic with environmental justice research (Martinez-Alier, 2007; Temper et al., 2015) has been instrumental in highlighting how the consequences of such interventions are considered undesirable by many, giving rise to ecological distribution conflicts (Scheidel et al., 2018). For example, in examining socio-metabolic transitions on small islands, social ecology has explicitly identified the role of social and ecological tipping points in explaining observed occurrences of socio-metabolic collapse (Petridis & Fischer-Kowalski, 2016; Singh et al., 2022). Although the authors explicitly acknowledge that tipping points must not necessarily signal an undesirable change, the outcome of crossing the tipping points in these cases was undesirable for the local population.

Industrial ecology considers the flows of energy and matter between human activities and nature. One of the first definitions of industrial ecology points to its contribution to the study of social–climatic tipping points: 'Industrial ecology is the study of the means by which humanity can *deliberately* and rationally approach and maintain a *desirable* carrying capacity' (Graedel & Allenby, 1995, p. 9, italics added). Industrial ecology quantifies the environmental impacts and pressures of human activities and evaluates strategies that might help approach *desirable* sustainability targets. In general, sustainability assessments (e.g. life cycle assessment) determine the damage of systems on certain areas that should be protected over time, such as human well-being, ecosystems and natural resources, but balancing the impacts and benefits of human activities on these areas remains a challenge (Schaubroeck & Rugani, 2017). What is considered a desirable outcome is often constrained by intentional policy targets guiding global, national or local actions (e.g. Sustainable Development Goals) or science-based targets with a widespread public acceptance (e.g. planetary boundaries). Thus, intentionality and desirability can contradict each other through trade-offs and rebound effects. For example, the much-contested 'circular economy' concept, which *intends* to close material loops and slow down material consumption, can increase overall production of primary materials and thus lead to *undesirable* effects (Zink &

Geyer, 2017). To account for the 'absolute' benefits and impacts of intentional actions, the concept of 'planetary boundaries', stemming from Earth sciences (Rockström et al., 2009), is being increasingly integrated into these assessments. This involves evaluating the environmental impacts and pressures of regions and sectors, to understand to what extent they operate within or beyond humanity's safe operating space (Rockström et al., 2009), that is a sustainable *stable state*, and provide *target (intentional and desirable)* recommendations for policy and practice (e.g. Sandin et al., 2015). However, conducting such assessments invariably raises questions of ethics and values: which ethical principles should be used to divide emission budgets across nations and regions? Whose values guide the allocation of impacts across individuals, regions or market segments? (Sandin et al., 2015).

2.2 | Incorporating intentionality and desirability into the definition of tipping points

Common across the social sciences and social–environmental research on tipping points described above is a recognition that social tipping points cannot solely be identified by and understood through the description of system changes used in natural sciences, for example, what the initial and final (stable) states are, what sustains or reinforces changes (feedbacks) and whether the changes are reversible or abrupt. To understand and navigate social–climatic tipping points, *intentionality* and *desirability* must be explicitly considered. Intentionality translates into regulations, adaptation processes and paradigm shifts (e.g. deep transformations) that aim to take action in light of past or future (impending) damage. Whether these intentions are desirable (i.e. acceptable or just) depends on the current and historical social context and on who interprets what is (un)desirable. Thus we not only need to consider the extent to which human agency can bring about transformative change (as per Milkoreit, 2023), but if such human agency exists, whether it is possible to disrupt existing social networks and resources to ensure that intentional actions do not further exacerbate existing vulnerabilities and injustices. This requires recognition that navigating social–climatic tipping points challenges the power of those with vested interests in maintaining the status quo, and paying close attention to who are the winners and losers.

Future interdisciplinary research on social–climatic tipping points needs to consider (1) whether the new stable states are *desirable* and by whom, taking into account the often unequal impacts of changes on human societies and (2) the role that individuals, groups and institutions have, either *intentionally* or *unintentionally*, in generating the changes and feedbacks, and who is excluded from such action. Thus, we propose that a conceptual framework needs to consider six constitutive features: desirability, intentionality, stable states, feedbacks, abruptness and irreversibility (Figure 1). Incorporating the concepts of desirability and intentionality into the general definition of tipping points proposed by Milkoreit et al. (2018) results in an

