frontiers | Frontiers in Climate

TYPE Original Research
PUBLISHED 04 March 2024
DOI 10.3389/fclim.2024.1303767

Check for updates

OPEN ACCESS

EDITED BY
Edmundo Molina-Perez,
Monterrey Institute of Technology and Higher Education (ITESM), Mexico

REVIEWED BY
Luis Serra-Barragan,
Monterrey Institute of Technology and Higher Education (ITESM), Mexico
Laurens Bouwer,
Climate Service Center Germany (GERICS), Germany

*CORRESPONDENCE
Thomas Schinko
✉ schinko@iiasa.ac.at

†PRESENT ADDRESS
Stefan Kienberger,
GeoSphere Austira, RiskLab - Weather, Climate and Natural Hazards, Vienna, Austria

RECEIVED 28 September 2023
ACCEPTED 14 February 2024
PUBLISHED 04 March 2024

CITATION
Schinko T, Karabaczek V, Menk L and Kienberger S (2024) Identifying constraints and limits to climate change adaptation in Austria under deep uncertainty.
Front. Clim. 6:1303767.
doi: 10.3389/fclim.2024.1303767

COPYRIGHT
© 2024 Schinko, Karabaczek, Menk and Kienberger. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Identifying constraints and limits to climate change adaptation in Austria under deep uncertainty

Thomas Schinko [1]*, Veronica Karabaczek[1], Linda Menk[2] and Stefan Kienberger[2†]

[1]International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, [2]Interfaculty Department of Geoinformatics - Z_GIS, Paris-Lodron University of Salzburg (PLUS), Salzburg, Austria

Although humanity has always been adapting to a changing environment, the accelerated rate of climate change in combination with continued socioeconomic development and the delay in climate action result in deep uncertainties, further challenging policy, and decision making. A main are of concern, triggered by the increasing frequency and intensity of climatic hazards are growing uncertainties regarding the effectiveness of prevailing adaptation strategies, as well as constraints and eventually limits to adaptation. The existing literature is largely conceptual and focusses on the Global South, where evidence for reaching adaptation limits already exists. In this study, we aim to uncover whether Austria, a Global North country, faces intolerable risks from climate change and experiences adaptation constraints that may trigger limits to adaptation. As there are still considerable uncertainties involved in quantifying potential adaptation limits, we use a social science approach to collect first empirical evidence on this crucial issue. We identify and discuss sources of concern based on semi-structured interviews ($n = 26$) with climate change adaptation and disaster risk management experts. Our results indicate that although Austria may currently not face physical constraints, which could lead to "hard" adaptation limits, it is nevertheless essential to upgrade existing adaptation strategies for more severe climatic events that may impose "soft" adaptation limits at the local and individual level. Many of these perceived soft adaptation limits are linked to constraints in imagination, awareness, and knowledge, but also to confining decision-making processes and the locked-in focus on technical adaptation measures, which cannot be scaled up indefinitely. To overcome these constraints and avoid adaptation limits, we suggest more inclusive stakeholder involvement in adaptive planning and the design of climate strategies by fostering bottom-up or participatory processes and integrating disaster risk management and climate change adaptation more strongly within polycentric risk governance approaches. Our insights can be seen as a precursory scoping study for the establishment of comprehensive decision making under deep uncertainty approaches in Austria and beyond, since at least many Global North countries share similar constraints and uncertainties regarding technological, economic, and political trends.

KEYWORDS

limits to adaptation, intolerable risks, climate risk management, adaptative planning, climate resilience strategies, deep uncertainties

1 Introduction

The adaptation of human societies to a changing environment is nothing new, and necessary to human survival (Adger et al., 2009). However, anthropogenic climate change and its interplay with socioeconomic development processes possess an increasingly significant challenge to policy and decision making because of deep uncertainty[1] (Marchau et al., 2019). Even though the uncertainty as to whether climate change is taking place and whether human activities are its main driver has been removed through collective efforts by the global research community over the last years, other considerable uncertainties remain (IPCC, 2021, 2022a,b). These comprise the magnitude and speed of climate change and its impacts, their geographical distribution and in turn adequate climate mitigation and adaptation policies.

A main area of concern, triggered by accelerated rates of climate change and the resulting increased frequency and intensity of natural hazards, are intensifying uncertainties regarding the effectiveness of individual adaptive measures and countries' climate change adaptation (CCA) strategies and whether limits to adaptation could be reached (Adger and Vincent, 2005; Adger and Barnett, 2009; Berkhout, 2013; Brondizio et al., 2016; Leal Filho and Nalau, 2018; Haasnoot et al., 2020). Evidence suggests that neither mitigation nor adaptation measures will suffice to safeguard socio-ecological systems from harm (Smith et al., 2011) or prevent losses and damages from climate change, which are already observable in certain regions of the world, beyond natural climate variability (Verheyen, 2012; Warner et al., 2012, 2013; IPCC, 2022a).

Adger et al. (2009) stress the importance of considering adaptation limits as "endogenous to society" and influenced by values, norms, and culture rather than simply conceptualizing them as physical, economic, or technological constraints, which are insufficient to describe them fully. Adaptation limits are socially constructed and materialize when impacts on physical or ecological systems are considered unacceptable or intolerable (Barnett et al., 2013). This makes adaptive action an issue of justice, as the prioritization of measures above others can adversely impact certain population groups more strongly than others (Barnett, 2010). Moreover, decision-making is driven by human cognition and perceptions, and the inability to imagine being vulnerable to climate change, also referred to as "limits of imagination," reduces the willingness to act and thereby the adaptive capacity of a system (Coulter, 2018) increasing the risk of breaching adaptation limits. All of this makes the case of adaptation limits a "wicked" policy problem, characterized not only by "deep uncertainty" but also "deep conflict" (Linnerooth-Bayer, 2021).

Building on a classification of uncertainty introduced by Walker et al. (2003), adaptation limits represent a "Level 4" uncertainty, i.e., the deepest level of recognized uncertainty and before the domain of "total ignorance," particularly when it comes to the Global North. Information on adaptation limits within scientific literature tends to be more conceptual than analytical (Thomas et al., 2021). Knowledge on the constituents, functional relationships and data (e.g., probability distributions of key parameters) of limits to adaptation is still lacking and requires further investigation (Barnett et al., 2015). As a result, analysts still struggle to specify appropriate quantitative models for effective policy and decision support. In addition, discussions on limits to adaptation within policy and research are also often focussed on countries of the Global South, for which some evidence of adaptation limits already exist (IPCC, 2022a). However, Global North countries could also be impacted by risks beyond adaptation limits and benefit from further research on the experiences of vulnerable groups (McNamara and Jackson, 2019). Assessing concrete examples of places and population (sub)groups at risk would lead to important advances in policy-oriented adaptation research (Barnett, 2010).

In this paper, we aim to contribute to a better understanding of adaptation constraints under deep uncertainty imposed by anthropogenic climate change and how they may lead to adaptation limits in the Global North by focusing on Austria as one specific example. We set out to empirically uncover by means of expert interviews (1) whether Austria faces climate change risks which are considered intolerable, (2) whether there is awareness for adaptation constraints potentially causing limits to adaptation and (3) what possible solutions to reduce such constraints could be, thereby supporting the development and design of robust adaptation strategies.

We argue that this social science approach can be an important first step toward establishing a comprehensive Decision Making Under Deep Uncertainty (DMDU) approach (Lempert et al., 2003; Stanton and Roelich, 2021) in countries like Austria as we shed light on all three generic elements of DMDU approaches (Marchau et al., 2019): (1) framing the analysis, by formulating triggering issues and problems, (2) performing an exploratory uncertainty (about external factors, system structures and outcomes) analysis based on expert opinion, and (3) identifying initial actions of incremental or transformative nature.

