nature climate change

Review article

https://doi.org/10.1038/s41558-023-01774-6

Navigating the continuum between adaptation and maladaptation

Received: 2 November 2022

Accepted: 19 July 2023

Published online: 21 August 2023

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Adaptation is increasing across all sectors globally. Yet, the effectiveness of adaptation is inadequate, and examples of maladaptation are increasing. To reduce the risk of maladaptation, we propose the framework, Navigating the Adaptation–Maladaptation continuum (NAM). This framework is composed of six criteria relating to outcomes of adaptation for ecosystems, the climate (greenhouse gases emissions) and social systems (transformational potential) as well as equity-related outcomes for low-income populations, women/girls and marginalized ethnic groups. We apply the NAM framework to a set of representative adaptation options showing that considerable variation exists in the potential for adaptation or the risk of maladaptation. We suggest that decision-makers assess adaptation interventions against the NAM framework criteria and prioritize responses that reduce the risk of maladaptation.

There are currently intensive international policy discussions around the preparations of the first global stocktake of the Paris Agreement (Article 14d)[1] and the related Global Goal on Adaptation. The first global stocktake is due in 2023, requesting governments to "review the overall progress made in achieving the Global Goal on Adaptation"[1]. This process is supported by the United Nations Framework Convention on Climate Change (UNFCCC) Glasgow–Sharm el-Sheikh work programme established in 2021 (UNFCCC; Decision 7/CMA.3), which aims, among other things, to discuss frameworks and methodologies to assess the "adequacy and effectiveness" of adaptation efforts globally. In the UNFCCC language, 'adequacy' refers to the match between adaptation needs and necessary responses and instruments (for example, finance), while 'effectiveness' refers to the outcomes of these instruments relative to a predefined goal. Understanding effectiveness demands an understanding of the responses and instruments implemented today, and an examination of whether they actually reduce current and future climate risk[2,3].

Assessing adaptation responses is fraught with challenges because of a lack of consensus on how adaptation at local, national and international levels can be examined and tracked[4–6]. Scholars repeatedly stress that assessing adaptation is difficult due to definitional issues (adaptation can be assessed related to inputs, processes, outputs or outcomes), comparability issues (risk baselines, outcomes, impacts and other indicators differ greatly across case studies), aggregation issues (metrics of adaptation vary because adaptation takes different forms across local, regional and global scales) and temporal issues (outcomes, including lock-ins and trade-offs of adaptation, will only occur in the future)[4,7–10].

Scientists, civil society organizations, low-income nations and Indigenous peoples express concern that collective efforts in adaptation do not contribute sufficiently towards risk reduction[11], and that, in many cases, they may heighten the risk of maladaptation[2,12]. Working Group II of the Intergovernmental Panel on Climate Change (IPCC WGII) identifies that adaptation has been increasing across all regions, generating multiple benefits[2]. However, it also highlights that adaptation remains inadequate in scale (that is, not widespread enough) and scope (that is, not systematically addressing the root

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https://doi.org/10.1038/s41558-023-01774-6