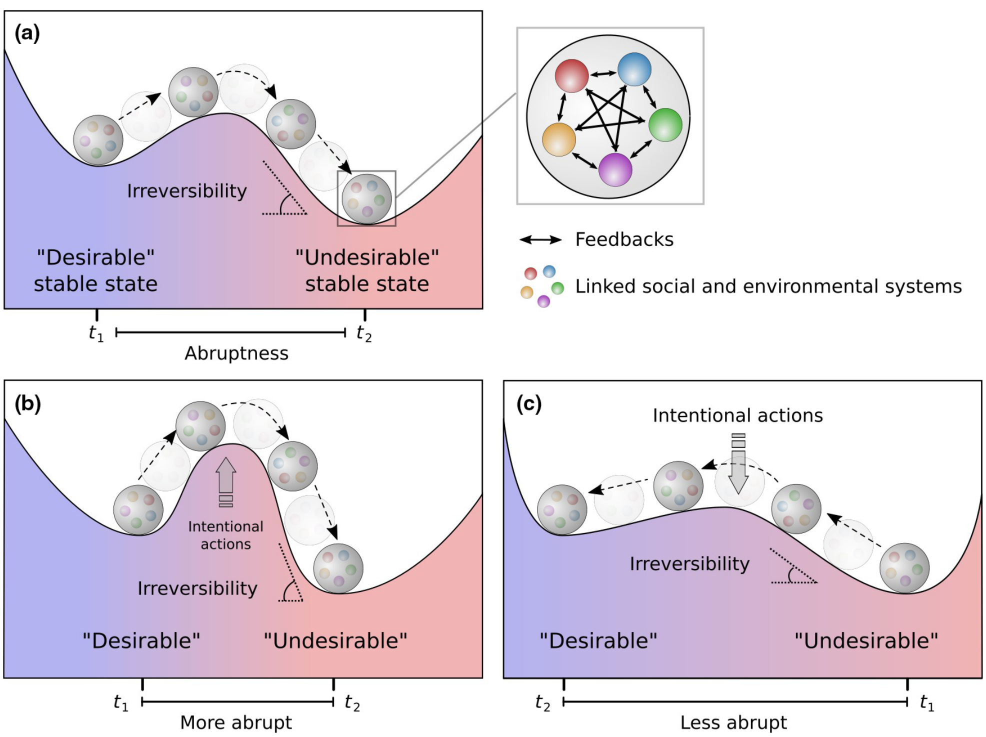

FIGURE 1 Six constitutive features of our interdisciplinary framework for the study of social–climatic tipping points: desirability, intentionality, stable states, feedbacks, abruptness and reversibility. Quotation marks indicate that desirability is subjective and not universal. (a) A social–climatic tipping point. Intentional actions can make such a tipping point harder to cross by increasing its irreversibility (b), or easier to reverse by decreasing its irreversibility (c).

expanded definition of social–climatic tipping points that can inform interdisciplinary research on climate change:

> A social-climatic tipping point is one for which *intentional* actions have the potential to trigger *abrupt* changes in social-environmental systems that are sustained or amplified as a result of *feedback* mechanisms and that, by addressing *reversibility*, lead to a qualitatively different and *desirable state* of the interlinked systems. The drivers, feedbacks and impacts result from interactions between natural and social systems.

Through our framework and definition, we recognise that social and environmental systems are linked through co-evolutionary dynamics (Otto et al., 2020), that is that there are co-determining drivers that lead to cascading feedbacks in such coupled systems (van Ginkel et al., 2020). An interdisciplinary approach needs to consider the links between multiple climate and social tipping points and other non-tipping changes and their cumulative impacts.

3 | APPLYING AN INTERDISCIPLINARY PERSPECTIVE TO SOCIAL–CLIMATIC TIPPING POINTS: THE CASE OF AMOC SLOWDOWN AND ASSOCIATED FLOODING IN GERMANY'S AHR VALLEY

Here we demonstrate the value of our expanded interdisciplinary framework by working through a contemporary example of a social–climatic tipping point that spans local to global scales: the large-scale Atlantic Ocean circulation slowdown and localised flooding of the Ahr valley in Germany. In this example, attending to questions of desirability and intentionality across the other four constitutive features (stable states, reversibility, abruptness and feedbacks) demonstrates the depth and complexity of co-evolving systems and highlights how social and climate tipping points are linked.

