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Limits to adaptation: building an integrated research agenda

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Abstract

The IPCC's 6th Assessment Report Working Group II report of (2022) has brought greater attention to the issue of limits to the capacity to adapt to climate change. But the report also showed that research in the field continues to be fragmented and under-developed, and that the problem of limits is not widely considered in policy. In this paper we argue for a more coherent, interdisciplinary approach to research on adaptation limits, linked to the concept of transformative adaptation. A risk-based approach to adaptation limits offers a framework to deepen, broaden and connect research which responds to the needs of policymakers. We set out four promising directions for future research on: the dimensions of limits; the dynamics of limits; formalisation of research on limits; and ethics and justice challenges underpinning adaptation limits.

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Introduction and context

Limits to the capacity of nature and society to adapt to climate change impacts are implicit in international climate policy. If there was an unlimited capacity to adapt, 'dangerous anthropogenic interference' (article 2, UNFCCC) would likely not be of great concern. Instead, there is accumulating evidence that adaption limits to climate-related risks are emerging in relation to some hazards (heat, flooding, fire, sea level rise) in different geographical and social contexts (coasts, water, food and agriculture,) (Pörtner, H.-O. et al. 2022).

Although the problem of adaptation limits is widely accepted, it is complex and contested. For instance, conventional economic analysis assumes high levels of adaptiveness to climate change and, as a result, delivers high 'optimal' global warming targets, in the range +3-4˚C (Nordhaus 2019). Contrasting economic analysis (e.g.,the 2006 Stern Review and responses to it), suggest that limits to the capacity to adapt, especially to potentially catastrophic impacts, are at the heart of debates in climate economics and policy (Stern 2006; Weitzman 2007), underpinning the argument for early emissions reductions.

Making progress on characterising and analysing climate adaptation limits, and on integrating approaches to adaptiveness and its limits across climate research, is therefore a critical research question, with significant implications for climate policy. Too little progress has been made towards this objective of understanding the limits to social and ecological adaptability in the face of climate risks. Analytically, the central problem is to understand changing *climate-related* risks to ecosystems and people in the context of multiple stressors and capabilities that shape exposure, vulnerability and adaptation, and how risks and impacts cascade through socio-ecological systems locally to globally. The uneven distribution of risks and limits - spatially, socially, temporally is widely recognized (Pearse 2017; Tol 2021). As risks change and escalate, so these uneven distributions of exposure and vulnerability will tend to become entrenched, deepening inequalities (Antwi-Agyei et al. 2018; Datey et al. 2021). At the local, national and international scales, there are political and policy implications of this unequal pattern of climate-related risk and losses. More positively, there are opportunities to support transformative adaptation to achieve desired futures.

A risk-based definition of adaptation limits (Dow et al. 2013), developed further in IPCC Sixth Assessment Report (2022), argues that adaptation effort by all social actors to cope with climate-related risks increases up to a point where risks become intolerable, leading to substantial and irreversible loss and damage, and radical changes in behaviour (such as land abandonment or human migration) (O'Neill, B. et al. 2022). We believe that this risk-based framework offers new research

opportunities with implications across climate sciences, and for framing and informing policy on climate risk management and adaptation.

This short paper aims to sketch out an agenda for further research on adaptation limits to inform public policy. It is organised into three sections. The next section provides an overview of currently disconnected but relevant literatures on limits, followed by a discussion of new research questions, and a brief conclusion.

A multi-faceted, disconnected literature

Adaptation limits have attracted inconsistent research attention. Over the past decade, at least eight substantial and distinctive strands have emerged, but not coalesced. The main strands of literature salient to understanding adaptation limits are related to: physiological limits to healthy living conditions, focusing on extreme heat (Bennett et al. 2021; Sherwood and Huber 2010; Xu et al. 2020); the social context of limits (Adger et al. 2009; Barnett et al. 2015; Siders 2019); transformative adaptation (Chu et al. 2019; Fedele et al. 2019; Kates, Travis, and Wilbanks 2012; Pelling, O'Brien, and Matyas 2015; Shi and Moser 2021; Wilson et al. 2020); the risk-based concept of limits (Dow et al. 2013; Dow, Berkhout, and Preston 2013; Klein et al. 2015); case study research, often at the community level (e.g., Harvey et al. 2014; Karapinar and Özertan 2020; Karlsson and Hovelsrud 2015; B. P. Warner 2016); qualitative research illuminating power, agency and difference in adaptation outcomes (Daoud 2021; Ensor et al. 2021; Garcia et al. 2021); concepts of loss (Tschakert et al. 2019); and systematic reviews of adaptation literature, including constraints and limits (Berrang-Ford et al. 2021; Mechler et al. 2020; Thomas et al. 2021).