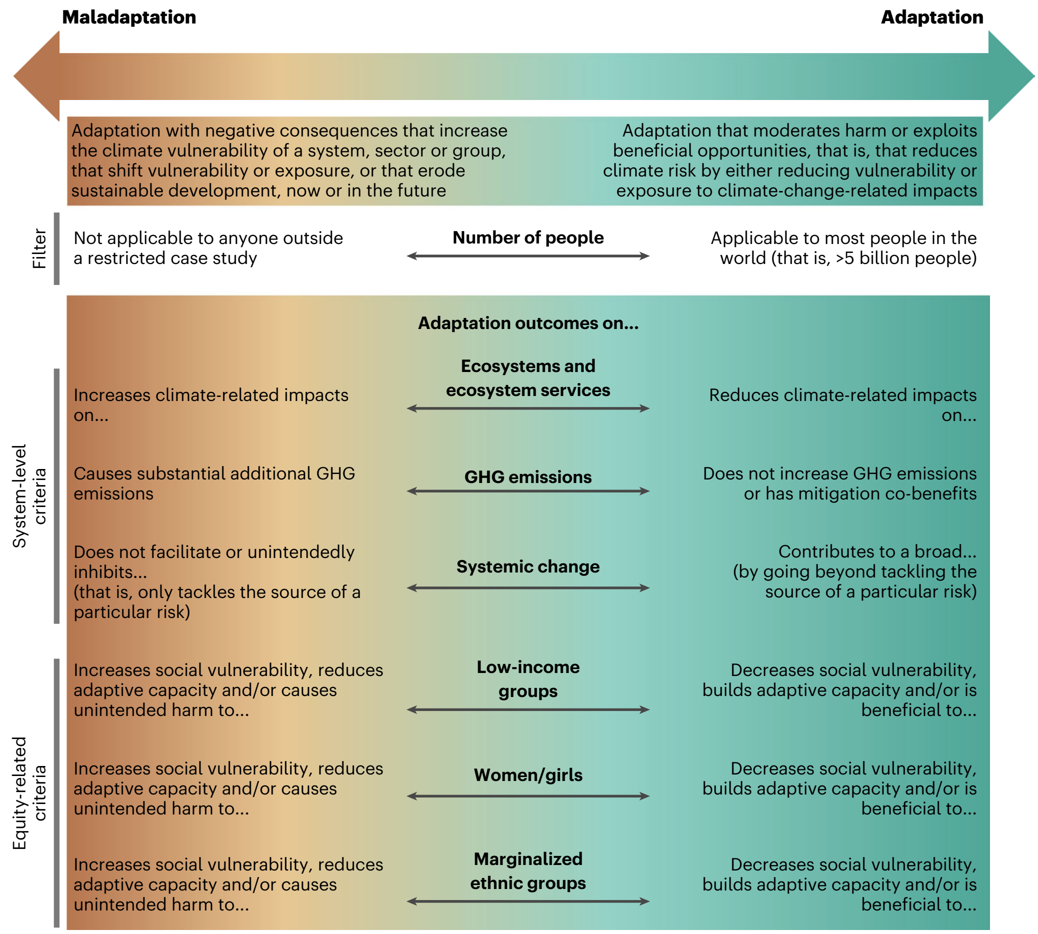

Fig. 1 | The conceptualization of the NAM framework. Adaptation and maladaptation are conceptualized as the two end points of a continuum, with every response undertaken in the name of adaptation locating somewhere along the continuum based on six outcome criteria. The figure draws on refs. 20,21,23.

causes of exposure and vulnerability), and there is increasing concern around maladaptation[2], that is, when measures backfire, increasing risk (through increased exposure and/or vulnerability) rather than reducing it. Overall, there is insufficient understanding of the conditions under which adaptation-related responses reduce risk or have unintended side effects that increase risk.

Taking stock of successful adaptation (that is, effectively reducing risk without negative side effects) and the risk of maladaptation raises important research questions: how can the outcomes of adaptation be assessed? How can benefits and potentially harmful effects of adaptation across time, space and population groups be anticipated? And can climate adaptation success or failure be contextualized within a broader set of goals towards equitable and sustainable development?

To answer these questions, we argue that successful adaptation and maladaptation are at the opposing ends of a continuum that requires suitable tracking, monitoring and evaluation. To do so, we develop a multi-dimensional framework—Navigating the Adaptation–Maladaptation continuum (NAM)—that weaves together critical dimensions that we have identified for determining whether an adaptation is more likely to succeed or fail.

Framing the adaptation–maladaptation continuum

Adaptation in human systems is understood as the process of adjustment to actual or expected climate change and its effects, in order to moderate harm or exploit opportunities[13]. Maladaptation refers to current or potential negative consequences of adaptation-related responses that exacerbate or shift vulnerability or exposure of a system, sector or group of the population[14–18], or that erode sustainable development[15,19]. Maladaptation differs from 'failed' or 'unsuccessful' adaptation[16,20]; the latter describing an "adaptation initiative not producing any significant detrimental effect"[16]. Maladaptation occurs when adaptation unintentionally creates harm. Such definitional issues suggest that adaptation and maladaptation are not distinct, but rather the opposing ends of a spectrum that combines negative, neutral and positive consequences in terms of climate risk reduction and its distribution across space, time and social groups.

Recent scholarship has challenged the dichotomy that categorized adaptation responses as either adaptive or maladaptive[18,20–23]. It highlights the absence of a clear-cut boundary and the multiplicity of criteria by which adaptation is judged. Allowing mixed outcomes on these criteria permits the conceptualization of the adaptation–maladaptation space as a continuum[20,22,23] (Fig. 1), emphasizing the following: (1) most responses are not inherently 'bad' or 'good' for reducing exposure and vulnerability to climate hazards; (2) positive and negative outcomes of adaptation depend on local context specificities, including how adaptation is planned and implemented, who is judging the outcomes to whom (that is, adaptation decision-makers, planners, implementers or local populations), when the outcomes are assessed, which metrics are used and which scale is considered; and (3) adaptation outcomes can shift along this continuum over time, because local conditions can change and consequences may only become apparent over time.

https://doi.org/10.1038/s41558-023-01774-6

Table 1 | Evidence across the IPCC WGII AR6 for a new conceptualization of adaptation supporting alternative approaches when tracking adaptation