2 Background

2.1 Conceptualizing limits to adaptation

The Intergovernmental Panel on Climate Change (IPCC) defines CCA in human systems as "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC, 2019). Constraints make adaptation processes more difficult and are unevenly distributed across regions and groups. The IPCC distinguishes between physical, biological, economic, financial, human resource, social and cultural, as well as governance and institutional constraints (Klein et al., 2014). Constraints to CCA may lead to adaptation limits, defined as "conditions or factors that render adaptation ineffective as a response to climate change and are largely insurmountable" (Adger et al., 2007, p. 733) or "the point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions" (Dow et al., 2013; IPCC, 2019). Intolerable risks are those which "exceed a socially

1 In a situation of deep uncertainty, "the experts do not know or the parties to a decision cannot agree upon (i) the external context of the system, (ii) how the system works and its boundaries, and/or (iii) the outcomes of interest from the system and/or their relative importance" (paraphrasing Lempert et al., 2003; Marchau et al., 2019, p. 2).

negotiated norm (e.g., the availability of clean drinking water) or value (e.g., continuity of a way of life) despite adaptive action" (Dow et al., 2013, p. 385). Values refer to what is considered important by a group or society. Together with societal norms, they shape how rules and institutions are developed, and which actions are taken. Recognizing adaptation limits as socially constructed stresses the importance of ethics, knowledge, risk and culture in understanding where adaptation limits may arise (Adger et al., 2009). Adaptation limits can be qualified as "soft" when they can be shifted, for example once adaptative measures become available, and as "hard" when no adaptive action is possible (Klein et al., 2014). Soft adaptation limits are also referred to as constraints, which can be overcome in principle (Dow et al., 2013) or with concerted effort, changes in thinking or shifts in resources (Moser and Ekstrom, 2010; Barnett et al., 2015).

Limits to adaptation can also occur when the adaptive capacity of a human system is exceeded (Adger and Vincent, 2005). Constraints that may lead to adaptation limits are context-specific and vary according to sectoral, spatial and temporal scales (Biesbroek et al., 2013), while adaptive capacity depends on a combination of physical and intangible assets (Brown and Westaway, 2011), as well as political and social power relations (Birkmann, 2011). The actual feasibility of adaptative measures depends on available resources and measures, their appropriate and culturally acceptable use, as well as other external constraints (Füssel, 2007; Brown and Westaway, 2011). Although research on adaptive capacity is growing, it remains fragmented and would benefit from the identification of general patterns applicable in different contexts (Siders, 2019).

2.2 The Austrian context

Austria is expected to be disproportionately affected by climate change, with average temperature increases already above the global average. The mean temperature during the year 2020 was 2.1°C higher than the mean temperature of the reference period 1961–1990 (Stangl et al., 2021). Temperature extremes are predicted to increase, along with the frequency of extreme events (APCC, 2014). Under a moderate climate change scenario, the costs of weather- and climate-related disasters for society are predicted to rise to an average annual level of 4.2 to 5.2 billion EUR by mid-century if no measures are taken, compared to an annual average of around 1 billion EUR for the first decade of the twenty first century for direct damages, which represents slightly above 0.25% of GDP (Steininger et al., 2016). Austria relies heavily on its tourism industry which was directly and indirectly responsible for 6.2% of the county's nominal GDP in 2022 (BMWA, 2022), especially in terms of outdoor activities. The expected changes in precipitation and temperature will therefore strongly impact this sector (Pröbstl, 2021). Winter tourism in particular, which is responsible for almost half of annual overnight stays in Austria, is predicted to change fundamentally toward the end of the twenty first century as skiing will no longer be possible in all locations where it is practiced today (Steiger et al., 2021). Landscape changes can also be caused by the loss of forests, which provide not only timber, but important ecosystem services, including leisure and the protection of infrastructure and settlements from gravitational hazards (Getzner et al., 2017). Floods and droughts pose a high risk for health and wellbeing in Austria, which is predicted to increase further in the future due to the increased frequency, intensity and duration of extreme events (Haas et al., 2019). Substantial damages were caused by riverine flood events in 2002, 2005 and 2013, while insurable damages from agricultural droughts for 2013–2019 exceeded other types of agricultural losses, for instance those from storms or hail (Leitner et al., 2020).

Despite this comprehensive scientific evidence on potentially severe socioeconomic effects of climate change in Austria, the current policy narrative asserts that Austria's adaptive capacity is sufficiently high to deal with any future impacts of climate change. However, this perception does not necessarily mean that adaptation will occur and/or that adaptation strategies will be successful. This phenomenon, also referred to as the "adaptation myth" (Repetto, 2008), can be observed in a number of cases. Both in the U.S. and in Norway, two other industrialized Global North countries, there is evidence of a high risk of insufficient adaptation despite high adaptive capacity due to reactive rather than anticipatory adaptation practices (Naess et al., 2005; Repetto, 2008), or insufficient focus on indirect impacts of climate change (O'Brien et al., 2006). The scientific literature finds that delaying CCA action does not only lead to substantial costs in the future, but also to policy traps that inhibit the implementation of effective measures against the impacts of climate change (Nair and Howlett, 2016), with the risk of generating adaptation limits.

3 Methodology

To assess intolerable risks and adaptation constraints that may lead to adaptation limits in Austria, we opted for semi-structured interviews to systematically gather stakeholder perceptions, given the lack of and high uncertainty in long-term quantitative risk assessments. This is in line with most studies assessing adaptation limits examined by Thomas et al. (2021, p. 10), which carry out surveys, interviews and focus groups: "the actorcentric emphasis of these methodologies shows how social conditions and governance systems enable or limit adaptation." Semi-structured interviews are often used to investigate complex topics and opinions, or diverse viewpoints (Longhurst, 2009). This approach also allows interviewees to include contextual information and mention related issues they consider relevant. We designed an interview protocol divided into 5 sections: (1) natural hazards trends in Austria, (2) roles in disaster risk management (DRM) and CCA, and effected sectors, (3) CCA measures, potential limits, and transformation, (4) risk tolerance and intolerable risks, (5) international dimension. All interview questions were related to the current and future situation in Austria and aimed to gather interviewee perceptions, for instance on the most important types of extreme events in Austria, the status of cooperation between DRM and CCA institutions, or the measures which would be needed to tackle climate-related issues along with reasons why those are not implemented yet. We identified issues as adaptation constraints if they represent factors that inhibit appropriate and timely CCA measures, with the potential of leading to intolerable risks or undesirable outcomes for ecosystems and society. This was

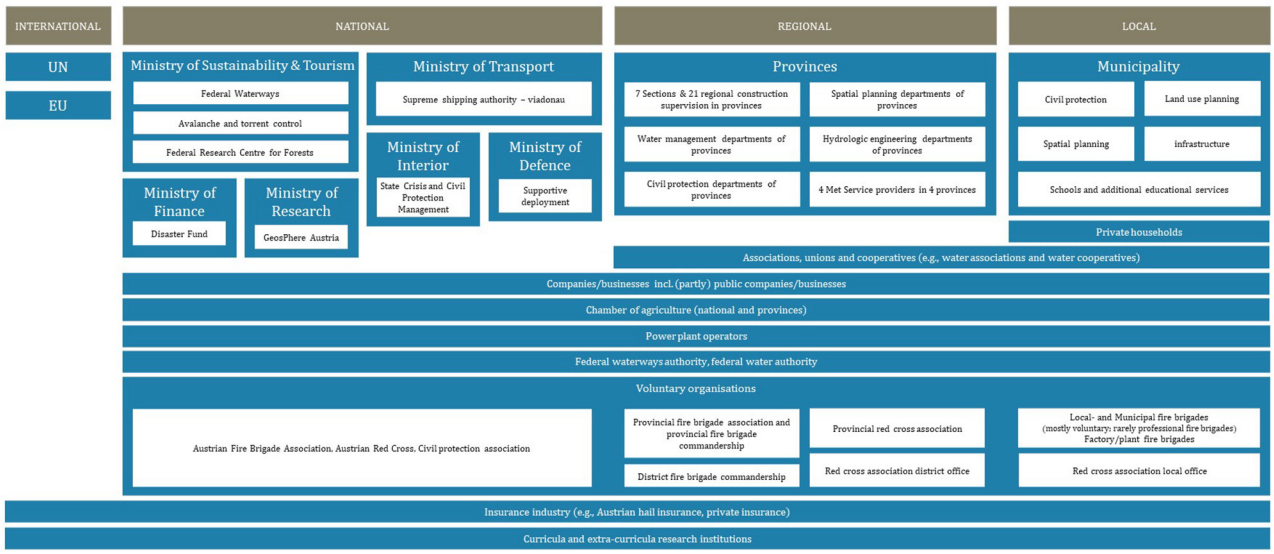

FIGURE 1
Risk governance mapping for the case of flood risk in Austria. Based on Leitner et al. (2019).

done through direct elicitation (e.g., "what does 'not being able to adapt' mean to you?" or "please describe a likely damage scenario which you would classify as intolerable") and by extracting implicit information from answers to other questions.