Slowdown in North Atlantic ocean circulation, and associated storminess variability, is one of the changes very likely attributed to human-induced climate change (Caesar et al., 2018; Collins et al., 2019). The effects of this slowdown are already being felt across Europe. Recent flooding in the Ahr valley in Germany in 2021, which took the lives of 134 people and affected the livelihoods of a further 17,000 people, has been attributed to weakening of the high-altitude jet stream connected with the AMOC (Kathawala, 2021). The cross-scale links between the climate and social systems are clear in this example. The flood was one of the worst to hit Germany in recent years and caused widespread damage and loss of life, constituting an unprecedented event in recent decades in Central Europe (Möller, 2023). At the national level, the flood led to a significant increase in public demand for action on climate change and has since been a driving force for policy changes aimed at reducing greenhouse gas emissions and strengthening resilience to climate impacts in Germany (Möller, 2023). Thus, the 2021 Ahr valley floods provide an example of AMOC slowdown induced social–climatic tipping points being reached at local and national scales in the European Union's largest economy, opening the door for integrated interdisciplinary work to help prepare for and potentially ameliorate further impacts of climate change.

3.1 | Stable social–climatic states

The AMOC slowdown is likely to be a response to anthropogenic warming, associated ice melting and changes in the water cycle (e.g. Caesar et al., 2018; Thornalley et al., 2018). The AMOC, a key component of global ocean circulation, was relatively active over at least 1400 years, and possibly 10,000 years (Spooner et al., 2020). AMOC reconstructions show an anomalous slowdown since the mid-1800s that accelerated from the 1960s (Caesar et al., 2018, 2021; Thornalley et al., 2018). AMOC-slowdown simulations indicate an increased frequency of winter storms in some European coastal areas (e.g. Jackson et al., 2015) while climate predictions depict an increase in storm intensity (e.g. Feser et al., 2015). Projections indicate that the AMOC will weaken further, although its tipping point and collapse are unlikely during the 21st century (IPCC, 2013).

Anthropogenic forcing of global warming and the AMOC slowdown has co-evolved with economic and societal power structures. The stability of the current social state is evident internationally in the Conference of the Parties (COP) deliberations and the limited progress on reducing global carbon emissions (Carattini & Löschel, 2021). At the local level, implementation of climate change mitigation has also been slow. Yet, concern about future undesirable social–climatic states continues to bring communities and governments together to deliberate and attempt to negotiate a path towards limiting temperature increases to 1.5°C above pre-industrial levels and preventing a tipping point from occurring. Social research about these negotiations points to questions of justice in terms of whose voices count in negotiations, and how those most responsible for contributing to global warming can help those most affected by and least able to cope with climate change impacts (Okereke, 2010). Indeed, in the COP27 deliberations in November 2022, there was a breakthrough agreement to establish a dedicated 'loss and damage' fund for the countries most affected by climate disasters.

With respect to the AMOC specifically, concern about the undesirability of future social–climatic states is driving calls for action and adaptation. There is a growing recognition that increased storminess combined with ecological changes will have ramifications for all aspects of social life: health, relationships, livelihoods and recreation (Figure 2). In Germany, rising concern about increased frequency and intensity of extreme weather events triggered by the 2021 Ahr valley flood has reinforced calls by the climate movement for better mitigation and adaptation. One policy change currently being considered involves amendments to national construction laws to facilitate faster reconstruction of residential areas in higher grounds after flooding disasters (Lang, 2023). Thus, concern about undesirable future climatic states at a global scale is driving changes in social