	IPCC WGII AR6 sectoral and regional chapters													
Key topics	**2. Terrestrial and freshwater ecosystems**	**3. Ocean and coastal systems**	**4. Water**	**5. Food**	**6. Cities**	**7. Health**	**8. Poverty**	**9. Africa**	**10. Asia**	**11. Australasia**	**12. Central-South America**	**13. Europe**	**14. North America**	**15. Small islands**
(1) Difficulties of tracking adaptation														
	Difficult to assess the effectiveness of climate adaptation	NA	No consensus on effectiveness assessment methods	Adaptation outcomes depend on context, design, and implementation	Many adaptation outcomes are difficult to measure	NA	Impacts of adaptation responses differ across locations	NA	Lack of clear adaptation goals, uniform metrics and empirical evidence of effectiveness	NA	NA	Importance of joint understanding of feasibility and effectiveness	NA	NA
(2) Advantages arising from an interdisciplinary approach that stresses ancillary and co-benefits of adaptation, synergies, trade-offs														
	Empirical evidence, theory and modelling of impacts jointly enable assessment of appropriate adaptation measures	Successful adaptation improves ecosystem health and addresses current and historical inequities	Positive adaptation outcomes often align with mitigation co-benefits	Addressing the land, water, energy and food nexus enhances synergies and reduces trade-offs	Responses deliver adaptation and mitigation co-benefits, and health and development benefits	Effective adaptation requires considering multiple interacting sectors that affect population health and the effective functioning of health systems	NA	Synergies between adaptation and SDGs can lead to CRD	Effectiveness is assessed through four framings: potential to reduce risk; benefits to ecosystems; economic benefits; and human wellbeing outcomes	NA	Responses at multiple scales and through multiple actors are critical for effective adaptation	Integrating adaptation and mitigation with environmental, social and economic sustainability offers CRD; adaptation relates to trade-offs and synergies with SDGs	Successful adaptation considers coupled social–ecological networks across sectors and values IK	NA
(3) Ingredients of successful adaptation														
	Interdisciplinary scientific information, practical expertise, LK/IK are essential to effectiveness	Successful adaptation implementation depends on bottom-up, participatory and inclusive processes, including IK and empowerment of women	Contextual nature and boundary conditions determine the success of adaptation outcomes; Indigenous peoples are often best placed to enact successful adaptation	Successful adaptation is achieved through partnerships of researchers, managers and local actors	Adaptation can enable transformation towards long-term equitable and sustainable development; successful adaptation is responsive to local needs	Successful adaptation includes reductions in infectious disease incidence, improved access to water and sanitation, and improved food security	Successful adaptation depends on equitable development and climate justice (gender); actions can be evaluated in terms of social, economic or other benefits	IK systems contribute to the success of climate change response strategies.	Mainstreaming environmental sustainability, poverty alleviation and social justice should be foci of climate responses	Considering the social context and individual vulnerability are key to successful adaptation	Successful adaptation depends on stakeholder-based processes and the decision-making power of stakeholders	Inclusive and participatory approaches enhance quality of adaptation processes and decisions; aspiring in-depth and comprehensive transformational changes can be a consensus frame to work towards	Co-benefits between adaptation, mitigation and SDGs; ecosystem- and nature-based solutions are the basis for many synergies	Success depends on migrant agency and choice in decisions about whether to move, where, when and how

LK, local knowledge; IK, Indigenous knowledge; CRD, climate-resilient development; NA, no available information regarding topics reported in lines 1, 2 and 3 in the respective chapter. A more detailed account of the evidence in each IPCC WGII AR6 chapter with quotes and references is provided as Supplementary Table 1.