To identify relevant interviewees we have further developed and updated risk governance maps for Austria developed by Leitner et al. (2019) for various climate-related risks based on desktop research (see Figure 1 for the up to date governance map for flood risk in Austria). The initial set of interviewees was selected to cover these key public and private stakeholders in Austria in the field of climate risk management, specifically dealing with flood and drought risk, and across different levels of governance. The initial list of interviewees was continuously expanded through a snowballing approach, which permitted the identification of further relevant interview partners. Interviews lasted between 45 and 90 min and were carried out between June and September 2020 with a total of 26 respondents.

3.1 Data analysis

The qualitative data gathered through the interviews was evaluated in the software NVivo using Qualitative Content Analysis (QCA), which is a method used for the analysis of large datasets to systematically extract relevant qualitative information (Mayring, 2010). Responses were coded within a two-stage process into deductively predefined categories, which summarize into six higher-level headings (see Table 1 for the coding scheme). The first coding stage is reflected by the heading "Adaptation constraints" and the associated categories, which are based on the categories of adaptation constraints described in Thomas et al. (2021) (see first line in Table 1). We chose the categorization by Thomas et al. (2021) as first stage coding scheme because it is based on a comprehensive, systematic literature review and summarizes recent insights on constraints and limits to adaptation across the world. The second stage of the process then evaluated the interviews according to five additional headings, which represent the five sections of the interview protocol (see Supplementary material), and related categories (see lines 2–6 in Table 1). The second stage coding scheme allowed for a more nuanced and detailed evaluation of the interviews. The initial coding scheme was adjusted inductively during the coding process in order to better reflect the main themes discussed by the interviewees.

Interviewees were anonymised and given a coded name starting with A (for stakeholders from policy), F (for stakeholders from research), O (for stakeholders from public administration) and V (for stakeholders from the private and financial sector), followed by a number. These coded names are used in the following section to refer to interviewees.

4 Results

Our results indicate that climate-related risks in combination with adaptation constraints can potentially lead to various adaptation limits in Austria. In the following sections, we present more detailed examples of perceived adaptation constraints, their potential implications, and suggested measures to tackle them, structured according to the different categories of constraints presented in the first row of Table 1, our primary coding layer.

4.1 Economic constraints

4.1.1 Economic structures

Prevailing economic structures may impose constraints and lead to adaptation limits. The economic system can inhibit change and the implementation of new measures, as that would mean

TABLE 1 Coding categories.

Heading	Deductively pre-defined categories	Inductively adjusted categories
Adaptation constraints [based on Thomas et al. (2021)]	Economic	Economic
	Social/cultural	Social/cultural
	Human capacity	Human capacity
	Governance/Institutions/Policy	Governance/Institutions/Policy
	Financial	Financial
	Information/Awareness/Technology	Information/Awareness/Technology
	Physical	Physical
	Biological	Biological
Natural hazard trends in Austria	Heat and drought	Heat and drought
	Floods	Floods
	Precipitation	Precipitation
	Avalanches	Avalanches
	Permafrost	Bark beetles
	Bark beetles	Pests*
		Rockfalls*
		Storms and strong winds*
		Cold and frost*
Roles in disaster risk management (DRM) and CCA, and effected sectors	DRM	DRM
	CCA	CCA
	DRM and CCA	DRM and CCA
	Forestry	Forestry
	Agriculture	Agriculture
	Tourism	Tourism
	Industry	Industry
	Households	Households
		Critical infrastructure*
CCA measures, potential limits, and transformation	Technical/infrastructural measures	Technical/infrastructural measures
	Legal measures	Legal measures
	Spatial planning measures	Spatial planning measures
	Institutional measures	Institutional measures
	Behavioral changes	Behavioral changes
	Hard limits	Hard limits
	Soft limits	Soft limits
	No limits	No limits
	No new measures	No new measures
	Incremental adaptation	Incremental adaptation
	Fundamental changes	Fundamental changes Hard limits
Risk tolerance and intolerable risks	Tolerable risks	Tolerable risks
	Intolerable risks	Intolerable risks
	Monetary	Monetary

(Continued)

TABLE 1 (Continued)

Heading	Deductively pre-defined categories	Inductively adjusted categories
	Non-monetary	Non-monetary
	Evitable	Existential*
	Inevitable	
International dimension	Loss and damage	Loss and damage
		Climate finance*
		Climate justice*

Keywords in italics were removed while keywords marked with an asterisk were inductively added throughout the coding process.

devoting resources to activities not related to short-term profits (O2). Focussing on short-term economic objectives often also does not encourage participatory processes which could initiate change processes: "I think that if certain economic interests are in the foreground, then (participatory) initiatives can be blocked easily. When they are prioritized over voices in the population or social aspects, for example" (O3). Financial constraints could be removed through new regulations to support companies which would like to implement new, more sustainable practices (O6).

4.1.2 Dependence on natural resources

Many climate change-related impacts on ecosystems can also lead to economic constraints because of the importance of natural resources for certain economic sectors. In Austria, this is the case for the forestry sector. Increasing temperatures raise questions about which tree species to plant in Austrian forests in the future, which can mean negative economic impacts for those relying on timber for their livelihoods (A5). Spruce monocultures are frequent due to their quick growth and the versatility of the wood they provide. In cases of bark beetle infestations, livelihoods are threatened and cannot be replaced easily (F4).

Agricultural production is also at high risk of encountering adaptation limits, meaning the loss of livelihoods for many farmers. Increasing temperatures and more frequent or longer droughts facilitate the spread of pests, and can make it impossible to cultivate certain crop types in the future (V2). However, farmers are obligated to plant crops for which there is sufficient demand and for which they can get a good price. Increasing costs due to droughts, harvest losses or increasingly expensive insurance premiums can also lead to existential threats (O4). More details on biological constraints linked to forests and agriculture can be found in Section 4.8.

The tourism sector is economically very relevant in Austria, particularly during the winter season. Individuals in certain regions depend on tourism as their main source of income, while alternative livelihoods are not easily available. This means that they could experience great losses of income and existential threats (F1, F3, O3, O4) due to increasing temperatures and predicted decreases in snowfall and snow cover (A6, A9, O3, O4). As a solution, tourism in Austria could become more nature-oriented (F3): "I don't think it will be possible to completely switch from skiing holidays to hiking holidays in the winter. I think new concepts will be needed, also on how time can be spent in nature to enjoy the qualities of that space without endangering ecosystems" (O3).

4.2 Social/cultural constraints

4.2.1 Acceptance and willingness to change

One of the most frequently discussed adaptation constraints pertains to the willingness of individuals to implement or accept the implementation of CCA measures (A1, A5, A6, A8, A9, F2, O2, O5). Aversion to change, for example when measures necessitate a new lifestyle (O2) or relocation (O5), or the perception that CCA measures could lead to disadvantages (A9), are contributing factors. There are stronger concerns regarding restrictions to personal rights and freedom than possible impacts of climate change (A1, A6). It has also been observed that the implementation of new measures is challenging because people tend to revert to what they know despite expert advice on new methods (O2).

Another driver of the low acceptance of CCA measures may be the lack of urgency felt by individuals (A2, A4, A10, F4, O2), due to the uncertain and slow nature of climate change processes. These slow processes also mean that climate change needs to be communicated appropriately in order to motivate people to act (F4). People tend to forget about disasters when they are not a current topic, or their last occurrence dates back too long for them to be perceived as relevant (A10, F4, O2). However, urgency can and likely will increase and lead to behavioral changes or increased technological preparedness when permanent damages start occurring regularly (A4). It may also well be that people will have to learn to live with more damages, and that this will lead to more adaptive behavior (A7, O5, V1). "There will of course be damages, or more damages, but people will have to learn to live with this" (A7).