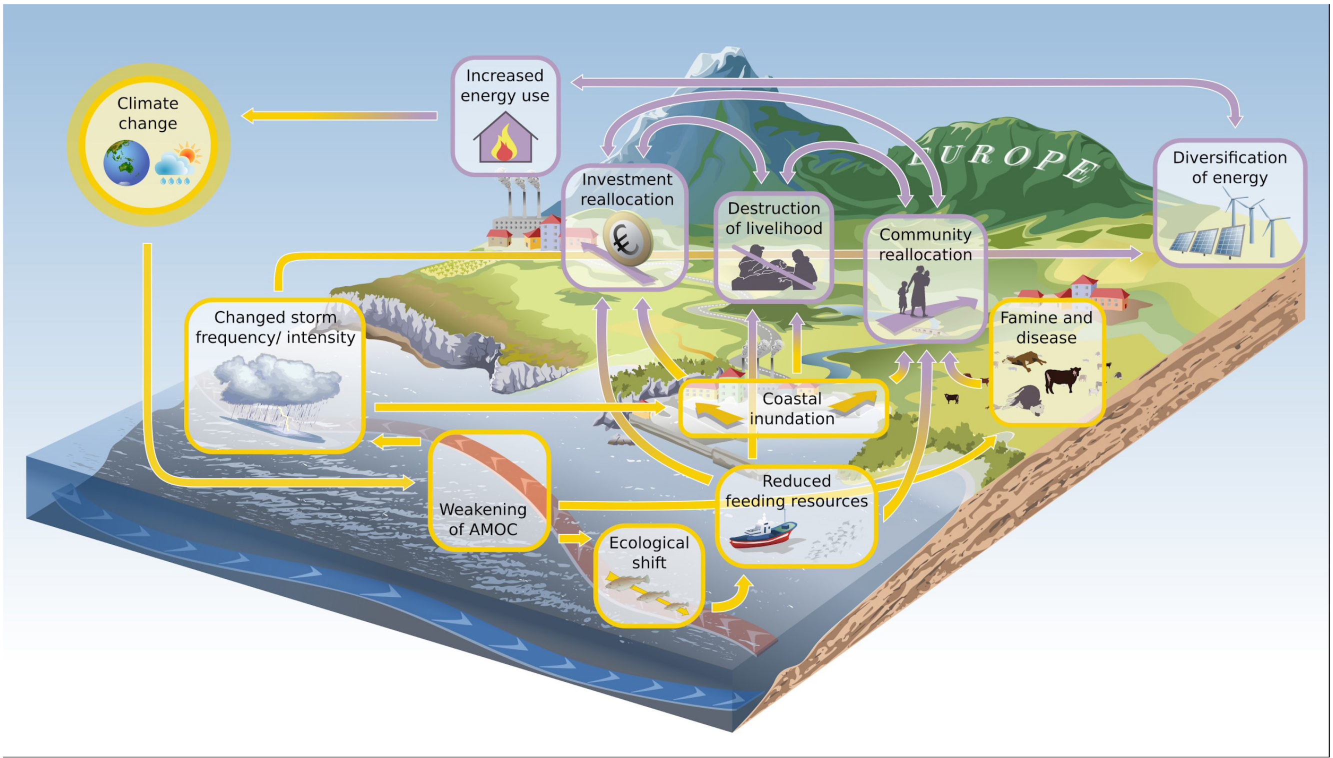

FIGURE 2 Examples of interconnected social, climate and ecological systems that drive and are impacted by a weakening of the Atlantic Meridional Overturning Circulation (AMOC). Environmental (yellow) and social (purple) systems and interactions (arrows) are shown.

behaviours and policies at national and local scales. Further empirical research is needed to determine the desirability and equality of such social changes and whether they result in new social–climatic states.

3.2 | Abruptness

While the AMOC slowdown is gradual (century scale; Caesar et al., 2021; Lenton et al., 2008), changes in storminess and related impacts are being recorded at pluri-annual and shorter scales among scientists and citizens alike (Lozano et al., 2004). At its worst, storms result in significant decline in human welfare, loss of life and damage to infrastructure (Ciavola & Jiménez, 2013), transformation and permanent displacement of coastal communities, resulting in significant disruptions to social, cultural and economic practices (Galappaththi et al., 2019; Zhang, 2012). The Ahr valley flood, for example, was an unusually abrupt event due to the concentration of rainfall (100 L/m^2 of rain falling over a 24-h period) in a critical part of the basin.

While such abrupt climatic changes have significant ecological consequences, they have also been shown to push social systems to surpass tipping points (Pelling & Dill, 2010). The Ahr valley flood is considered to have triggered a social tipping point because it marked a turning point in the public awareness and concern about the effects of climate change and shaped new discussions about adaptation. As in the case of other disasters resulting in social tipping points, the flood reconfigured social networks and resources (Möller, 2023). The federal and state governments provided 30 billion euros for reconstruction in the area, the largest post-flood package ever given in Germany. For the residents of the region, the experiences of living through the flood have affected their relationships with one another and expectations of the State. Citizens have formed working groups to develop new proposals on how government infrastructure should be rebuilt differently (Möller, 2023). While this example shows how abrupt social–climatic tipping points can result in deliberations about and intentional actions towards desirable developments, questions remain about whether humans are likely to engage as readily with less abrupt changes.