Perhaps more significantly, these strands have not been well connected to wider climate change impacts, economics and policy literatures. For instance, a new generation of economic studies of the link between climate change and economic performance, which emphasises the role of adaptation and the significance of 'adaptation gaps', has developed quite separately (Auffhammer 2018; M. Burke et al. 2016; Carleton and Hsiang 2016). Conversely, influential impacts and integrated assessment modelling efforts have not yet sought to address adaptation and limits to adaptiveness consistently.

Taken together, the current literature does not provide responses to key questions posed by policymakers related to the identification of adaptative responses and limits, the social, spatial and temporal distribution of limits, the effectiveness of adaptation in avoiding limits, and the public policy responses available to deal with the consequences of limits being approached, reached, and exceeded. The focus of studies of climate change impacts and adaptation has been on measuring the

'avoided impacts' of early climate mitigation action (Sanderson et al. 2018), with less attention paid to present-day risks and the wider consequences for adaptation effort. Where there has been a concern with adaptation itself, systematic reviews find a paucity of empirical research, much of it in the form of case studies with a lack of consistent application of concepts and methods (Berrang-Ford et al. 2021). One of the reasons for this is that exposure, vulnerability and adaptive response have been seen as context-specific. Multiple contributions on the social, political, and cultural context of adaptation limits have suggested that the variability of these conditions makes drawing more general conclusions difficult (Adger et al. 2009; Bezner Kerr et al. 2022). Even understanding differences in individual and public risk perceptions and defining a consistent set of desired outcomes for adaptation remains elusive (Dilling et al. 2019; Schneiderbauer et al. 2021; Singh et al. 2021). We believe there is an urgent need to step beyond the particular and for research to address the generic features of adaptiveness and its limits.

An important, related strand of research has been concerned with the idea of *transformative* adaptation: more radical changes that seek to address underlying structural inequities, while also reducing vulnerability to climate risks (Pelling and Manuel-Navarrete 2011; Pelling, O'Brien, and Matyas 2015; Shi and Moser 2021). To an extent, limits to adaptation and transformative adaptation, while conceptually connected, have emerged as bifurcating concepts. An adaptation limit, whether for an individual, group, or sector, is potentially, but not necessarily, a precursor to system level reconfigurations. Likewise, structural reconfigurations to achieve greater climate justice may come too late for communities facing irreversible losses today. Working with present-day realities of power and agency is the challenge. Loss and damage is another strongly-related concept, but with a specific intellectual heritage from within the United Nations Framework Convention on Climate Change (UNFCCC)(Huq, Roberts, and Fenton 2013; Mechler et al. 2020). Pursuit of the similar but distinct concepts has diverted effort from investigating the points of convergence around concepts, methods and towards building a broader, shared understanding.

In parallel, and again quite separately, assumptions about damage costs and the scope for these to be reduced through adaptation play a central role in sectoral and global integrated assessment models (Nordhaus 2019; Tol and Fankhauser 1998). The theoretical and empirical basis for estimates of damages has been questioned (M. Burke et al. 2016; Pindyck 2017), while the assumption of optimal adaptation – that all available adaptation options will be efficiently adopted by economic and social agents – has also been cast into doubt (Carleton and Hsiang 2016; Gawith et al. 2020; Hsiang et al. 2017). So far, this influential debate about adaptation and damage costs has not yet engaged with the insights from qualitative research on social and institutional contexts in which

adaptation happens. Nor has it reckoned with limits to adaptation or the tolerability of experienced damages and losses.

We believe that, to make progress, there is a need to broaden the disciplinary and methodological scope of research on limits to adaptation. This includes the need to seek to develop generalisations, starting with economic and social dimensions of loss, while building-in a sensitivity to context-specificity and multiple risk perceptions, preferences, values and trade-offs as they are expressed by people facing climate-related threats. This research is needed to inform major climate policy responses, including through sound approaches to risk assessment, residual damages and distributional questions in impact and assessment models.

New directions for adaptation limits research

Given the analytical and political importance of adaptation limits, we believe there is a need to deepen understanding, intensify research, and find routes to integrating analysis across climate research and policy. As climate change impacts continue to grow, building from existing conceptual frameworks to more integrated research would deliver policy-relevant and actionable knowledge which could play a role in addressing the human consequences of adaptation limits. We believe there are at least four pressing and interdependent dimensions for future research: integrating understanding of socio-economic and biophysical dimensions of limits and their interactions; synthesizing understanding of the dynamics of limits to adaptation; incorporating analysis of adaptation limits into economic modelling efforts; and addressing the fairness and justice problems apparent in the uneven distribution of limits to adaptation.

