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DISCUSSION



Climate overshoot implications for local adaptation planning

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ABSTRACT

As global warming increases, the topic of overshoot, understood as the temporary exceedance of the 1.5°C limit of the Paris Agreement, is gaining prominence both in scientific and political spheres. However, overshoot and its implications for adaptation in the short – and long-term remain unexplored. In this Perspective, we reflect on the current use of global climate scenarios and local impact projections in science-based adaptation planning. The risks arising from overshoot scenarios in relation to the transgression of limits to adaptation and impact irreversibility are highlighted. We find that the prospects of potential long-term impact reversibility may have limited relevance in most adaptation decision-making contexts, indicating that it might be peak warming, rather than a long-term outcome, that determines adaptation needs and costs. While overshoot may not be relevant for short-term planning, it should be considered for long-term plans and policies, for example for infrastructure-based measures and for irreversible impacts such as sea-level rise. Key insights from adaptation practitioners in four diverse urban vulnerability contexts (Bodø, Lisbon, Nassau, Islamabad) are presented on how these risks are perceived and integrated (or not) into local planning and policy-making. We find that current adaptation planning must be extensively evaluated against a wider set of future global climate outcomes to incorporate risks of transgression of local limits to adaptation and overshoot. To this end, data gaps on adaptation limits and impact reversibility need to be filled and capacity building needs on climate scenarios, overshoot and related concepts for local adaptation practitioners should be addressed.

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KEYWORDS

Overshoot; climate scenarios; impact projections; limits to adaptation; reversibility of climate change impacts; local adaptation planning

Key policy insights

- The topic of overshoot has yet to become well-established and widely considered by the adaptation community.
- Overshoot scenarios unfold on long time horizons making them most relevant for long-term adaptation planning, such as infrastructure-based measures.
- A strengthened science-policy interface and capacity-building at the local level are needed to support the design of adaptation plans that remain effective in the long-term.

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- Limits to adaptation and impact reversibility resulting from overshoot must be further researched to provide essential science-based inputs in forward-looking adaptation plans.
- Flexible designs of adaptation measures can be considered to allow the adjustment of the level of risk reduction/protection provided by the measures over time.

1. Introduction

Adaptation to climate change is a complex, context-specific and iterative decision-making process, taking place at various levels of governance and across many sectors. Global climate scenarios and local impact projections are essential in this process to, for example, make detailed climate risk assessments during the planning phase and assess the adequacy of existing measures during monitoring and evaluation. Many climate services have been developed in the past years to facilitate the inclusion of climate data in adaptation planning by presenting information on climate change impacts for various levels of future global warming (Climate Analytics, 2024; Copernicus, 2024; IPCC, 2024). Indeed, to avoid maladaptation and support effective adaptation measures, both in the short – and the long-term, it is crucial to consider a wide range of future potential climate scenarios. This includes raising awareness and capacity-building about the emergence of overshoot scenarios among decision-makers and adaptation practitioners across the world (Nature Geoscience, 2023), especially in national and sub-national contexts, where their use is incipient. In this Perspective, we reflect on the current integration of climate scenarios in adaptation planning (Section 2), before investigating the relevancy of overshoot scenarios and how they can be adequately included in local adaptation plans and national policies (Section 3). To do so, we also present an illustrative example showing the cost–benefit implications of considering overshoot scenarios in adaptation planning (Section 4) and outline results from focus group discussions and policy analyses in four diverse urban vulnerability contexts (Section 5).

2. Scenario use in adaptation planning

Currently, adaptation plans and policies do not always consider global climate scenarios and local impact projections when selecting and prioritizing adaptation measures and supporting decision-making processes on the ground (Lorenz et al., 2017; Theokritoff and D'haen, 2022; Thomas et al., 2019). In sectors where projections tend to be more often used, such as coastal adaptation measures, studies reveal that there is no global standard in the use of projections (Hirschfeld et al., 2023; McEvoy et al. 2021).

Generally, adaptation guidelines recommend considering various future climate scenarios when planning adaptation. The National Adaptation Plan (NAP) guidelines from the United Nations Framework Convention on Climate Change (UNFCCC) stress that current climate as well as future climate change scenarios should be assessed to identify adaptation deficits and define priorities (Least Developed Countries Expert Group, 2012). Both future climate and socio-economic scenarios should be considered to characterize risks and uncertainties. The Guidelines on Member States' adaptation strategies and plans from the European Commission state that risk assessments should be based on, *inter alia*, the latest projections on future climate scenarios (European Commission, 2023). They also emphasize that multiple future scenarios should be taken into account when developing an adaptation policy, to address inherent uncertainties about the future. In addition to potential future scenarios, it is vital to consider planning horizons. Both the NAP Guidelines (2012) and the EU's Guidelines on Member States' adaptation strategies (2023) state that it is important to consider medium and long-term risks and to set a clear time frame during which differentiated impacts can be expected in the short – (2030s), medium – (2050s) and long – (2100s) term (European Commission, 2023; Least Developed Countries Expert Group, 2012).