3.3 | Reversibility

While there is no consensus on the irreversibility of the AMOC collapse, scientists anticipate that changes to marine ecosystems are potentially reversible depending on whether the change is nonlinear (Schmittner, 2005). With respect to reversibility of impacts on infrastructure and social systems, the potential for reversibility depends on the efficiency, intensity and soundness of the policies, strategies and plans that local authorities develop and implement about land use, land take and local resources use (Kim et al., 2017). For example, Helderop and Grubesic (2019) note that there is an irreversible tipping point for infrastructure damage associated with hurricane storm surges that occurs between category III and IV hurricanes. A category IV hurricane results in a significantly greater number of households and businesses becoming flooded, more roads washed out, including official evacuation roads and roads that provide access to hospitals. The cutting off of access to hospitals is associated with higher morbidity and mortality (Helderop & Grubesic, 2019). The reversibility of the impacts also depends on strengthening the capacities of vulnerable communities and working across public sectors like housing, water and sanitation, parks, and health departments while centring the equity and affordability of measures (Graham et al., 2016; Shi et al., 2016).

In the case of the Ahr valley, reconstruction is progressing slowly. While much is able to be rebuilt, there are limitations on availability of building materials, tradespeople, engineers and capacity of the local government to process applications. While over the long-term, the communities may be rebuilt, many roads remain damaged and many buildings remain uninhabitable (Möller, 2023). The slow reversibility of impacts of the AMOC may have significant social consequences. For example, in the United States, post-disaster neighbourhood vacancy has been found to impact the mental health of those remaining and their quality of life (e.g. Newman et al., 2022). Elsewhere, extreme climatic events have resulted in community abandonment (Zhang, 2012), often because post-disaster recovery resources are inadequately and inequitably distributed to help already marginalised groups rebuild. And so, the speed with which, where and for whom, infrastructure and housing can be rebuilt may ultimately affect who stays and who leaves, with ramifications for local networks, community dynamics and capacities to respond to future climatic changes.

3.4 | Feedbacks

Social responses to cascading feedbacks associated with the AMOC have the potential to further exacerbate or ameliorate the slowdown. For example, care needs to be taken when building new infrastructure and adapting industries, for example, tourism and fisheries, to avoid maladaptation and accommodate changing climatic and ecological conditions. The materials and energy needed for their implementation have a carbon footprint dependent on their life cycle (Wiedmann & Minx, 2008). Similarly, while implementing flood adaptation measures, such as traditional dikes or novel green infrastructure, requires an investment in material and energy resources, their impacts might be offset if damage is avoided, for example, to vehicles, houses or urban infrastructure (Hennequin et al., 2018; Petit-Boix et al., 2017). Further shifts in our production and consumption patterns can reduce or create risks for additional cascading effects.

In the case of Germany's Ahr valley, changes triggered by the 2021 floods conform to an emerging new stable social–climatic state in which extreme climatic events are primarily perceived, and responded to, as a consequence of climate change, thus moving away from pre-existing 'natural disaster' or 'anthropogenic hazard' rationales. Such changes at the local (Ahr valley) and national (Germany's emergency/disaster mechanisms) level resonate and are amplified by long-ranging processes associated with the ongoing transformations in the European political system. Several national Western European Green Parties received strong electoral support in the May 2019 European Parliamentary Elections in the constituencies of Belgium, Germany, Finland, France and Luxembourg, trends influenced by the Fridays For Future movement. In Germany specifically, opinion polls indicate an abrupt increase from 5% to 40%–60% in just 1 year (autumn 2018 to autumn 2019) in concern for the environment. Polling data indicated that the Green Party had become effectively equal with the conservative party as the preferred political party of German voters in the latter half of 2019. Such developments in the European Union's electoral scene and public opinion have been interpreted as constitutive of a potential 'social tipping element' in the European political system (Winkelmann et al., 2022) that may result in cascading network dynamics and positive feedback mechanisms when coupled with extreme events, such as the Ahr valley flood in 2021.