Socio-economic and biophysical dimensions of limits and the nature of losses

Advancing the understanding of factors and conditions influencing limits to adaptation and developing generalisable insights about how factors interact in conditioning and structuring limits is a fundamental research need. There are several features of vulnerability and adaptation to climate risks which obstruct generalisation. Vulnerability and adaptation are complex outcomes of many factors, many of which are context-specific (Ensor et al. 2021; Noll et al. 2022; Owen 2020; Smit, B. et al. 2000). Social and ecological conditions construct exposure to risk and the capacity to adapt, with institutions conferring differential power and resources among people (Carr 2019). Climate and non-climate dimensions work together to shape risks faced by social actors (people, households, businesses, communities) embedded in socio-ecological systems. Influencing factors may be incommensurable (biophysical and cultural factors, for instance), they may operate across different scales (local to global) and their expression in risk may depend on the context (for instance, ambient

temperature has varying impacts on economic productivity across climatic zones (Szewczyk, Mongelli, and Ciscar 2021). Analytically, this complexity presents serious challenges, but there have been significant advances recently in building more complete understanding in the qualitative (Eriksen et al. 2021) and quantitative (Auffhammer 2018) literatures.

We believe there is a need to support further assessment, planning and policy approaches that anticipate and promote engagement with projected futures and that the risk-based framework offers ways of doing this. Examining the interactions of biophysical and social factors shaping limits is key to this goal. A useful distinction can be made between biophysical factors which represent "hard" limits to the functioning of species, ecosystems or people, and socioeconomic factors forming so-called "soft" limits that are potentially modifiable over time, as options and capabilities emerge. To a large extent biophysical factors can be regarded as exogenous to human activity and not subject to direct modification, even if their impacts may be modified (air conditioning as a modifier of exposure to heat, for instance (Barreca et al. 2016; Vicedo-Cabrera et al. 2021)). Perhaps the most well-researched biophysical limit is extreme heat as a threat to health and life for people and animals (Ebi et al. 2021; Kjellstrom et al. 2016; Mora et al. 2017; Sherwood and Huber 2010), affecting crop productivity (Cheabu et al. 2019; Deryng et al. 2014; Siebert and Ewert 2014; Zachariah, Mondal, and AghaKouchak 2021), as well as more general impacts on economic productivity (Dell, Jones, and Olken 2012). A broader assessment of the 'human climate niche' emphasising temperature generalises this argument and shows that there may be a safe space defined by prevailing temperature for human development which is now in danger of being breached (Xu et al. 2020). Defining biophysical limits and mapping the changing distributions for key activities and sectors, and for human development more generally, and understanding how they influence risks to people and ecosystems continues to be a research priority (e.g., Holsman et al. 2019). For public policy it also represents a signal and threshold for implementation of adaptation strategies.

Social factors influence adaptation limits in complex and intersecting ways across scales. These include technological, economic, institutional, social and cultural factors (see Figure 1). While these factors can be seen as shaping relative vulnerability (Shi and Moser 2021), they also condition adaptative capacity and through this come to frame the differential availability of an 'adaptation space' for social actors. Limits, and the actions that they lead to, are an outcome of a situated social, economic and institutional process in which social actors have access to and can draw on certain resources, capacities and capabilities, that are denied to others. As these social conditions are mutable, so too can adaptation limits be mitigated, delayed or amplified. Interactions between social factors shaping adaptiveness are documented in a growing qualitative literature on adaptation

limits (Azhoni, Holman, and Jude 2017; Thomas, Serdeczny, and Pringle 2020; Tschakert et al. 2017; B. P. Warner 2016; K. Warner and Geest 2013). But there would be value in greater comparability of future studies. Clarity about the social preferences and values underpinning adaptive effort would be helpful in achieving such convergence. In a risk-based framework, evaluation of outcomes would be framed in terms of reduced vulnerability, lower damage costs, or tolerable risks to the valued objectives of actors, and their more equal social distribution.