4.2.2 Individual responsibility for DRR and CCA

There is also the perception that individuals see the implementation of DRR measures as the responsibility of the state (F2). This means that they have little reason to deal with securing their property or preparing for climatic hazards. Many interviewees believe that it would be essential to give individuals more responsibility for their own risk reduction and protection against natural hazards (A1, A4, A5, A6, A7, A9, A10, F1, F2, F3, O1, O2, O6, O8). This could for instance mean behavioral changes such as regulating indoor temperatures to avoid overheating or using water with more care (A6), lifestyle changes (A9, F1, O2, O6), or more financial participation by individuals benefitting from protective measures (A2). Insurance costs could also be raised for individuals who choose to build in hazardous zones (A8).

In Austria, there is a high level of trust in technical protection measures. This mind set encourages people to build in hazardous zones close to infrastructure such as mudslide breakers because they feel safe, despite the knowledge that there could still be high residual risk (F3). Raising awareness for climate change-related issues within companies, schools and universities could facilitate this shift (A6, A8, A9, A10, F3, O1, O3). This could also increase the acceptance for CCA measures within the general population and reduce adaptation constraints (A6, O5).

4.3 Human capacity constraints

4.3.1 Individual capabilities

Human psychology and behavioral patterns were mentioned as constraints to adaptation. For instance, knowledge about a subject does not necessarily lead to action (A2, F4), and hearing about climate change is often not sufficient to lead to behavioral changes. This gives particular importance to knowledge transfer and the way technical and scientific topics are communicated (A9, F4). Communicating emotionally about climate change can aid in inciting people to act (F4). It is also not easy to grasp complex issues such as climate change and identify measures which would be truly effective. One of the interviewees mentioned that "there are probably many limits to adaptation, but it is probably impossible to say which ones yet" (A9). This suggests a limit of imagination and uncertainty about the best course of action in light of an uncertain future. Effective adaptation can therefore be hindered by the implementation of ineffective measures. This can give individuals a false sense of success and limit any further action. An example would be the distribution of information brochures about climate change: "if you want to do something, what is always easy is to provide information. And then you did something, you can say 'alright, issue closed' and don't have to deal with the questions further" (F2)

4.3.2 Societal capabilities – systemic risk

We also identified constraints due to compound or systemic risks, which fit best into the "human capacity" category as they arise from to the way social systems are organized. The COVID-19 pandemic is a good example of a factor increasing the risk for adaptation limits because capacities are needed elsewhere, and no structures are in place to ensure the smooth handling of climatic hazards which may occur simultaneously (A1).

When critical infrastructure is affected, large-scale issues will arise that will be hard to manage due to the dependence on certain services such as health care or electricity provision (O6). Damages will go beyond the loss of a building or structure and be felt in other parts of the system. Such adaptation constraints can also exist on an individual level, for example when a person is faced with multiple stressors simultaneously such as losing their job, taking care of a sick family member, and losing their home because of an extreme event (F2).

4.4 Governance/institutions/policy constraints

4.4.1 Willingness to act and risk communication

A lacking willingness to implement stronger CCA measures is not only observed among individuals, but also among policymakers (A2, A5, O6, V1). This may be due to the belief that "things will work out" (A2), or again, a lacking feeling of urgency (O6).

The low acceptance of CCA measures within the population could be rooted in the fact that there are still too few bottom-up processes involving individuals in decision-making processes (A5, F2). This governance constraint therefore feeds into the social constraint identified above. More bottom-up processes including individuals in the different steps of the risk management cycle would aid in tackling climate-related issues more effectively (A4, O3) and could increase individuals' responsibility for their risk reduction (F2). "I think it needs a clear commitment at the political level, that there is an awareness of the changes which are to come, that new processes are being designed which include the population in the creation of new formats, options, possibilities, whatever. I think it would be very important, I would wish for that, that one has the possibility to be included in such processes, that the problems and concerns of different groups are being listened to, and that it's not just about growth and the loss of jobs and numbers" (O3).

Added to that, policymakers are perceived to have an aversion against raising the debate of increasing the responsibility of individuals and households in cases of natural hazard damages (F2). Similarly, "catastrophic scenarios" due to climate change are rarely addressed and discussed in public by decision-makers to enforce the image that everything is under control (F3). This makes it more difficult to implement appropriate measures to prepare for them. Interviewee A9 recognizes the role of the state in initiating and leading a discussion on possible future scenarios and lifestyle changes: "we have many good reasons to say that the conditions in which we have lived are not sustainable, and are actually terrible. We don't have positive stories of the future. That means that this discourse has to be conducted, socio-politically, this is not the duty of universities and experts, this is a socio-political discourse, and we have to provide input" (A9). More communication is therefore needed with individuals (A5), especially from affected population groups, in order to ensure that risk and consequences of actions (e.g., the impact of frequent flying on the climate) are understood (A2, A9, O6).

4.4.2 Established governance systems and regulations

It was mentioned that, as with any established governance system, it is difficult to change the status quo and to change power balances (F3, F5). Bringing CCA to the forefront of political decision-making therefore remains challenging. Certain interest groups may also not want to change anything about the current situation and are actively working toward keeping things the way they are (O3). "That means that it could happen to us that we already have answers, but that they are politically not feasible. And if we lose as much time with CCA as with climate change mitigation, then I think the situation will be quite serious" (A9).

Similarly, it is difficult to change regulations and framework conditions to become more favorable to the implementation of CCA measures. "I mean, one thing is the willingness, if someone wants to do something or not, but of course the framework conditions are also essential. I may really want something, if the legal and the financial, economic framework conditions don't allow it, it simply will not happen" (A2). For example, the law makes it difficult for authorities to tell individuals and households to rebuild their destroyed houses in another location (F3). Households are therefore at risk of experiencing damages repeatedly.

Policy constraints were also mentioned in the context of disaster risk insurance. In Austria, floods are currently not insurable, leading to inadequate compensation of households suffering from flood damages. According to interviewee V1, this is simply a matter of regulatory enforcement. If flood insurance, or natural hazard insurance in general became compulsory for everyone, this could be avoided. Currently, it represents an adaptation limit at an individual level due to a policy constraint.

4.4.3 Spatial planning

There is recognition for the importance of spatial planning within CRM. The large number of diverging interests concerning the use of space makes it difficult to restrict spatial planning if all interests are to be weighed in decision-making processes (A10). In Austria, spatial planning competencies lie at the municipal level. This can impede agreement on new hazard zones, as they mean the loss of construction space and are rarely in the immediate interest of local decision-makers. "There should be more flood risk zones. In Salzburg, there are efforts to address this, but the mayors say 'not in my municipality, please, but the next one'. This is also the case in Tyrol, essentially everywhere where there are valleys" (A11). Interviewees generally agree that hazard zones should become more restrictive, e.g., in terms of what can be built in them, especially with increasing hazard risks (A2, A5, A6, A7, A8, A9, F3, O5, O6). Space should be used more carefully, which could necessitate a more holistic approach to spatial planning going beyond municipal and district borders (A10). This could mean including federal province governments in spatial planning decisions (F5), or redistributing spatial planning competencies altogether (O2) in order to follow a more trans-regional (O4) or centralized (F3) approach. "If somebody asked me, what is the most important CCA measure, I would argue in favor of climate spatial planning, climate change mitigation and adaptation within spatial planning" (A5).

In Austria, the settlement of alpine valleys is common practice and part of the country's settlement strategy. For some, this strategy is not the right way forward: "this permanent offer, to have to preserve settlement space, to have to preserve the alpine economic space, and under this viewpoint, more or less everything has to be financed, is unbelievable" (F3). Relocation in alpine areas is extremely difficult because nearly every safe space available for construction is already in use (A1). Another reason why relocation is not considered as an option could be due to the available funding in Austria: "(this discussion) only exists rudimentarily simply because Austria is a very rich country and can afford very good technical measures, and as long as money is there and this can be done, the pressure on policymakers to make different, harder decisions, is not great enough" (O2). However, this could change with more frequent or intense hazards: "what we are already experiencing today, is that certain areas are no longer suitable, I have already mentioned flood relocation, which is already occurring, and I think that will become worse with extreme events. Especially in alpine regions, there is extreme urban sprawl in those valleys, there are scattered settlements, where possibly not every site can be maintained, because that is of course very expensive" (A5). Relocation may therefore have to be increasingly considered as a CCA option, at least in individual cases (A2, A5). "This big discussion, can we really afford completely developing every side valley in Tyrol? Does not yet exist. I think sooner or later it will come, because costs will increase excessively" (O2). This suggests future financial constraints which could lead to adaptation limits.