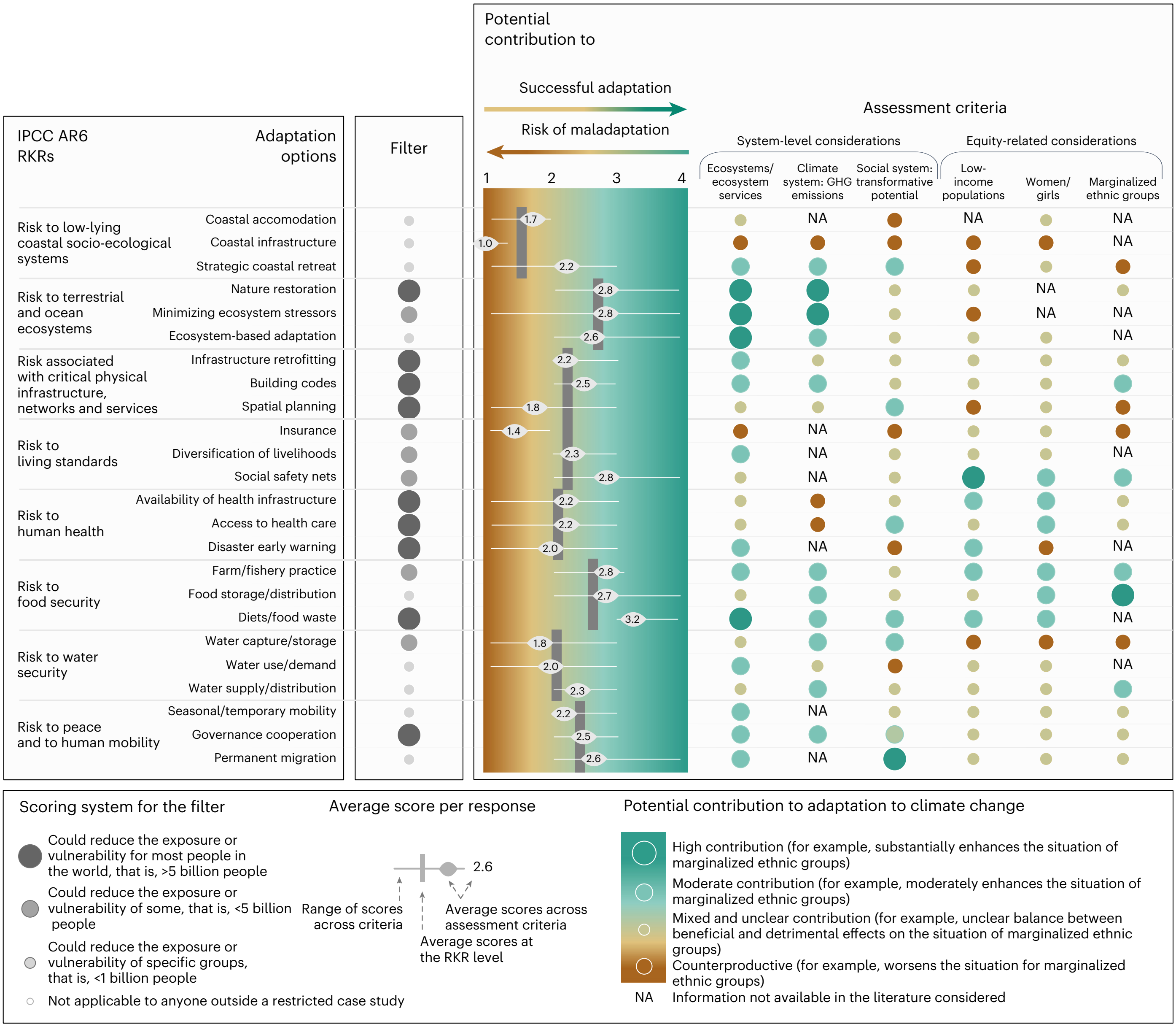

Fig. 2 | Location of adaptation options along the adaptation–maladaptation continuum, contributing to potentially successful adaptation or the risk of maladaptation. Results are shown as mean scores for individual assessment criteria per adaptation response (coloured circles) as well as mean scores across all six assessment criteria and at the level of the RKRs of the IPCC WGII AR6. Scores of the six criteria represent a high potential to lead to adaptation versus a high risk to lead to maladaptation, in line with the representation in Fig. 1. Scores range from counterproductive to highly contributing to adaptation, except for the criteria 'transformative potential', which ranges from no systemic change to broad systemic change. In particular for that dimension, specifying the negative is challenging, as it concerns the time dimension. Considering the IPCC 1.5 °C report[149], we know that no systemic change is not desirable and incremental adaptation is insufficient. Hence, we regard incremental change as the negative end point of that criteria.

Multiple dimensions and criteria to be considered

Scholars acknowledge "the challenge of lacking consensus on how adaptation ... can be tracked"[4,7,24]. There are numerous contributions that evaluate adaptation at one point in time at international[25], national[26,27] and local[28–37] levels. There are various outcome criteria by which adaptation could be evaluated[21,36,38]. Although there is agreement that adaptation broadly refers to actions and policies that effectively reduce climate risk, particularly vulnerability and exposure[39], risk reduction is hard to measure[10,24,40] because it is difficult to identify relevant assessment criteria and account for the temporal dimensions of responses (long time horizons of outcomes)[23,41] as well as the context-specific nature of risk drivers and adaptation outcomes. The context-specific nature of adaptation is visible through, for example, a multitude of applied adaptation definitions, the overlap of adaptation with development interventions, different goals of adaptation and local values on 'tolerable' risk[4,10,23,24,40,41]. Similar challenges relate to the assessment of maladaptation[20,23,42].

Consequently, as a way forward, and in addition to the challenges outlined above, recent literature stresses the value of ancillary adaptation benefits to wider societal goals, such as synergies with, for example, economic, societal and other environmental goals[2,4,9,43,44], and the minimization of trade-offs[33] across diverse objectives, perspectives and values[19,24,45]. The IPCC WGII Sixth Assessment Report (AR6)[4] supports a more complex view of adaptation by addressing both climate risks and other local or broader societal goals, such as the Sustainable Development Goals (SDGs; Table 1). This systematic assessment of a set of adaptation responses concerning co-benefits, synergies and trade-offs for climate risk reduction in human and natural systems, and equity and justice concerns, is particularly relevant to the study of maladaptation. Guiding principles for preventing maladaptation have been proposed[14,16,19,46,47], suggesting, for example, decreasing in-situ or ex-situ vulnerability and greenhouse gas (GHG) emissions, reducing detrimental outcomes on justice and equity, and avoiding long-term negative consequences of path dependency effects.

This paper develops this work further and extends previous scholarship by providing an operational framework to examine adaptation and maladaptation jointly, and by allowing a rigorous, transparent and replicable methodology applicable to decision-making in real-world settings. We argue, first, that such assessments allow the necessary nuanced picture of adaptation–maladaptation-related outcomes; second, that adaptation assessments using similar, or at least comparable, frameworks are decisive to increase comparability beyond the case study level[48], which in turn requires more general frameworks; and third, that repeated assessments at a given spatial scale are key to additionally and effectively capturing the complexity of adaptation outcomes through time (as more information progressively becomes available), which is a vital ingredient in identifying and preventing maladaptive outcomes.

Based on Table 1, we propose an assessment methodology called NAM (Fig. 1) to evaluate the extent to which responses developed in the name of adaptation lead to positive outcomes (that is, successful adaptation) or increase the risk of maladaptation. The analysis is based on the scientific literature of specific adaptation responses in particular locations that we use to judge the outcomes of responses. The findings from individual adaptation-related responses are then combined to broader categories of adaptation options, such as coastal infrastructure, ecosystem-based adaptations, spatial planning or social safety nets and so on, which are found in many settings and cover a wide range of potential responses to increasing climate risks. The framework is applied at the level of adaptation options (24 in total).

A first step (labelled 'Filter of analysis' in Figs. 1 and 2) indicates the application scope[14,15,17,39], estimating the number of people for whom vulnerability or exposure can potentially be decreased using an adaptation option, that is, to how many people the option is theoretically applicable. Such a filter is useful to estimate the potential extent or reach of an adaptation option. For adaptation options with large potential applicability there may also be more data on which to base assessments.

A second step consists of applying the six assessment criteria, which can be grouped into two categories: system-level considerations allow us to understand the distributional effects of an adaptation option on systems relevant for adaptation and sustainable development, that is, whether an adaptation option (1) was shown to benefit, have no effect on or worsen the situation of relevant systems in the past, or (2) is likely to benefit, have no effect, or worsen the situation of relevant systems in the future. The systems considered are:

(1) Ecosystem and ecosystem services[49]: we evaluate whether the adaptation option is likely to negatively affect ecosystems or ecosystem services, have no effect or have positive outcomes such as relieving pressures on ecosystems and their services (for example, Table 1, chapter 3, topic 2).
(2) Climate system, that is, GHG emissions[4,44]: we evaluate whether a particular adaptation option tends to reduce GHG emissions, have no benefits or increase GHG emissions (for example, Table 1, chapter 14, topic 3).
(3) Social system, that is, transformational potential[4]: this specifically assesses whether an adaptation response offers potential to lead to systemic change. Adaptation with transformational potential goes beyond tackling the source of a particular risk, while incremental actions (only) tackle the source of a risk and aim to reduce it (for example, Table 1, chapter 6, topic 3).