Social factors influencing limits are often structural, and require explanations that look across scales at the operation of institutional, economic and cultural factors, including interactions among them (Adger, Arnell, and Tompkins 2005). These multiple factors, operating across scales, shape the adaptation space available to social actors and may transfer vulnerability, undermine resilience and alter limits among groups and places (Atteridge and Remling 2018; Barreteau et al. 2020; Eriksen et al. 2021). Despite the many complexities, there is a need for a redoubled effort at assessment of climate adaptation outcomes, including incremental and radical adaptations. More information on the economics of adaptation decisions is also of significant interest among decision-makers, marking an opportunity for a productive dialogue with economic analysis to theorise and measure behaviour in respect of risks and adaptation limits at micro- and macro-scales, including interactions across markets and communities.

FIGURE 1 ABOUT HERE

Another area for investigation centres on the nature of experienced or anticipated risks associated with climate change impacts. There are tangible losses linked to property or economic outputs (such as crop losses caused by drought) and these have conventionally been included in damage functions in climate assessment models (Farmer et al. 2015; Oberpriller, Q. et al. 2021). However, several authors have drawn attention to the variety of ways in which losses are experienced, including non-economic and intangible losses, such as place-attachment (Tschakert et al. 2017). Tangible and intangible dimensions of risk and loss, form an important context for actors' choices when investing in adaptation effort to protect a valued objective (Carr 2019). The most important determinant of adaptation limits may be connected to culture and identity. Conversely, gains that could flow from transformational adaptation leading to more just and desired futures, also condition attitudes (Mach and Siders 2021). Anticipated outcomes of adaptive action will play a role in defining where a social limit to adaptation sustaining the *status quo* lies. There are rich perspectives from agrarian and

development studies, risk analysis and behavioural economics which can be applied in understanding and predicting responses to loss under conditions of uncertainty.

The risk-based approach to adaptation limits argues that adaptation effort grows until the actor experiences intolerable risk. This raises a further question of how and when risks or losses are experienced as intolerable, accepting that attitudes to risk vary between individuals and groups. There are social and collective attitudes to the tolerability of risks, which are institutionally- or culturally-mediated. For instance, attitudes to the tolerability of flooding differ greatly between the Ganges-Brahmaputra and the Rhine deltas. Debates about risk are often, at base, about the adequacy of institutions which manage them (Kasperson 1983). In short, there are a set of foundational issues at stake in understanding adaptation limits and a wide range of theoretical perspectives with which they may be tackled.

Dynamics of limits

Adaptation to climate risk occurs over time and an analysis of adaptation and limits needs to take account of the relative rates of change, adaptability and the temporalities of institutions and multi-scalar systems. The aim of this research would be to understand how limits evolve through time and propagate through social systems. There are at least four dimensions to the temporality of adaptation limits. First, many significant risks will stem from recurrent extreme events and the adaptation choices made by social actors will be concerned with making sense of and responding to perceived patterns and trends. There is an important set of questions related to how social actors respond to extreme events leading to losses. While neo-classical analysis would suggest that adaptation decision-making is based on an analysis of risks, costs and benefits under varying assumptions of foresight, other risk research suggests that assumptions of optimal responses rarely hold, especially in relation to large or catastrophic losses (Gawith et al. 2020; Pham, Nong, and Garschagen 2019). Applying such insights to the analysis of adaptation limits would bring important advances to our ability to make predictions about 'behaviours at the edge', including likely institutional and cultural inertia. Rather than focusing narrowly on the context for enabling or constraining transformative adaptation, there is also a need to understand the triggers to more radical options being taken.

Second, climate risks are reshaped through time everywhere – extreme events change in frequency, underlying social vulnerabilities evolve, attitudes to risk change (Field et al. 2012; Raymond et al. 2020). In responding to changed conditions and evolving capabilities and expectations, social actors will make judgements about whether or not to invest greater resources in adaptation and when, including the need to anticipate and respond along 'adaptation pathways' (Haasnoot et al. 2013;

Ojea, Lester, and Salgueiro-Otero 2020). Third, the availability of adaptation options may be enabled or constrained by prevailing conditions or capabilities (financial, economic, institutional or cultural) and these may change over time, for instance by growing wealth and resources. Or new adaptation options (technological, organisational or nature-based) may become available over time through innovation. This emergence of options suggests that limits will be mutable, a feature captured in the notion of 'soft limits' (Dow, Berkhout, and Preston 2013). In this sense, the resources and options to adapt would be expected to evolve over time, also affecting the choices actors have in defining and responding to adaptation limits. Comparison of the relative rates of change possible in different contexts (for instance, the evolution of behaviours, identities, regulations or markets) and the pace of change in specific climate risks offers policy relevant opportunities to anticipate limits and the time available to act. Fourth, we can predict that with intensified and more extreme climate impacts, adaptation limits will be experienced more widely, by more people, in more places, sectors and systems. There is an emerging literature on *systemic* climate risks (Centeno et al. 2015) which envisages connecting, cascading and amplifying risks over time. We anticipate these affects to precipitate the onset of cascading multilevel and transnational climate adaptation limits. Just as a scalar appreciation of limits is needed, so the propagation of limits through scales needs to be considered. This suggests a new set of global risk dynamics, with implications for broader scale risk and discontinuity.