4.4.4 Institutional dependencies and cooperation

There is also awareness for the importance of voluntary engagement in disaster risk management in Austria, with beginning concerns regarding the number of volunteers and financial support they could receive in the future (A6, A9, O5). "We have a very strong volunteer system in Austria, we will surely have to come up with something, be it premiums for companies which give their employees leave, which are already being discussed, and other things" (A9).

4.5 Financial constraints

Potential financial constraints for the state were identified by multiple stakeholders from research and the public sector in the case that the magnitude and frequency of hazardous events would increase too much (F1, F2, F5, O1, O6, O7). Individuals may also lack the financial means to invest in protective infrastructure for their property (A2).

In Austria, the disaster fund ("KatFonds") exists to compensate households for damages caused by natural disasters. It is an established system, "[…] but at a certain point, a limit will be reached where you say that it is no longer financeable, or it would be cheaper to relocate buildings" (A5). Similarly, insurance could become too expensive to cover damages from natural hazards in the future (A5, A9, O4, V2). It could be that discussions around the affordability of measures are needed, as decision-makers are perceived to believe that everything can be afforded in Austria (O2).

Financial constraints can also arise from decision-making processes and conflicts of interest regarding the allocation of public funds (A5, A6, A9, A10). For example, the need for social housing stands in opposition with more expensive climate-resilient housing (A5). During the COVID-19 pandemic, Austrian state funds were used to compensate for economic losses, which reduced the amount of money potentially available for CCA measures (A10). Even without such crises, financial constraints can arise when insufficient money is allocated to CCA measures (A6, A9). This can also be expressed as lacking willingness to pay, depending on whether something is recognized as valuable or not (A8, A9, F2). This will also be the case in the future, when more damages are predicted.

"Over the long term, the debate will arise for the state: which infrastructure are we upholding, at which cost?" (A9).

New regulations for the financial redistribution between the national, federal province and municipal level could be necessary for funding allocation and use as the distribution of funding does not always reflect the distribution of work: "it is unfortunately a fact that communes have had to increasingly take on tasks from federal province governments in the last 10, 15 years, be it in education, healthcare, supply, and we simply no longer have the financial capabilities" (O6).

4.6 Information/awareness/technology constraints

4.6.1 Knowledge and awareness

Lack of awareness of potential risks and the need to act can be a constraining factor for adaptation (A3). It can arise when climate change-related topics are not sufficiently taught and emphasized in schools, universities and at company level yet (A6). Lack of awareness can be observed at different scales, among individuals, or decision-makers at national and local levels. "Decision-makers in this commune, they are not yet aware. They do not recognize the intensity of what is occurring, and prefer to delay it" (O6).

More awareness by the state and public sector is needed to implement necessary measures (A2, A4, A6, O3). "We are still far from having the awareness required to ensure that necessary measures are happening, or preparations are happening at a public level, but I see the urgency of it all the more" (A4). However, even when awareness about climate change exists, it is very difficult to turn it into concrete political measures (A4), due to the elaborate nature of decision-making processes, diverging interests or uncertainty about the future. Lacking knowledge was in fact mentioned more frequently as an adaptation constraint than lacking awareness. Despite being aware of the need to act, lacking knowledge on future conditions under climate change makes it difficult to plan (A4, A9, F1, F3, O8). This can be caused by the complex interactions between different systems and ecosystems (A4, A9). Lack of knowledge often extends to geographically specific examples. For instance, the lack of knowledge of where hazards can occur can lead to construction in hazardous zones (A7, O7).

4.6.2 Technical limits

In terms of technical limits, it was recognized by multiple interviewees that there are limits associated with protective infrastructure (A1, A2, A9, F1, O1, O5). "In reality, it is not possible to protect everything with technical means and this will probably become less and less possible" (A2). This statement refers to the notion of residual risk, and the fact that measures can always fail (A10, O7, O8, V1). "And we always say "protective infrastructure can work, but doesn't have to work." [. . .] We cannot do that, control nature, we really cannot" (A10). Due to changing conditions, hazardous events could go beyond the capacity of current flood protection measures (A9, O2). In alpine regions, the limited available space constrains the possibilities of what can be built (A1).

The height of flood protection measures cannot be increased indefinitely (A9, O2, O5), meaning that larger flood events cannot simply be tackled with larger dams. Riverine flood events are not expected to cause adaptation limits in Austria because the country is well-prepared and has a lot of experience with this type of hazard (A3, F4). The implementation of necessary measures is possible (A6) and damages from floods are not expected to be permanent (A7). Climate change is however predicted to lead to more floods from extreme precipitation than is currently the case, which are a lot more difficult to prepare for with technical measures and may lead to adaptation limits (O1). Measures which were previously not considered may then be needed: "I think that at some point you will no longer have to ask yourself if a dam's height has to be increase by 10 cm or 1 m, but you have to think, how will you manage a flood that will come in certain areas that you will not be able to prevent, and how do you adapt as a society to ensure the flood does not create the damage it would currently create?" (O5). This also implies a certain mind set shift of what is considered to be an acceptable CCA measure. Relocation may only be reluctantly accepted today, but this could change in the future with increasing natural hazard risks. For instance, it could be argued that "in principle, relocations are about shifts of economic zones, not about losses. We gain even more through relocations, namely retention space, and we gain space that we no longer have to protect in the future" (A7).

Technical measures are also not a substitute for lost protection forests (F1). "[Protection forests] are a relatively cheap system, and when this system no longer works, because conditions are too dry for forests at high altitudes, which is quite possible in the Central Alps, then we lose the settlements along with the forests, because we can probably not afford technical measures, and if we could afford them, we wouldn't want them, and then we would have to cement the mountains to ensure that everything there remains fixed. All these regions that make Austria so attractive, the mountain landscapes, are very threatened in my opinion" (F1).

Another limiting factor of technical measures is that they can take a long time before becoming effective, for example due to long decision-making or construction times (A4, F5). Climatic conditions may however change in the meantime, making them less effective than intended at the moment they were planned. Existing infrastructure also faces issues under climate change, as it cannot be moved, or only at a very high cost (A9). Sewer systems could become too small to receive the amounts of water predicted from extreme precipitation events (A6, O6). This means that timely interventions are necessary to ensure sufficient preparation for future conditions. More resilient buildings should be constructed to reduce natural hazard risks (A5, A6). High temperatures in critical infrastructure and public buildings such as hospitals will require appropriate levels of cooling in order to maintain suitable conditions for vulnerable population groups (A9, O6). Technical snowmaking, which is already a fundamental part of winter tourism, will become impossible when temperatures increase too much (O3).

4.7 Physical constraints

No constraints potentially leading to adaptation limits in Austria were identified by the interviewees in this category. Examples of physical constraints would for example include the loss of land due to sea level rise, flooding or desertification, which are currently not predicted in Austria.

4.8 Biological constraints

Most biological constraints identified by interviewees stem from increasing temperatures and altered meteorological conditions, such as drought and extreme precipitation. The forestry and agricultural sectors are particularly affected by these changes and are frequently discussed due to their economic importance. Forests also play an important role in Austria due to the ecosystem services they provide and protective functions against hazards such as landslides, avalanches and rockfalls. Forests are recognized as particularly vulnerable to climate change (A9, F3, O1, O2), especially to droughts (V2). This can lead to landscape changes (O2). Temperature increases will also change the forest composition and move the treeline to higher altitudes, which can change the local hydrology and reduce natural hazard protection (A1).