Equity-related considerations[50,51]: we assess the distributional effects of the adaptation option on marginalized groups, that is, whether an adaptation response was shown to benefit, have no effect on or worsen the situation of marginalized groups. The groups assessed are:

(4) Low-income populations[52,53] (for example, Table 1, chapter 8, topic 3).
(5) Women and girls[52,54,55] (for example, Table 1, chapter 3, topic 3).
(6) Marginalized ethnic groups, specifically people from ethnically marginalized populations, racial categories, castes or other ethnic backgrounds (for example, Table 1, chapter 2, topic 3).

The combination of these elements (one filter + six assessment criteria) is assumed to characterize the adaptation–maladaptation space (Fig. 1). Instead of very detailed metrics of limited generalizability that are necessary for activities at the local or project level, we provide broader categories of criteria that can be adjusted to different responses and contexts, and applied across scales. This approach, we argue, is decisive for synthesis assessments such as national to global scale aggregations to, for example, feed into the five-year global stocktake cycle.

Locating options on the adaptation–maladaptation continuum

To show the usefulness of the framework, here we report the results of its synthesis-level implementation to a set of illustrative adaptation options across specific risks highlighted as 'representative key risks' (RKRs) in the IPCC WGII AR6[4,43]. We use the literature base developed under the Global Adaptation Mapping Initiative[56] assessing adaptation responses on all six NAM outcome criteria individually per case study described in individual papers, if information was available. The Global Adaptation Mapping Initiative contains a literature base on adaptation responses globally, across 2,032 screened articles, selected using a systematic literature review[56]. We use a scoring scale from 1 to 4 (Supplementary Table 2), representing a range from negative (score 1) to neutral (score 2) and smaller and larger positive outcomes (score 3 and 4), that is, from a contribution to the risk of maladaptation to a high contribution to successful adaptation (Fig. 2). The criteria scores of individual responses are then aggregated (mean value) into a score of the broader adaptation option. Subsequently, criteria scores for adaptation options are aggregated (mean value) into a cross-criteria assessment score (see central panel of Fig. 2) which positions each option along the adaptation–maladaptation continuum. We do not apply any weighting across the assessment criteria when aggregating, to avoid pre-empting the major role of any context specificities in judging which dimensions are more important than others, or what level of threat is acceptable or not.

The assessment yields that none of the options are situated at the end points of the continuum, suggesting that innately a priori 'good' or 'bad' options do not exist. Every adaptation option shows some potential for both adaptation and maladaptation (shown by the range of horizontal white bars in the central panel of Fig. 2). This finding reflects the fact that none of the adaptation options have only major (co-)benefits, looking at criteria individually (Fig. 2, right panel, green circles), and that every option has some detrimental side effects (brown circles). Summarizing the outcome further, that is, across the representative adaptation options, indicates that with a mean score of 2.3, adaptation as documented in case studies in the scientific literature globally has created (slightly) more benefit than harm (a score of 2 is the turning point between maladaptation and adaptation; Supplementary Table 3).

Adaptation outcomes by RKR

The 24 representative adaptation options (categories of adaptation responses) are clustered to the eight RKRs (Fig. 2, central panel) identified in the IPCC WGII AR6 as illustrating "potentially severe risk [that is, that are] especially relevant to the interpretation of dangerous anthropogenic interference with the climate system, the prevention of which is the ultimate objective of the UNFCCC as stated in its Article 2"[43]. Interpreting the results across RKRs yields:

- Adaptation options in RKR 'Risk to terrestrial and ocean ecosystems' and RKR 'Food security' show the largest potential for adaptation (average of 2.7 and 2.6, respectively, compared with 2.2 at whole RKR sample; Supplementary Table 3). In the case of risks to ecosystems, many of the adaptations associated with this risk promoted ecosystem health, including restoration of ecosystems[57,58], natural regeneration, reduction of ecosystem stressors[59–61] and ecosystem-based adaptation. We find examples of projects that had negative impacts on marginalized populations[62–67], such as those documenting payments for ecosystem services[68] and green gentrification[69] or tree-planting programmes that avoided areas with high percentages of residents of ethnic minorities[70]. However, there are also many counter-examples of ecosystem-based adaptations with positive outcomes[71–76], such as community members reporting greater food and employment opportunities in Colombia[71–76]. Overall, most examples of those adaptations also reduced GHG emissions, and some were transformational, such as the efforts to redefine cities with 'living infrastructure'[77]. In the case of food security, many adaptations to farm-level practices have been shown to benefit low-income populations or marginalized ethnic groups[78–82], and many of these responses have not meaningfully increased GHG emissions[83–85]. For example, conservation agriculture in India resulted in increased yields and reduction in GHG emissions[84]. Likewise, diet transitions and reduction of food waste have mitigation and human health co-benefits[86–89], with few, if any, examples where these responses failed to benefit marginalized populations, such as wealthier livestock owners being better able to manage market access[90].
- The average for RKR 'Low-lying coastal systems', RKR 'Water security' and RKR 'Risk to human health' (average of 1.6, 2.1 and 2.1, respectively) show the lowest scores, that is, options that demonstrate a high potential for contributing to the risk of maladaptation. In the case of low-lying coastal systems, many examples of coastal infrastructure involve major GHG emissions[91], have negative environmental consequences[92–94] and worsen the situation for marginalized groups because those groups are not protected directly[95–97]. For example, scholars document the pitfalls of 1,484 hard structures on the coast of Colombia, mostly to protect tourist locations, which have resulted in substantial erosion[93]. Other coastal adaptations, such as strategic retreat, have also been implemented in a way that worsens the situation for marginalized groups[98–103], for example, because of the inability of the programme to relocate a whole community. In the case of water security, many adaptations that focus on water capture and storage, such as dams, had negative outcomes for marginalized groups[104,105], and mixed ecosystem outcomes[106]. An example is 'green-grabbing' in China, in which riverine populations were not adequately compensated for the losses they experienced when new hydropower plants were created[105]. Efforts to reduce water demand or improve water distribution have tended to be incremental, rather than transformational[107,108], and a good number have had negative outcomes for ecosystem services[109]. For example, plastic film mulching to improve water-use efficiency in wheat crops can lead to microplastic pollution and soil contamination[109]. When it comes to risk to human health, GHG emissions[110] associated with improvements to health systems/ infrastructure contributed to low scores. While these adaptation options can be associated with improved equity outcomes[111], actual implementation is often criticized for failing to benefit those who are most in need[112,113].