Using climate scenarios and local impact projections for adaptation planning result in two main sources of uncertainty: firstly, global mitigation action will strongly affect the amount of adaptation required; secondly, there are inherent uncertainties that come along with the climate data being used. Up until mid-century, the differences in emerging climate impact drivers between scenarios tend to be smaller than the imprint of natural variability (Lehner and Deser, 2023). Including the effects of natural variability, either through explicitly

assessing outcomes of large ensembles of climate model simulations (Deser et al., 2020), or the use of emulator tools (Nath et al., 2022) to boost ensemble statistics is necessary given that the use of a single realization of a very high emission scenario (i.e. SSP5-8.5 or RCP8.5) does not guarantee that high end climate risks on the regional level are sufficiently covered, in particular in the near-term. Not accounting for natural variability might result in a risk of overconfidence in regional climate impact projections and increase the risk for maladaptation.

This section highlights that it is essential to consider diverse scenarios and long timeframes when planning adaptation despite uncertainties, making overshoot scenarios a relevant case to consider, which is further explored in the following sections of this Perspective.

3. Overshoot scenarios in adaptation planning

Overshoot scenarios are defined by the IPCC as ‘pathways that first exceed a specified concentration, forcing or global warming level, and then return to or below that level again before the end of a specified period of time (e.g. before 2100)’ (IPCC, 2022, p. 2917). In the 2015 Paris Agreement, countries agreed on pursuing efforts to limit global warming to 1.5°C by 2100 to prevent the worst impacts of climate change (United Nations, 2015). However, this leaves the door open to a temporary exceedance of the 1.5°C limit, if global mean temperature peaks and decreases back to 1.5°C by the end of the century. As time progresses and climate change mitigation remains highly insufficient, the risk of an overshoot scenario occurring increases. Consequently, global warming could temporarily exceed 1.5°C before the temperature is brought down again in the following decades. In these overshoot scenarios, climate change impacts would likely become more severe, and while some impacts may be reversible in the long-term (e.g. impacts from extreme heat), others will be irreversible (e.g. desertification) (Pfleiderer et al., 2024). It must be noted that the large-scale carbon dioxide removal that would be required to bring temperatures back down again may be limited by technical, economic, political and sustainability considerations (Schleussner et al., 2024).

Overshoot scenarios could potentially create additional risks or intensify existing ones, which both strongly affect adaptation planning. Up until global warming levels peak (and in some cases even beyond), the risk of reaching adaptation limits continues to increase. Adaptation limits are defined by the IPCC as ‘the point at which an actor’s objectives (or system needs) cannot be secured from intolerable risks through adaptive actions’ (IPCC, 2022, p. 2898). Thus, it is essential to adequately identify limits when planning for adaptation. For example, biophysical limits (e.g. human tolerance to extreme heat) can be defined quantitatively through natural sciences whereas socio-economic limits (e.g. lack of finance to implement a project) can be identified by decision-makers based on specific contextual factors and local risk tolerance. Furthermore, the evolution of climate change impacts after peak warming, in particular their potential reversibility or irreversibility, would influence long-term adaptation needs. Despite constraints on the rate of decline in GMT, this would largely manifest over decades and thus beyond the time spans currently used for adaptation planning, however, it can still be relevant for plans made for several decades ahead such as large-scale infrastructure projects (Schleussner et al., 2024).

It is therefore important that decision-makers and adaptation practitioners are aware of the implications of potential overshoot scenarios, in particular when making plans that span over several decades. They can provide additional useful insights in the complex and multifaceted process that adaptation constitutes. Generally, science on the implications of overshoot for local climate impacts and their reversibility remains nascent (Mengel et al., 2018; Pfleiderer et al., 2024; Schleussner et al., 2024) and adaptation limits are still challenging to identify and quantify (Berrang-Ford et al., 2021; Thomas et al., 2021) (Table 1). Consequently, this also poses additional challenges for the inclusion of overshoot considerations into today’s adaptation planning.