Research under this theme could include a range of approaches from qualitative, historical case studies and surveys to cross-sectional, quantitative analysis employing long- or shorter-run differences in adaptive response. There would also be a role for experimental approaches which seek to test 'willingness to pay' for and 'willingness to accept' risk and adaptation under different risk contexts and with differentiated resources. In looking forward there would be a significant role for expert elicitation, in developing projections for aggregate scenarios of cascading risks linked to adaptation limits.

Integration of adaptation and limits into formal models

We have argued that formal economic and integrated assessment models for analysing climate impacts, damages and adaptation currently do not include plausible, consistent or theoretically- and empirically-grounded approaches for handling adaptation limits. Accordingly, a third needed research theme is developing an 'economics of adaptation limits' capable of bringing such constraints and limits to light. As impacts of climate change expose economic activities to risk, effort and investment to mitigate risks will increase up to a limit, at which point activity patterns will switch, with costs and benefits to individual agents and for the economy as a whole. Intuitively, this

simple insight could be integrated into a wide range of models, ranging from flood and crop models to integrated assessment models. For example, the shape of the 'adaptability constraint' would likely be determined by capabilities, assets and flexibility, and be grounded in either theoretical or empirical analysis (Buzan and Huber 2020) .

At the global level some attention has been paid to adaptation in global integrated assessment models. For example, the AD-DICE model extends the DICE model and shows that adaptation brings down the damages associated with climate change (de Bruin, Dellink, and Tol 2009). This conceptual, global study found that optimal adaptation reduced damage costs by 33%, leaving substantial and growing residual damages as global mean temperatures rise. A critical feature of such global models is the specification of damage functions, with a variety of approaches being taken, but until recently resting on a thin empirical and theoretical basis (Farmer et al. 2015).

More recent research on the social costs of carbon has made significant progress by developing more granular global data for the link between climate and economic, social and health outcomes, confirming the non-linear relationship between temperature and economic productivity (Hsiang et al. 2017; Kotz, Levermann, and Wenz 2022). These studies also emphasise the importance of including adaptation in economic analysis (Burke, Hsiang, and Miguel 2015; Carleton and Hsiang 2016). Auffhammer characterises the most promising approaches to costing the impacts of climate change as combining panel data estimations of damages with a Ricardian approach using a cross-sectional approach for characterising damages, while also arguing that adaptive responses need to be included in a more realistic way (Auffhammer 2018). These studies argue for greater attention to adaptation in assessments of damages, while questioning the robustness of the assumption that adaptation will be optimal (Carleton and Hsiang 2016). This gets to the problem of how 'constraints' on adaptation might operate (Klein, R J T et al. 2015), but they do not specify the distribution of damage costs or speculate on systemic transition costs associated with adaptation limits.

Beyond global assessments, there is also a need for microeconomic analysis which includes adaptation limits. In particular, there is a need to understand in greater detail the risk preferences of social agents (a vast field in economics, (Hertwig, Wulff, and Mata 2019), adaptive responses to changing probabilities of climate-related risk, including extreme events and slow-onset risks, considering the differential capacities, resource constraints and the availability of adaptation options. Such analysis would be strengthened by insights from behavioural studies with respect to risk, loss, uncertainty and expectations, and would contribute to the integration of adaptation limits in damage and adaptation functions in sectoral models. There are significant distributional aspects to vulnerability, damages and the capacity to adapt (Hsiang, Oliva, and Walker 2019), and identifying

these will inform policy interventions tuned to achieving greater equity in outcomes where adaptation limits are exceeded. Finally, the economic dynamics of adaptation, as growing climate change impacts lead to more transformative and widespread adaptive responses in sectors and regions, will call for the integration of adaptation limits in macroeconomic and trade models. As limits in food, urban and economic systems begin to connect and cascade through scales, new mechanisms for managing systemic risks may need to be developed at the international level.