A different and more varied tree species composition could however also reduce damages from bark beetles (F4), which pose a significant threat to Austrian forests (F1, F3, O1, V2). Bark beetle infestations are becoming more common as increasing temperatures create more favorable conditions for their spread. They can now be found in regions which were previously unaffected, including at higher altitudes, and are very difficult to combat. An added challenge is the long growth time of trees, which makes it difficult to make up for the loss of forests and represents an important biological adaptation constraint (A1, F3, O1, O7, V2). Thanks to ongoing research on heat-resistant tree species, however, A1 believes that despite these difficulties, there will be no overall adaptation limit for forests in Austria. Other interviewees believe that more research on protection forests and forest ecosystems is still needed (F3, O6). In the agricultural sector, one interviewee believes that water management would be sufficient to prevent intolerable impacts, provided that only the seasonality of precipitation events changes, not quantities of water (F4). Adjusting crop types would also help in reducing vulnerability (A6, O4).

Higher temperatures also lead to more moisture in the air, and therefore to more extreme precipitation events (A5, A7, V1). There is the concern that climatic changes will occur so quickly in the future that it will not be possible to adapt (A9, O6). Ecosystems can degrade very quickly after certain thresholds are reached (A9), which can lead to sudden adaptation limits, and irreversible loss. The loss of protection forests would leave many settlements vulnerable as there are no technical alternatives that offer the same level of protection (F1), while it takes ~50 years for a reforested area to be ready (F3). Changing water regimes and decreasing snowmelt may lead to reduced groundwater availability (O4). Water scarcity could in turn lead to the irreversible loss of land, which would have a strong impact on the agricultural sector (O4). Damages from extreme events occurring over large areas such as large-scale frost or drought are not preventable (A6, F1, V2). Similarly, the intensity of extreme events may stand in the way of effective adaptation. "We have weather events, for example if we have hurricanes that reach proportions we can no longer handle, that technology cannot handle, then damages will be considerable. I think that we will not be able to reduce this residual risk through future measures" (A6). "When a larger flood occurs, then that will of course result in a catastrophe, and 1 day a flood will occur which, possibly reinforced through climate change, will lead to this catastrophic scenario, but it is difficult to prepare for that. I mean it would mean reserving funds over decades for an event that may not occur" (A7).

Biological constraints may also relate to humans themselves. Higher temperatures create conditions which increase the health risks of vulnerable population groups, such as the sick and elderly. Measures tackling heat-related excess mortality are lacking and will be urgently needed in the future (F4, O6, O7, V1).

4.9 Constraints vs. limits to adaptation

Although most interviewees were able to give examples of potential adaptation constraints and challenging or even catastrophic scenarios, many state that at the country-wide level, Austria does not appear to face immediate adaptation limits. "Policymakers are aware of the need to further invest, and in that sense, everything which is needed to deal with the current impacts that we see is available. [...] We are currently not on the edge of capacity limits concerning risk management. It is maybe always a question of personal conditions, when individual citizens are affected, it hurts of course, but society in Austria is currently not faced with any limits because of natural hazards. That can change, naturally" (A1). This was also identified on a regional level, specifically because of the perception that all potentially affected stakeholders are aware of the risks and ensure careful planning and good cooperation among relevant parties (O7).

Any losses of land or damages which are incurred locally can be compensated at a macroeconomic level, as opposed to states such as Kiribati or Tuvalu, which may lose large areas of land and face existential risks (O4). The risk of certain areas in Austria becoming uninhabitable is perceived as "not as extreme as in other areas of the world" (A8), and is only relevant at very small scales, if at all (O5). There is also the belief that necessary measures are affordable (F4) and that damages from climatic changes can be covered by insurance (V1). "In Austria, no, I don't believe that things will happen where we will have to say that we have to leave. We adapt, [...] we are doing relatively well, we just have to make sure that it all stays in a certain financial frame which works. And for that, planning with foresight, spatial planning, zoning, are important topics. And for that, assertive policymaking is necessary" (A8).

5 Discussion and conclusion

As there are still considerable and deep uncertainties involved in identifying and quantifying potential adaptation limits, we use a social science approach to shed light on this crucial issue.

The results from the semi-structured expert interviews show awareness of different types of adaptation constraints from various stakeholders with different roles in the political, scientific and organizational landscape in Austria. Whether these constraints will eventually lead to adaptation limits or are rather points which should be improved to optimize existing adaptation strategies is not easy to distinguish, as it is difficult to predict under deep and long-term uncertainty which impacts will actually materialize, with which outcome. The possibility of constraints leading to soft adaptation limits, which can be overcome in principle, contributes to this lack of clarity.

The interviews were an effective method to gain an insight into perceptions on adaptation constraints and limits in Austria at different levels and from different perspectives. The results are a valuable addition to quantitative data such as monetary losses or available funding for DRM, as they highlight developments in important sectors and groups, or important interlinkages between sectors, that cannot easily be quantified yet. As such, our qualitative results can support the design of climate adaptation strategies and help ensure that these achieve their development and resilience objectives despite long-term uncertainty (Moallemi et al., 2022).

Importantly, we find little awareness among interviewed stakeholders of systemic risks which, however, hold a high potential for leading to intolerable damages and adaptation limits. Their consideration in developing climate strategies under deep uncertainty would be essential for effective adaptation and requires more focus from policy and research (Li et al., 2021; Renn et al., 2022). Possible "tipping points" due to climate change, for example in the tourism sector, are not yet sufficiently understood and bear great risks for certain regions in Austria (Steiger et al., 2021).

It was frequently stated that the incentives for risk reduction measures at the individual level are very low in Austria, as it is understood that the state is responsible for impact compensation after the occurrence of natural hazards. This was described by Adger and Vincent (2005) as the "nested nature of decision-making," meaning that individual adaptation actions are constrained by regulatory decisions, a governance challenge that is also present in the context of climate change mitigation in Austria (Irshaid et al., 2021). The creation of an enabling environment with regulations supporting sustainable behavior would greatly reduce potential adaptation constraints such as the commonly identified lack of willingness among individuals to implement or accept the implementation of CCA measures, possibly driven by a lacking sense of urgency. "No sense of urgency" was also identified by Biesbroek et al. (2011) as an important potential adaptation barrier. They further list "insufficient financial resources," "short-termism in politics," and "insufficient knowledge about adaptation." The lacking willingness to implement stricter measures among policymakers was also discussed in our interviews, as well as the resulting need for more awareness by the state and public sector for the potentially strongly increasing climate-related risks in Austria. Coulter (2018, p. 223) presents similar results relating to stakeholders from Australia and Canada minimizing climate change threats due to "perceived high adaptive capacity and low exposure." Such "limits of imagination" bear the risk of missing the appropriate timeframe for implementing CCA measures and acting only when it is too late.

Regarding necessary measures to overcome adaptation constraints within current practices and to avoid future adaptation limits, the strongest consensus was found regarding the need to give individuals more responsibility for their own risk reduction and protection against damages from climatic hazards. Although this is an important aspect of effective adaptation strategies, it does not remove the importance of governmental responsibility for enabling adaptation and sustainable behavior across all societal levels, including institutions and businesses. Adaptation can for instance be further mainstreamed into existing policies, while new regulations or financial support can be introduced to facilitate transformational change. Spatial planning is also very influential in reducing risks and cannot be adjusted without the involvement of the regional and local government. Existing tools such as the disaster fund, however, will have to be adapted in light of projected increases in damages due to climate change, as discussed by Schinko et al. (2017).

Low awareness of adaptation limits does not mean a lack of CCA or DRM action, especially in countries such as Austria, where DRM has a long tradition and residual risks are accounted for. A stronger integration of CCA and DRM, which is a comprehensive approach also known as Climate Risk Management (CRM), would however strengthen the existing DRR capacities in Austria by introducing a more forward-looking approach to disaster risk management (Birkmann and von Teichman, 2010; Schinko et al., 2017; Leitner et al., 2020). This would be greatly facilitated by more communication between institutions and relevant stakeholders, which could be institutionalized through an Austrian climate risk council (Leitner et al., 2020).