4. Cost-benefit implications of considering overshoot scenarios in adaptation planning

In a hypothetical case where adaptation is planned over a long timescale and impacts decrease after a decline in GMT, it can be unclear which level of adaptation may be most appropriate to implement, at least from a cost-efficient perspective. Adapting to the level of impacts expected at peak warming, rather than to the final GMT

level after overshoot, has potential to avoid more damages but would also require higher investments. To address this question, we run a cost–benefit analysis using a simple mathematical model for economics of climate adaptation, that allows to assess the cost-efficiency of adaptation measures protecting economic assets under changing climate conditions (see SPM1).

In this idealized experiment, we assume that an adaptation measure is implemented in 2040 on the onset of an overshoot above a GMT level of 1.5°C, under perfect foresight that global warming and its resulting impacts would peak in 2060 before declining. Here, we only look at adaptation to a rare 1-in-100-year event, assuming its severity to scale linearly with GMT and that the percentage of impact reduction through adaptation is the same at every GMT level. These assumptions are compatible with past research investigating damages from tropical cyclones in coastal environments (Bresch and Aznar-Siguan 2021, Hinkel et al., 2018; Lenk et al., 2017; Prah et al., 2018). Total costs (expected damages with adaptation plus adaptation costs) for two different strategies are compared: adapting to peak warming impacts in 2060 (Adapt_PW) and anticipating post-overshoot impact levels after GMT to come back to 1.5°C (Adapt_1.5). This analysis is conducted for a range of adaptation measures and different overshoot scenarios, also testing the influence of the discount and economic growth rates affecting the total asset value.

Under these simple assumptions, we find that a strategy that adapts to peak warming impacts (Adapt_PW) is more cost-efficient for adaptation measures with benefit–cost ratios of around three and higher (Figure 1). These ratios are reported for most ‘soft’ adaptation options in coastal environments, such as nature-based solutions, measures that increase societal preparedness and early warning systems (whereas ‘hard’ adaptation options that focus on large infrastructures such as dikes commonly have benefit–cost ratios of between one and three) (Bresch and Aznar-Siguan, 2021). The benefits of adapting to peak warming in 2060 reflect the no-regret nature of implementing high efficiency options, shown in Figure 1. Assuming higher discount rates shifts the assessment in favour of the Adapt_1.5 strategy (Figure 1), while higher growth rates have the opposite effect (Figure SM1). In this analysis, the influence of the value of these economic parameters is similar in magnitude to that of the level of peak warming reached in the overshoot scenarios (Figure 1),

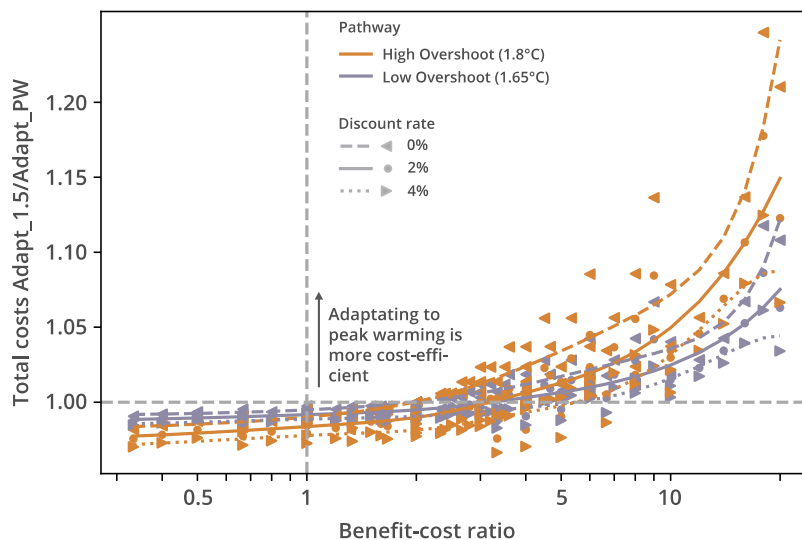


Figure 1. Illustrative example of costs of adaptation strategies under overshoot scenarios. The coefficient of total costs for two strategies (Adapt_1.5 and Adapt_PW) as a function of the benefit-cost ratio of the adaptation measure are shown (avoided damage by adaptation/adaptation costs). Values higher than 1 for the total cost ratio indicate that the Adapt_1.5 is overall more costly than Adapt_PW. Results are shown for a high overshoot scenario (peaking at 1.8°C, orange markers, solid line indicates spline fit) and a lower overshoot scenario (peaking at 1.65°C, purple markers, solid line indicates spline fit). The sensitivity of the adaptation appraisal results to the choice of the discount rate is visualized by the various markers: Values of 0 (triangles pointing to the left, dashed line), 2% (dots, solid line), and 4% (triangles facing to the right, dotted line) are considered.

while the duration of the overshoot and even whether GMT stabilizes or declines after peaking only have a limited effect with no clear direction, and for adaptation measures with benefit–cost ratios above 4 (Figure SM3).