Fairness and justice

The fourth research theme focuses on procedural and distributional consequences of adaptation limits and how to address them (Byskov et al. 2021; Robinson and Shine 2018; Woroniecki et al. 2019). Advances in this area will require analytical tools – including metrics, indices and proxies – for identifying contemporary or emerging adaptation limits at different scales and mapping their distribution socially, spatially, and over time. These methods and tools will need to give particular attention to marginal communities where social and economic processes and structures have crystallised the greatest relative risks and vulnerabilities. One approach could be to draw on evidence of short-run adaptive responses to risk, with the aim of developing anticipatory markers or metrics, possibly resembling and building on early warning systems for natural disasters (Andersson et al. 2020; Naumann et al. 2014).

Second, normative, political and cultural considerations will underlie adaptive responses, as they will shape what is valued and what adaptive options are viewed as appropriate. Likewise, prevailing norms and values will determine what are viewed as tolerable and intolerable risks requiring adaptation. Attention will also be needed to the potential for adaptation strategies to transfer vulnerability to these places or groups or to generate maladaptation (Atteridge and Remling 2018; Eriksen et al. 2021; Magnan et al. 2016). Understanding how adaptive responses and expectations unfold across different social, cultural, and economic settings is vital and could draw on a variety of analytical approaches including qualitative comparative case study research, cross sectional analysis, experimental and hedonic approaches, deliberative and participatory approaches and mixed methods combining these.

Third, there is a cluster of questions related to practical and policy responses which seek to address the procedural, distributional, equity, and justice consequences of adaptation limits. For example, work in this area could include the design of risk and resource transfer mechanisms applied to adaptation limits and anticipatory public policy and humanitarian responses. Insurance and bond markets have been created as a response to natural disasters and these could be extended to include provisions for transformative adaptation at limits as part of an overall adaptation policy

(Jarzabkowski et al. 2019). Research is needed to understand the wider equity consequences of these adaptation measures, such as flood buyout schemes or green infrastructures (Anguelovski et al. 2018).

Conclusion

Limits to adaptation, like many other expressions of climate change, are no longer just anticipated, but are increasingly observed and experienced. As those limits come into focus, some people can find paths to maintain climate-related risks to tolerable levels, while others find themselves unable to escape significant damage and loss precipitating radical changes in activities, livelihoods, welfare and identity. The recognition of the broader significance of adaptation limits is apparent in the number of research themes tackling aspects of the issue, but the connections to transformative research and action are still to be made. More effort is needed to advance an integrated understanding that is relevant for practitioners and policymakers as they engage with collective responses to significant changes to regional and global climates. We have sketched out four interrelated research themes which promise to generate convergent research insights that can inform policy and action. If escalating loss and damage can no longer be avoided, even in a 1.5˚C world, there is a need for a mature and well-articulated knowledge base to inform the critical choices that lie ahead.

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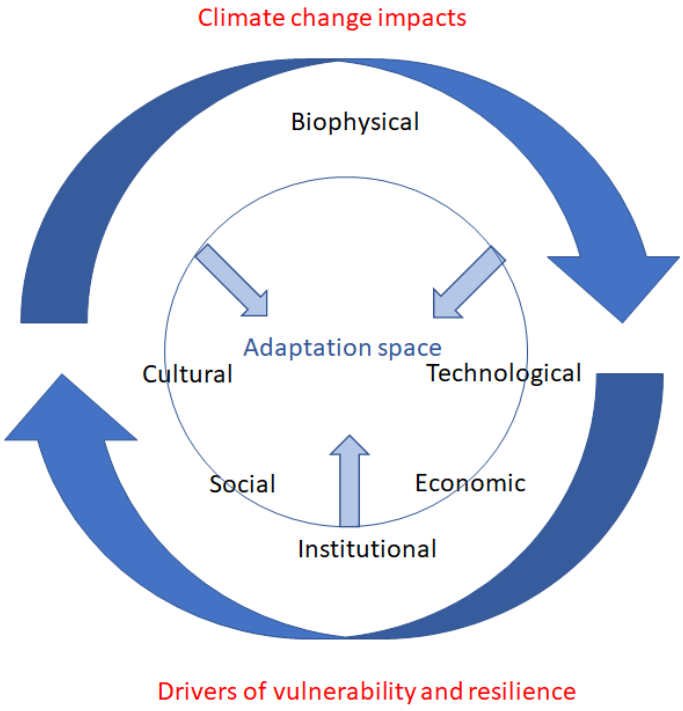

Figure 1: Biophysical and socio-economic factors influencing the adaptation space of actors (adapted from Shi and Moser, 2021)