Although Austria may not be faced with physical constraints such as sea level rise or desertification, which could lead to "hard" adaptation limits, it is nevertheless essential to proactively prepare strategies for more severe climatic events and impacts that may impose "soft" adaptation limits at the local and individual level in Austria, as our results indicate. A backwards-looking approach relying on past events, historical data and existing DRR measures will not be sufficient as climate change is already changing the magnitude and frequency of hazardous events and will continue to do so in the future. Especially systemic risks should be at the core of both research and policymaking, with participatory processes ensuring that existing limits of imagination can be overcome, and that the needs of many are considered in the design and implementation of comprehensive CRM measures and strategies. In particular, the development of comprehensive climate strategies requires constant interaction with a vast and diverse set of stakeholders (Ross et al., 2021). To this end, Lempert and Turner (2021) demonstrate that Decision Making Under Deep Uncertainty (DMDU) methods can aid the integration of different worldviews and (quantitative) decision support (see also Linnerooth-Bayer, 2021). We are confident that our social science approach conducted in this paper has brought to the fore some important empirical insights across all generic elements of DMDU approaches (i.e., framing, exploring, choosing; see Marchau et al., 2019). These insights can be seen as a precursor or scoping study for the establishment of

comprehensive DMDU approaches in a Global North country like Austria.

Our insights are not only relevant for tackling adaptation limits in Austria, but also for many other countries across the globe. Since many Global North countries share similar constraints and uncertainties regarding technological, economic, and political trends, our insights from Austria are valuable for identifying adaptation constraints and eventually proactively addressing adaptation limits within robust adaptation strategies in other geographical contexts. Both climatic and non-climatic factors are at the root of adaptation limits and necessitate the involvement of stakeholders and the consideration of their diverse values and worldviews in order to be identified and successfully addressed. As research on adaptation limits is becoming more widespread, it is now essential to begin with the identification of potential impacts beyond adaptation by policymakers and the practical implementation of potentially transformational CRM measures and strategies to ensure tolerable levels of risks under climate change.

Data availability statement

The datasets presented in this article are not readily available because the data that support the findings of this study are not publicly available due to them containing information that could compromise research participants' privacy/consent. Requests to access the datasets should be directed to schinko@iiasa.ac.at.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the (patients/ participants OR patients/participants legal guardian/next of kin) was required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

TS: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. VK: Conceptualization, Data curation, Formal analysis, Investigation, Validation, Writing – original draft. LM: Writing – review & editing. SK: Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. The authors were supported by the Austrian Climate and Energy Fund [Austrian Climate Research Program (ACRP), project TransLoss, project number B960205].

Conflict of interest

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

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2024.1303767/full#supplementary-material

References

Adger, W. N., Agrawala, S., Mirza, M. M. Q., Conde, C., O'Brien, K., Pulhin, J., et al. (2007). Assessment of adaptation practices, options, constraints and capacity. *Clim. Change* 12, 717−743.

Adger, W. N., and Barnett, J. (2009). Four reasons for concern about adaptation to climate change. *Environ. Plan. A* 41, 2800–2805. doi: 10.1068/a42244

Adger, W. N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D. R., et al. (2009). Are there social limits to adaptation to climate change? *Clim. change* 93, 335–354. doi: 10.1007/s10584-008-9520-z

Adger, W. N., and Vincent, K. (2005). Uncertainty in adaptive capacity. *Comptes. Rendus Geosci.* 337, 399–410. doi: 10.1016/j.crte.2004.11.004

APCC (2014). *Summary for Policymakers (SPM). Austrian Assessment Report Climate Change 2014 (AAR14).* Vienna: Austrian Panel on Climate Change (APCC).

Barnett, J. (2010). Adapting to climate change: three key challenges for research and policy–an editorial essay. *Wiley Interdis. Rev. Clim. Change* 1, 314–317. doi: 10.1002/wcc.28

Barnett, J., Evans, L. S., Gross, C., Kiem, A. S., Kingsford, R. T., Palutikof, J. P., et al. (2015). From barriers to limits to climate change adaptation: path dependency and the speed of change. *Ecol. Soc.* 20, 200305. doi: 10.5751/ES-07698-200305

Barnett, J., Mortreux, C., and Adger, W. N. (2013). *Barriers and Limits to Adaptation: Cautionary Notes. Natural Disasters and Adaptation to Climate Change.* Cambridge: Cambridge University Press, 223–235.

Berkhout, F. (2013). *Rationales for Adaptation in EU Climate Change Policies. Climate Policy Options Post-2012.* London: Routledge, 377–391.

Biesbroek, G. R., Klostermann, J. E., Termeer, C. J., and Kabat, P. (2013). On the nature of barriers to climate change adaptation. *Reg. Environ. Change* 13, 1119–1129. doi: 10.1007/s10113-013-0421-y

Biesbroek, R., Klostermann, J., Termeer, C., and Kabat, P. (2011). Barriers to climate change adaptation in the Netherlands. *Climate Law* 2, 181–199. doi: 10.1163/CL-2011-033

Birkmann, J. (2011). First-and second-order adaptation to natural hazards and extreme events in the context of climate change. *Nat. Hazards* 58, 811–840. doi: 10.1007/s11069-011-9806-8

Birkmann, J., and von Teichman, K. (2010). Integrating disaster risk reduction and climate change adaptation: key challenges—scales, knowledge, and norms. *Sust. Sci.* 5, 171–184. doi: 10.1007/s11625-010-0108-y

BMWA (2022). *Tourismus in Österreich 2022. Bundesministerium für Arbeit und Wirtschaft*. Availble online at: https://www.statistik.at/fileadmin/user_upload/Projektbericht-Tourismusbericht_2022_barrierefrei.pdf (accessed December 14, 2023).

Brondizio, E. S., O'Brien, K., Bai, X., Biermann, F., Steffen, W., Berkhout, F., and Chen, C. T. A. (2016). Re-conceptualizing the Anthropocene: a call for collaboration. *Global Environ. Change* 39, 318–327. doi: 10.1016/j.gloenvcha.2016.02.006

Brown, K., and Westaway, E. (2011). Agency, capacity, and resilience to environmental change: lessons from human development, well-being, and disasters. *Ann. Rev. Environ. Res.urces* 36, 321–342. doi: 10.1146/annurev-environ-052610-092905

Coulter, L. (2018). "The limits of imagination," in *Limits to Climate Change Adaptation*, eds L. Filho, W. Nalau (Cham: Springer International Publishing), 211–226.

Dow, K., Berkhout, F., and Preston, B. L. (2013). Limits to adaptation to climate change: a risk approach. *Curr. Opin. Environ. Sust.* 5, 384–391. doi: 10.1016/j.cosust.2013.07.005

Füssel, H. M. (2007). Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sust. Sci.* 2, 265–275. doi: 10.1007/s11625-007-0032-y

Getzner, M., Gutheil-Knopp-Kirchwald, G., Kreimer, E., Kirchmeir, H., and Huber, M. (2017). Gravitational natural hazards: valuing the protective function of Alpine forests. *Forest Policy Econ.* 80, 150–159. doi: 10.1016/j.forpol.2017.03.015

Haas, W., Moshammer, H., Muttarak, R., and Koland, O. (2019). *Österreichischer Special Report Gesundheit, Demographie und Klimawandel*. Bäckerstraße: Verlag der Österreichischen Akademie der Wissenschaften, 331.

Haasnoot, M., Biesbroek, R., Lawrence, J., Muccione, V., Lempert, R., Glavovic, B., et al. (2020). Defining the solution space to accelerate climate change adaptation. *Reg. Environ. Change* 20, 1–5. doi: 10.1007/s10113-020-01623-8

IPCC (2019). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. eds. H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, and N. M. Weyer (Cambridge, UK; New York, NY: Cambridge University Press), 755. doi: 10.1017/9781009157964

IPCC (2021). "Summary for policymakers," in Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, eds P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, and N. Caud (Cambridge: Cambridge University Press), 3–32.

IPCC (2022a). "Summary for policymakers," in *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,* eds H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, and A. Alegría (Cambridge: Cambridge University Press), 3–33.

IPCC (2022b). "Summary for policymakers," in *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, eds P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, and D. McCollum (Cambridge: Cambridge University Press).