This illustrative analysis shows that from an economic perspective, the potential outlook of an overshoot and its shape do not matter much when it comes to deciding which level of adaptation is most appropriate to implement. This result was derived by calibrating a simple model that focuses on the impacts of tropical cyclones in coastal environments. For other types of impacts occurring in different contexts, the damage function would likely be different and give other results. Particularly impacts nonlinearly escalating with GMT or irreversible impacts would lead to higher damages at peak warming compared to post-overshoot levels, thus reinforcing the message that adapting to peak warming is more cost-efficient. The characteristics of adaptation measures may also change in varying contexts, in turn affecting the results. Lastly, in the real-world, assets can be exposed to numerous different climate hazards that can act in a compound manner, often resulting in higher impacts (Zscheischler et al., 2018). Such complex interactions render the outlook of obtaining perfect foresight of the upcoming potential climate damages even less tangible. A precautionary approach would then also speak for adapting against damages expected at peak warming, rather than to bet on potentially lower, but uncertain impacts in the future.

5. Insights from adaptation practitioners in four diverse urban contexts

To get a better understanding of the status of integration of overshoot scenarios in adaptation planning, three focus group discussions were conducted per city in Bodø (Norway), Lisbon Metropolitan Area (Portugal), Nassau (The Bahamas) and Islamabad (Pakistan) between March 2022 and July 2023, by the authors of this Perspective. These four regions and cities were selected to examine distinct vulnerability contexts, namely a polar climate region (Arctic Fennoscandia), a heatwaves and desertification region (Iberian Mediterranean), a glacial flooding and high mountain region (Upper Indus Basins), and a small island and hurricane prone region (The Bahamas). The aim of the focus groups was to introduce scientific concepts (such as overshoot scenarios and limits to adaptation), discuss how familiar participants were with the latter and explore the usefulness and potential consideration of these concepts. Each focus group was attended by between 10 and 40 adaptation practitioners and local policymakers and was held either online (via Zoom) or through in-person gatherings. Notes of the discussions were taken during all meetings and further data was collected through live questionnaires with Mentimeter. The focus groups were complemented with policy analyses from these four cities (see list of documents and analysis guide in SPM2). The overall results are summarized in Table 1.

Table 1. Familiarity with overshoot and related concepts for adaptation practitioners in Bodø (Norway), Lisbon Metropolitan Area (Portugal), Nassau (The Bahamas) and Islamabad (Pakistan). Interactions in Nassau and Islamabad also included NGO workers and private sector stakeholders.

	Bodø, Norway	Lisbon Metropolitan Area, Portugal	Nassau, The Bahamas	Islamabad, Pakistan
Climate scenarios	- Good familiarity but tend to use more considerations for increases in magnitude and frequency of events rather than specific climate scenarios	- Very good familiarity, as they are commonly used in adaptation strategies and plans	- Limited familiarity, as they have not been used for past adaptation planning	- Good familiarity with scenarios and their importance but little translation of the nuances between scenarios and their long-term implications in adaptation planning
Overshoot scenarios	- Limited familiarity, difficult to understand, and not used in current planning work	- Limited familiarity, since most scenarios used so far did not include temperatures decreasing again	- Limited familiarity, but aware of importance of 1.5°C limit for irreversible impacts affecting island nations	- Very limited familiarity, challenging for stakeholders to envision scenarios being worse than those currently experienced

(Continued)

Table 1. Continued.