4 | CONCLUSION

Based on the interdisciplinary efforts of the team of co-authors, and following the lead of recent scholarship on the topic (Milkoreit, 2023), we put forward desirability and intentionality as actionable concepts that help explain how social processes co-constitute abrupt, non-linear change in climatic systems, which we term social–climatic tipping points. These two concepts highlight a previously underconsidered 'social' layer in tipping point scholarship and give new ground for assessing how human agency shapes social–climatic states. To take the first steps towards a desirable future requires us to understand how desirability varies across spatial, temporal and social scales. It also requires compromises across interlinked systems; it cannot be done by taking a narrow environmental, social, economic, health or climate perspective. Taking acceptable intentional action depends on how the willingness, interests and capabilities of different actors within society can clash and conciliate within historical and geographical contexts.

The Ahr Valley provides a contemporary example of multi-scalar social–climatic tipping points. In this case, abrupt and extreme flooding and associated social devastation intersected with slower environmental (slowdown of the AMOC) and social processes (climate movements). The result was a reorganisation of community networks and relationships with government that transformed local and national adaptation efforts. What is yet to be determined in this example is whether the new adaptations have fundamentally changed pre-existing patterns of disadvantage and inequality. This speaks to our broader argument that understanding social action towards and in response to tipping points requires an analysis of power that pays attention to actors' agency through and despite (historically produced) structural constraints. Analysis of social–climatic tipping points requires consideration of contestation and struggle and how the outcomes of mitigation and adaptation action are spatially and socially uneven. Our interdisciplinary definition offers an avenue for examining questions of politics and justice about for whom future scenarios are desirable, who may intentionally act to achieve those outcomes, and the possible (adverse) feedbacks that may accrue from such actions from local to global scales.

AUTHOR CONTRIBUTIONS

Sonia Graham, Melanie Wary, Anke Schaffartzik, Sergio Tirado Herrero, Tristan Partridge, Santiago Gorostiza, Anna Petit-Boix and Ola Stedje Hanserud co-organised the workshop on which the article is based. With the exception of Panagiota Kotsila and Jagoba Malumbres-Olarte, all co-authors participated in the workshop. At the workshop, Patrizia Ziveri proposed the idea of writing an article about the ideas discussed. Sonia Graham and Melanie Wary took the lead on drafting the structure of the article and weaving together contributions from the co-authors. For the first draft of the manuscript, all co-authors who participated in the workshop contributed summaries of how transitions are conceptualised within their respective disciplines. Jagoba Malumbres-Olarte was invited to join the authorship team to provide a perspective from biological sciences and to develop the figures in collaboration with the co-authors. Panagiota Kotsila was asked to join the authorship team to contribute to the political ecology perspective. In revising the article, Sonia Graham, Anna Petit-Boix, Sergio Tirado Herrero, Sina Leipold and Anke Schaffartzik took the lead on redrafting key sections of the manuscript. All co-authors have made substantial contributions to the undertaking, writing and critical revision of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to report.

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ORCID

Sonia Graham https://orcid.org/0000-0003-4195-4559
Melanie Wary https://orcid.org/0000-0001-5211-2168
Fulvia Calcagni https://orcid.org/0000-0001-7935-8731
Mercè Cisneros https://orcid.org/0000-0001-7698-6628
Claudia de Luca https://orcid.org/0000-0001-6836-4298
Santiago Gorostiza https://orcid.org/0000-0002-8516-5642
Ola Stedje Hanserud https://orcid.org/0000-0002-0630-4203
Giorgos Kallis https://orcid.org/0000-0003-0688-9552
Panagiota Kotsila https://orcid.org/0000-0003-0498-8362
Sina Leipold https://orcid.org/0000-0001-5245-183X
Jagoba Malumbres-Olarte https://orcid.org/0000-0002-6878-5719
Tristan Partridge https://orcid.org/0000-0003-3770-8494
Anna Petit-Boix https://orcid.org/0000-0003-2048-2708
Anke Schaffartzik https://orcid.org/0000-0002-0284-6099
Galia Shokry https://orcid.org/0000-0002-2959-3677
Sergio Tirado-Herrero https://orcid.org/0000-0003-3187-1039
Jeroen van den Bergh https://orcid.org/0000-0003-3415-3083
Patrizia Ziveri https://orcid.org/0000-0002-5576-0301

ENDNOTE

[1] We use the term climate tipping points to refer to a subset of ecological tipping points that are associated with climate change.

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