Adaptation outcomes by adaptation option

Across different adaptation options, the potential for adaptation and the risk of maladaptation are distributed differentially across criteria (Fig. 2), and a fortiori from one case study to another. However, most adaptation options are located in the middle of the continuum, with the average score for the whole sample being 2.3. Adaptation options with the highest potential to contribute to adaptation are:

- Diets/food waste (mean score 3.2) is usually associated with mitigation, but has large potential for adaptation too. While specifics vary by contexts, food system transformations have been encouraged in all contexts around the world, promoting healthy foods and reducing food loss and waste[86,114]. In many cases, shifts to healthy diets also include reduced meat consumption, which reduces GHG emissions and often results in improved environmental outcomes. There is little evidence of how changing diets and reducing food loss/waste would affect equity, although some argue that such changes could benefit women and low-income groups[115,116]. This adaptation has the potential to be transformational, causing large-scale changes in global cropland use and facilitating positive human health outcomes[117,118].
- Nature restoration (2.8) can be applied in different forms across contexts, in rural and urban locations, and has the potential to benefit billions of people, strengthen ecosystem services and increase GHG sinks. In several cases, however, Indigenous and local knowledge has been overlooked in the development of nature restoration programmes. The distribution of benefits varies widely, sometimes exacerbating inequalities or directly benefiting marginalized or low-income groups. Restoring natural areas can transform the landscape and human systems, but in most cases it is incremental in nature and done at small scale.
- Farm/fishery practices (2.8) is a large category of adaptation options, encompassing a wide array of projects to improve the outcomes of farming and fishery operations, many of which focus specifically on benefits for low-income populations, marginalized ethnic groups or women[78–82]. While these tend to be incremental[119,120] adaptations, some of them have the potential to sequester carbon or improve ecosystem services[84,121]. However, there is substantial variability, with many examples of adaptation projects falling closer to the maladaptation side of the continuum[122].
- Social safety nets (2.8) exist in most countries of the world and therefore reach a large number of people. There is strong evidence that social safety nets can benefit low-income populations and women[123–126], and there is no explicit environmental benefit/ harm. When it comes to transformational potential, in principle, social safety nets can be transformative, but in practice, effectiveness is moderate[125,127,128]. For example, the guaranteed employment safety net in India has raised rural wages and empowered women with access to work with equal pay, but has been subject to top-down decision-making that has resisted power transfer to marginalized groups[127]. There are varying examples of safety nets locking people into existing economic, social and power structures.
- Minimizing ecosystem stressors (2.8) includes a variety of programmes designed to reduce stresses on ecosystems, which has benefits in terms of ecosystems being able to maintain their integrity and the provisioning of ecosystem services in a changed climate. Certain programmes, such as an invasive species management programme in South Africa, employed people and reported benefits for low-income groups[76]. In other examples, such as agreements to reduce fish catch to reduce pressure on marine ecosystems, have placed additional economic stress on fishers[129].

 https://doi.org/10.1038/s41558-023-01774-6

Adaptation options with the lowest contribution to adaptation are:

- Coastal infrastructure/hard protection (mean score 1.0) can be maladaptive, because sediment transfer has negatively impacted adjacent communities, which can reduce ecosystem services, and because investments in protection prioritize wealthy regions[92–94]. Most hard infrastructure also causes GHG emissions. In terms of transformational potential, a majority of coastal protection measures are intended to keep things 'as they are' without substantially changing the area that is being protected. Examples that fall closer to the adaptation side of the continuum have focused on flood reduction efforts in low-income communities.
- Insurance (1.4) applicability varies by context, with health insurance widely used, and agricultural insurance most developed for higher-income countries and population groups. Many low-income groups and marginalized ethnic groups are at a disadvantage or excluded when it comes to insurance, and this can widen disparities[130–132]. Insurance may signal the need for transformation if it is made more expensive or taken away. In most cases, however, it encourages households, business and the public sector to maintain their institutional structures[133].
- Coastal accommodation (1.7) tends to be incremental, making small changes to existing infrastructure to avoid climate impacts[134]. There is limited research available on who tends to benefit the most from coastal accommodation, but some studies find that infrastructure investments to accommodate rising seas, such as refurbishing houses, tend to accrue less to women-headed households[135]. Some ecosystem-based accommodation can have GHG benefits and benefits to ecosystem services[136].
- Water use/demand (2.0) reallocation often tends to be discrete and incremental. The impacts on GHG emissions are mixed, with plastic film mulching likely to increase emissions[109,137] and reducing transmission losses likely to decrease electricity use[138]. Water efficiency projects tend to have higher uptake rates by men and higher-income farmers, but there are examples of projects that specifically aim to benefit marginalized groups.