	Bodø, Norway	Lisbon Metropolitan Area, Portugal	Nassau, The Bahamas	Islamabad, Pakistan
Adaptation limits	- Good familiarity, they are more commonly considered/identified through recurring intervals of specific known events and previously experienced soft limits to adaptation	- Good familiarity, but difficulty in integrating limits into strategies, because of the perceived lack of existing empirical knowledge on limits and lack of defined limits in regulations	- Limited familiarity with biophysical limits (for e.g. loss of coral reefs due to ocean acidification) - Good familiarity with constraints leading to soft limits, particularly financial and human capacity constraints	- Limited familiarity with biophysical limits (for e.g. human productivity and survivability) - Good familiarity with economic limits, as they often occur in Pakistan (for e.g. during the 2022 floods, relocation of communities was not possible due to the economic situation)
Impact ir/reversibility	- Limited familiarity, more interested in reversible impacts than irreversible ones	- Limited familiarity, the concept of reversibility was initially not well understood since impacts were always considered to be irreversible. However, the importance of the concept for future revisions of the plans was recognized (e.g. to adjust the priority levels of certain measures)	- Limited familiarity, but there is awareness that there may be irreversible impacts to biophysical systems that would have implications for adaptation (for e.g. irreversible changes to the ocean, affecting the ability of coastal and marine ecosystems to provide critical ecosystem services)	- Limited familiarity, concerns over the potential irreversibility of certain impacts were expressed (for e.g. irreversible snow and glacial melt affecting the timing and availability of downstream water with consequences on agriculture, hydropower production, and domestic water use)

Table 1 highlights the prevailing knowledge gaps around overshoot and related concepts with local adaptation practitioners and policy-makers. When reviewing adaptation plans and policies, we also generally found that they do not include information linked to climate scenarios (except for adaptation plans and policies reviewed in the Lisbon Metropolitan Area), and that none mention overshoot. While some references were made to long-term impacts to describe the context in Nassau and Islamabad, they were not used as a basis for local adaptation planning. Moreover, specific adaptation limits as well as potential impact ir/reversibility are absent in all the reviewed documents. Nevertheless, participants of the focus groups recognize the importance of being aware of these concepts and considering them in future planning. Generally, there was a consensus that without knowledge about overshoot and related concepts, adaptation planning might fail to comprehensively address the complex dynamics of climate change impacts, leading to plans and strategies that could be less effective or even maladaptive in the long run.

Overall, we identify the need to further strengthen the science-policy interface to ensure that these novel scientific concepts are considered when relevant. In the four cities studied, it was noted that the lack of capacity from local practitioners and the rather short timescales around which adaptation is usually planned, oftentimes led to the negligence of limits to adaptation. In addition, it remains challenging to identify limits, as there is a need to expand quantitative data on where limits lie and improve guidance for defining adaptation limits. For example, for adaptation to heat in an urban context, specific climate risks and limits to urban forests at city scale is very relevant information to have (Esperon-Rodriguez et al., 2024). Identifying limits to adaptation can influence the levels of urgency of a sequence of adaptation options that are to be deployed. Once adaptation limits have been identified, they can be integrated into long-term planning through the adaptation pathways approach (Walker et al., 2013).

6. Conclusion and outlook

In conclusion, local adaptation plans and policies must be extensively evaluated against a wider set of future climate outcomes. The range of outcomes to be considered depends on various factors, including the type of

adaptation measure being planned, the availability of relevant scientific data, and the time horizon covered. The potential reversibility of impacts under overshoot represents a new point of interest for adaptation practitioners and might condition their scenario choice. Deciding which scenario to adapt to is also linked to financial questions, as it can be very expensive to adapt to warming at the upper end of the uncertainty range (Parry et al., 2008). Nevertheless, our illustrative cost–benefit analysis shows that a plan or strategy that adapts to peak warming impacts appears to be more cost-efficient, in particular for adaptation options such as nature-based solutions and various measures increasing societal preparedness and early warning. This highlights the no-regret nature of deploying high efficiency options.

To date, overshoot scenarios are likely to only be relevant for very long-term plans and policies. However, even if the 1.5°C limit is only exceeded for a short amount of time in an overshoot scenario, extensive adaptation is planning required. It is therefore crucial to inform adaptation practitioners about potential local impacts resulting from global warming scenarios, as this is vital to avoid maladaptation and support the effectiveness of adaptation. Furthermore, data gaps on adaptation limits and impact reversibility must be filled to allow for science-based planning. Scientists are also responsible for co-developing clear and operational concepts, frameworks and tools that are salient and relevant to adaptation practitioners, particularly when novel concepts are introduced. Based on the observed lack of awareness on overshoot and related concepts and the threats of worsening climate impacts globally, we conclude that the science-policy interface needs to be strengthened along with dedicated funding and capacity building for local adaptation planners, to better align local adaptation measures to existing and emerging needs. In addition, flexible designs of adaptation measures can be explored, allowing to adjust the level of risk reduction provided by the measures over time, to cope with various existing sources of uncertainty arising when planning for the future. Overall, we acknowledge that scenario selection and consideration is only one small piece of the vast puzzle that adaptation constitutes and that context-specific constraints can hinder adaptation processes even before the science-basis of plans and measures get to be discussed.

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