Irshaid, J., Mochizuki, J., and Schinko, T. (2021). Challenges to local innovation and implementation of low-carbon energy-transition measures: a tale of two Austrian regions. *Energy Policy* 156, 112432. doi: 10.1016/j.enpol.2021.112432

Klein, R. J., Midgley, G. F., Preston, B. L., Alam, M., Berkhout, F. G. H., Dow, K., et al. (2014). "Adaptation opportunities, constraints, and limits," in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, UK; New York, NY: Cambridge University Press), 899–943.

Leal Filho, W., and Nalau, J. (2018). *Limits to Climate Change Adaptation*. Cham: Springer International Publishing.

Leitner, M., Babcicky, P., Schinko, T., and Glas, N. (2020). The status of climate risk management in Austria. Assessing the governance landscape and proposing ways forward for comprehensively managing flood and drought risk. *Climate Risk Manage.* 30, 100246. doi: 10.1016/j.crm.2020.100246

Leitner, M., Glas, N., Babcicky, P., and Schinko, T. (2019). Klimarisikomanagement (KRM) in Österreich: Bestandsaufnahme der Stakeholder-Landschaft und der Governance-Strukturen für die Klimarisiken Hochwasser and Trockenheit/Dürre (RESPECT Working Paper No. 1).

Lempert, R. J., Popper, S. W., and Bankes, S. C. (2003). *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-term Policy Analysis*. Santa Monica, CA: RAND Corporation.

Lempert, R. J., and Turner, S. (2021). Engaging multiple worldviews with quantitative decision support: a robust decision-making demonstration using the lake model. *Risk Anal.* 41, 845–865. doi: 10.1111/risa.13579

Li, H. M., Xue-Chun, W., Xiao-Fan, Z., and Ye, Q. I. (2021). Understanding systemic risk induced by climate change. *Adv. Clim. Change Res.* 12, 384–394. doi: 10.1016/j.accre.2021.05.006

Linnerooth-Bayer, J. (2021). On decision-analytical support for wicked policy issues. *Risk Anal.* 41, 866–869. doi: 10.1111/risa.13750

Longhurst, R. (2009). "Interviews: in-depth, semi-structured," in *International Encyclopedia of Human Geography*, eds R. Kitchin, and N. Thrift (Oxford: Elsevier), 580–584 doi: 10.1016/B978-008044910-4.00458-2

Marchau, V. A. W. J., Walker, W. E., Bloemen, P. J. T. M., and Popper Editors, S. W. (2019). "Chapter 1: introduction," in *Decision Making under Deep Uncertainty*, eds V. A. W. J. Marchau, W. E. Walker, P. J. T. M. Bloemen, and S. W. Popper (Cham: Springer International Publishing).

Mayring, P. (2010). "Qualitative inhaltsanalyse," in *Handbuch Qualitative Forschung in der Psychologie,* eds G. Mey, and K. Mruck (Wiesbaden: VS Verlag für Sozialwissenschaften), 601–613.

McNamara, K. E., and Jackson, G. (2019). Loss and damage: a review of the literature and directions for future research. *Wiley Interdisciplinary Rev. Clim. Change* 10, e564. doi: 10.1002/wcc.564

Moallemi, E. A., Eker, S., Gao, L., Hadjikakou, M., Liu, Q., Kwakkel, J., et al. (2022). Early systems change necessary for catalyzing long-term sustainability in a post-2030 agenda. *One Earth* 5, 792–811. doi: 10.1016/j.oneear.2022.06.003

Moser, S. C., and Ekstrom, J. A. (2010). A framework to diagnose barriers to climate change adaptation. *Proc. Nat. Acad. Sci.* 107, 22026–22031. doi: 10.1073/pnas.1007887107

Naess, L. O., Bang, G., Eriksen, S., and Vevatne, J. (2005). Institutional adaptation to climate change: flood responses at the municipal level in Norway. *Glob. Environ. Change* 15, 125–138. doi: 10.1016/j.gloenvcha.2004.10.003

Nair, S., and Howlett, M. (2016). From robustness to resilience: avoiding policy traps in the long term. *Sust. Sci.* 11, 909–917. doi: 10.1007/s11625-016-0387-z

O'Brien, K., Eriksen, S., Sygna, L., and Naess, L. O. (2006). Questioning complacency: climate change impacts, vulnerability, and adaptation in Norway. *AMBIO J. Hum. Environ.* 35, 50–56. doi: 10.1579/0044-7447(2006)35[50:QCCCIV]2.0.CO;2

Pröbstl, U. (2021). *Tourismus und Klimawandel*. Berlin: Springer Spektrum.

Renn, O., Laubichler, M., Lucas, K., Kröger, W., Schanze, J., Scholz, R. W., et al. (2022). Systemic risks from different perspectives. *Risk Anal.* 42, 1902–1920. doi: 10.1111/risa.13657

Repetto, R. (2008). *The Climate Crisis and the Adaptation Myth. Forestry and Environmental Studies Publications*. Available online at: https://elischolar.library.yale.edu/fes-pubs/9 (accessed November 22, 2021).

Ross, K., Schumer, C., Fransen, T., Wang, S., and Elliott, C. (2021). Insights on the first 29 long-term climate strategies submitted to the united nations framework convention on climate change. *World Resour. Inst.* 21, 1–14. doi: 10.46830/wriwp.20.00138

Schinko, T., Mechler, R., and Hochrainer-Stigler, S. (2017). A methodological framework to operationalize climate risk management: managing sovereign climate-related extreme event risk in Austria. *Mitig. Adap. Strat. Global Change* 22, 1063–1086. doi: 10.1007/s11027-016-9713-0

Siders, A. R. (2019). Adaptive capacity to climate change: a synthesis of concepts, methods, and findings in a fragmented field. *Wiley Interdisciplinary Rev. Clim. Change* 10, e573. doi: 10.1002/wcc.573

Smith, M. S., Horrocks, L., Harvey, A., and Hamilton, C. (2011). Rethinking adaptation for a 4 C world. *Philos. Trans. Royal Soc. Mathematic. Phys. Eng. Sci.* 369, 196–216. doi: 10.1098/rsta.2010.0277

Stangl, M., Formayer, H., Hiebl, J., Orlik, A., Höfler, A., Kalcher, M., et al. (2021). *Klimastatusbericht Österreich 2020*. Colorado Springs, CO: CCCA.

Stanton, M. C. B., and Roelich, K. (2021). Decision making under deep uncertainties: a review of the applicability of methods in practice. *Technol. Forecast. Soc. Change* 171, 120939. doi: 10.1016/j.techfore.2021.120939

Steiger, R., Damm, A., Prettenthaler, F., and Proebstl-Haider, U. (2021). Climate change and winter outdoor activities in Austria. *J. Outdoor Recr. Tour.* 34, 100330. doi: 10.1016/j.jort.2020.100330

Steininger, K. W., Bednar-Friedl, B., Formayer, H., and König, M. (2016). Consistent economic cross-sectoral climate change impact scenario analysis: Method and application to Austria. *Clim. Serv.* 1, 39–52. doi: 10.1016/j.cliser.2016.02.003

Thomas, A., Theokritoff, E., Lesnikowski, A., Reckien, D., Jagannathan, K., Cremades, R., et al. (2021). Global evidence of constraints and limits to human adaptation. *Reg. Environ. Change* 21, 1–15. doi: 10.1007/s10113-021-01808-9

Verheyen, R. (2012). *Tackling Loss and Damage: A New Role for the Climate Regime?* Bonn: Germanwatch.

Walker, W. E., Harremoës, P., Rotmans, J., van der Sluijs, J. P., van Asselt, M. B. A., Janssen, P., et al. (2003). Defining uncertainty: a conceptual basis for uncertainty management in model-based decision support. *Integrat. Assess.* 4, 5–17. doi: 10.1076/iaij.4.1.5.16466

Warner, K., van der Geest, K., and Kreft, S. (2013). *Pushed to the Limit: Evidence of Climate Change-Related Loss and Damage When People Face Constrains and Limits to Adaptation.* Bonn: United Nations University Institute for Environment and Human Security, 11.

Warner, K., Van der Geest, K., Kreft, S., Huq, S., Harmeling, S., Kusters, K., et al. (2012). *Evidence from the Frontlines of Climate Change: Loss and Damage to Communities Despite Coping and Adapation.* Bonn: United Nations University Institute for Environment and Human Security, 9.