Adaptation outcomes per NAM assessment criteria

Focusing on the assessment criteria, the NAM framework allows us to determine specific adaptation or maladaptation drivers. For example, most options are designed in a manner that ignores the trade-offs or negative side effects on low-income populations (Fig. 2, five brown circles) or marginalized ethnic groups (four brown circles) and miss drawing on the transformational potential of adaptation (five brown circles). By these omissions, adaptation options most often risk being maladaptive. On the contrary, adaptation options that yield benefits for ecosystems and ecosystem services (only two brown circles) have the largest potential for successful adaptation.

Importantly, several options have synergies and trade-offs for other societal or climate goals. For example, choosing options that do not involve substantial additional GHG emissions is particularly critical when thinking of climate-resilient development and avoiding responses that undermine broader climate goals (on mitigating and adapting). For example, nature restoration and minimizing ecosystem stressors are particularly important for meeting climate mitigation goals, as these options often involve capturing carbon. If one is interested in options that are particularly beneficial for low-income groups, for example, social safety nets, next to strong public health infrastructure, well-functioning food storage and distribution mechanisms (Fig. 2) score highest, collectively building general and specific capacities to adapt[139].

Concluding remarks and remaining gaps

We offer the NAM framework to help assess progress with regard to adaptation and maladaptation practices. The framework (Fig. 1) provides adaptation researchers, practitioners and funders with a composite assessment approach to enable better anticipation of adaptation outcomes and/or the risks for counterproductive effects. The continuum approach mirrors the reality of adaptation implementation, going beyond suggesting interventions as 'good' or 'bad', and instead highlighting how interventions can in complex ways have mixed outcomes based on a number of assessment criteria. As Fig. 2 highlights for a cross-case analysis, the location of each adaptation response on the continuum is captured through the outcomes on ecosystems (and ecosystem services), the climate (GHG emissions) and social system (transformational potential), as well as on normative equity-related aspects, such as outcomes on low-income populations, women/ girls and marginalized ethnic groups. This method underscores ancillary benefits, co-benefits and synergies of adaptation that are seen as decisive in reaching local or broader societal goals, such as the SDGs.

The NAM framework acknowledges that the outcome of any adaptation response is inherently local and context-specific[140], and that ecological, socio-cultural and institutional conditions play a decisive role in defining where a response falls on the adaptation–maladaptation continuum. In this study, this contextual granularity is obfuscated because averaging across case-study-based evidence hides the circumstances in which adaptation responses can play out as successful versus maladaptive. By applying the framework across a large number of scientific papers and case studies, we highlight an overall emerging picture of the evidence. Further criteria could be included depending on the adaptation response and context (for example, when an adaptation option might increase risks related to other climate-related hazards such as floods, heat, drought or risks for neighbouring communities).

We also acknowledge the limits that come from the biases that could underlie the selection of case studies. The included literature aims to reflect the breadth in regional and temporal scales, and stakeholder voices and views of studies available. However, we also note existing reporting biases. We do not include missing values ('n.a.' in Fig. 2 and Supplementary Table 3) in the calculation of averages, and for most adaptation options there is a gap in information for some criteria. This is particularly the case for the outcome of adaptation on GHG emissions as well as equity. These knowledge gaps indicate the need for further research and for more systematic, inclusive monitoring and evaluation.

Further, the six assessment criteria are weighted equally. In practice, some criteria will be 'valued' more than others based on normative goals that are socially acceptable or desirable at a given local context. In addition, aggregating synergies, co-benefits and trade-offs neglects comparability challenges: for example, is a slightly negative consequence of adaptation for a vulnerable group to be considered as important as a slight positive outcome on ecosystem services? Such discussions are to be held on a case-by-case basis and across stakeholders to reach decisions that fit the political, socio-economic and cultural context in which the framework is applied. Furthermore, higher numbers on the NAM assessment criteria mean a higher potential for adaptation, but the intervals from 1 to 4 (or any other scale) need to be considered carefully. For example, at the criterion level it is hard to judge whether the distance between scores 1 and 2 means the same from a long-term climate adaptation perspective as the distance between scores 2 and 3.

The NAM framework focuses on assessing outcomes of adaptation, rather than the process of designing and implementing them, which can introduce factors that contribute to a maladaptive outcome[12]. We acknowledge substantial institutional barriers such as those accompanying funding processes; however, the NAM framework does not explicitly engage with how an adaptation project has come about. These processes are well-addressed elsewhere[12,141] and are complimentary

 https://doi.org/10.1038/s41558-023-01774-6

to the NAM framework proposed here. Moreover, the assessment as presented is a static representation of potential adaptation outcomes. However, adaptation benefits or trade-offs change and emerge over time, often long after the intervention is implemented, and thus dynamic assessments using the NAM framework would be needed to monitor and evaluate evolving adaptation outcomes.

In summary, this assessment addresses the timely question of how to conceptualize and operationalize the understanding of adaptation versus maladaptation. The main conclusion is that an adaptation option is rarely fully adaptive or maladaptive, but rather that it can be located along a continuum dynamic in its position across space and time. Attention to specific, potential outcomes on the six assessment criteria of the NAM framework before implementation can help anticipate and potentially reduce maladaptive outcomes. This framework could help adaptation planners and other social actors detect, account for and minimize negative side effects, and identify and promote synergies and co-benefits. Applying the NAM framework after an adaptation response has been implemented can also be beneficial. To shift responses towards more successful adaptation, it is critical to focus on criteria that the option fares poorly on.

We note differences across options. The highest potential for successful adaptation is found in social and behavioural systems' options (for example, changes to diets/food waste and increasing social safety nets) as well as ecosystem-based options (for example, nature restoration, farm/fishery practices, minimizing ecosystem stressors). Both have direct and indirect positive outcomes for human livelihoods and wellbeing, and often also for low-income groups dependent on natural resource-based livelihoods, for example, through provisioning services. A higher risk of maladaptive outcomes is seen for infrastructural options such as coastal infrastructure or water storage and capture. Adaptation options such as insurance and coastal accommodation can also have maladaptive outcomes by way of excluding certain vulnerable groups and by fortifying the status quo. However, we also want to stress again that the circumstances of implementation play a large role. For example, social safety nets may potentially be a good option, but they are not if they miss certain groups of people. The way and processes of implementation can be decisive.

Our assessment has implications for adaptation implementation and policy. For funders, for example, this means that the potential of a given adaptation option can be evaluated before funding, and then regularly assessed to allow for adjustments. Monitoring and evaluation systems may rely on the NAM framework to be adjusted to fit the identified, explicit criteria to measure the potential of successful adaptation versus the risk of maladaptation. The fact that informing the NAM framework relies on an expert judgement to decide on scores (1–4 scale) makes it widely applicable, as the 'experts' are not only scientists, but also decision-makers, practitioners and local people familiar with the contextual specificities and having a clear understanding of desirable goals, including goals of climate risk reduction. All in all, implementing the NAM framework could raise critical knowledge on the changing nature of adaptation outcomes as well as the need for regular adjustments to overall adaptation[142–146]. That is, it could lay a foundation to facilitate adaptation pathways[147,148], adjusting an adaptation response itself throughout its operational lifetime or implementing additional adaptation responses that are able to buffer potentially detrimental side effects of the first response.

We conclude that an assessment of the multi-dimensional nature of adaptation is first practicable and second allows navigating along the adaptation–maladaptation continuum. This conceptualization prevents a narrow view of thinking in terms of immediate effectiveness and isolated responses. It highlights adaptation along pathways of responses that allow optimizing synergies, co-benefits, trade-offs and conflicts, ideally through multi-stakeholder decision-making. We argue that there is value in establishing more generic guidance to support case study analysis and, that way, achieve some consistency in how (mal)adaptation is captured across contexts, for example, to feed into international processes such as the global stocktake of the Paris Agreement, which requests governments to review the progress made in achieving the Global Goal on Adaptation. We suggest every adaptation response should be assessed against the potential outcomes on ecosystems (and ecosystem services), the climate (GHG emissions) and social system (transformational potential), and equity-related outcomes on low-income populations, women/girls and marginalized ethnic groups. We urge adaptation decision-makers and practitioners to accept responsibility and accountability for their actions, as we expect officials to be increasingly judged according to the outlined criteria by society.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

Some data generated or analysed during this study are included in this published article (and its Supplementary Information files). All datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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Acknowledgements

We thank all our colleagues from Chapter 17, AR6, IPCC WGII. In particular, we thank and acknowledge the help of M. Cattino, R. Chakraborty, S. Huo, I. Cojocaru-Durand, L. Pei, A. R. Rinaldi, Z. A. Klobus, Q. Krasniqi and I. M. Boussebaa. D.R. received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement no. 101036458 (LOCALISED project), no. 101019707 (RiskPACC project) and no. 869395 (HABITABLE project), and the JPI Urban Europe programme funded by NWO under grant agreement no. 438.21.445 (project COOLSCHOOLS). A.K.M. received funding from the 'Investissements d'avenir' programme supported by the French National Research Agency (ANR; grant ANR-10-LABX-14-01) and also acknowledges the World Adaptation Science programme for support.

Author contributions

D.R., A.K.M. and C.S. conceptualized the study. D.R., A.K.M., C.S., M.L.-S., B.O., E.L.F.S. and E.C.d.P. contributed to writing and editing. D.R. and A.K.M. synthesized the analysis. E.C.d.P. and B.O. oversaw data collection and synthesized the case study data. A.K.M. developed Fig. 2. C.S., D.R. and A.K.M. developed Fig. 1. M.L.-S. and D.R. developed Table 1.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41558-023-01774-6.

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Peer review information *Nature Climate Change* thanks Erik Glaas, Annah Piggott-McKellar and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

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Last updated by author(s): May 18, 2023

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Research sample	Paper based on the extensive (and updated) literature review developed under the IPCC AR6 Working Group II report (Chapter 16 and 17 especially), and the GAMI database reported in Ch.16 of IPCC AR6 WGII
Sampling strategy	Classical literature review process
Data collection	Classical literature review process + NAM framework synthesis + expert judgement (see Supplementary Material for description)
Timing and spatial scale	Papers published from 2015 until 2022
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