# Climate Change Maladaptation

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Maladaptation is caused by adaptation that fails to reduce vulnerability or inadvertently increases it. Maladaptation can be defined as: "maladaptation occurs when short-term strategies increase vulnerability in the long term" or "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increase the vulnerability of other systems, sectors, or social groups."

adaptation maladaptation spatial and temporal land spatial analysis

## 1. Maladaptation

The terms “adaptation” and “maladaptation” are widely used to describe responses to climate change [1]. Adaptations are adjustments to natural or human systems aimed at exploiting the beneficial opportunities or mitigating the possible negative effects caused by new or changing environments [2]. Adaptations can be also defined as the actions implemented to reduce the vulnerabilities caused by climate change [3]. Vulnerability can be simply described as susceptibility to harm [4]. According to the IPCC [5], “vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.” According to the IPCC [3][6], vulnerability is a function of three factors: exposure, sensitivity, and adaptive capacity. Exposure is the degree to which a system, such as people, locations, objects, or assets, is physically subjected to potential threats or existing hazards. Sensitivity is the degree to which a system, such as a transportation, water, or agricultural system, is adversely or beneficially affected by the stress of climate change. Finally, adaptive capacity refers to a system’s ability to cope with and adapt to the impact of climate change and to take advantage of the opportunities created by climate change. Thus, adaptive capacity can affect vulnerability through structural, institutional, and social actions and influence the impact of, exposure to, and sensitivity to climate change [4]. In general, adaptive capacities generated by adaptations can reduce the socioeconomic vulnerability caused by climate change [7]. Thus, the components of vulnerability can be a basis for classifying the functions of adaptation measures. According to the definition of vulnerability, adaptation measures can be classified into three categories [8]: (1) measures intended to increase adaptive capacity; (2) measures intended to reduce sensitivity by decreasing the susceptibility of a sector, system, or social group to damage; and (3) measures intended to reduce the exposure of a sector, system, or social group to climate change.

Maladaptation is a concept relevant to adaptation and vulnerability but has not been investigated in detail [9]. An intended adaptation is considered a maladaptation when it increases the long- or short-term vulnerability of social groups and sectors [10]. Certain studies have defined maladaptation by referencing intrinsic features. Maladaptation is caused by adaptation that fails to reduce vulnerability or inadvertently increases it. For instance, Jones et al. [11]

defined maladaptation as follows: “Maladaptation occurs when short-term strategies increase vulnerability in the long term.” Barnett and O’Neill [10] defined maladaptation as the “action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors, or social groups.” One of main reasons for maladaptation is the uncertainty of climate change. Gersonius et al. [12] stated that uncertainties make it difficult to design adaptive measures and decide which measures are suitable for reducing climate risks. Adaptive measures may lead to decreased flexibility in response to uncertain changes in climate conditions. However, climate uncertainty is not the only factor that increases maladaptive risks. Adaptation involves many systems, fields, time frames, development processes, and actors. Moreover, adaptation effectiveness is affected by human behavior and institutional adjustment. In certain cases, the overall adaptive capacity decreases [13] and vulnerability increases.

Vulnerability to climate change increases due to adaptation initiatives and causes short- and long-term effects on society. Vulnerability is not an invariant state but a dynamic state [14]. Adaptation has a time-delayed characteristic and various temporal and spatial effects [10]. Maladaptive risks change with time; thus, developing consistent thresholds of maladaptation as evaluation criteria is not possible. However, one can comprehensively examine whether the implementation of adaptation has achieved social goals can be examined.

## 2. Existing Conceptual Frameworks for Maladaptation Evaluation

Maladaptation is a major issue; however, no framework is available for identifying and evaluating the risks of maladaptation [15] because maladaptation development is affected by natural and human-induced changes at any time. According to Granberg and Glover ([16]: page 150), identifying maladaptation is difficult for several reasons. The authors stated, “there are no widely accepted criteria, no suitable yardsticks against which to judge the adaptation measures, local circumstances vary considerably, the passage of time can alter the extent of success or failure and there are the usual problems of subjective judgements.”

In the reviewed studies, at least four useful frameworks were proposed that can help governmental agencies and decision makers identify suitable adaptation initiatives by considering maladaptive risks in the planning stage. These four frameworks are the Precautionary Framework (proposed by [17] and reviewed by [14][15]), Assessment Framework [14], Feedback Framework [18], and Pathways Framework [10]. The Pathways Framework and Feedback Framework can be used to assess the plausible risks of maladaptation. Moreover, unlike the Pathways Framework and Feedback Framework, the Precautionary Framework and Assessment Framework can be used to prevent maladaptation in the initial planning stage of adaptation.

The Precautionary Framework and Assessment Framework provide concrete guidelines and checklists to avoid exacerbating the risks of maladaptation through ex ante measurement. However, these frameworks are unsuitable for screening the maladaptation caused by implemented adaptation measures. This phenomenon was demonstrated by Magnan et al. [14], who stated that “maladaptation, however, is difficult to quantify because of the qualitative nature of maladaptation indicators, making it difficult to determine a precise way to measure it.”

The Feedback Framework [18] is a novel and valuable assessment structure based on the definition of maladaptation proposed by Barnett and O'Neill [10]. It considers spatiotemporal effects for classifying the feedback mechanisms of maladaptation. This framework is useful for identifying the progress of adaptation initiatives and the entities negatively affected by an adaptation through three mechanisms of maladaptation: (1) shifting vulnerability, (2) rebounding vulnerability, and (3) eroding sustainable development. The first mechanism is related to adaptation measures that increase vulnerability for one or more external actors in the short or long term. The second mechanism is related to adaptation measures that increase climate vulnerability for implementing actors in the short or long term. Finally, the third mechanism is related to the effects of increased greenhouse gas emissions on environmental, social, and economic factors. Using the Feedback Framework to capture the vulnerability caused by ineffective adaptation or maladaptation is difficult. However, this framework can be used to investigate the maladaptation generated from specific adaptation measures, the interactions of risks among stakeholders, and who or what is affected by maladaptation effects in what manner.

Barnett and O'Neill [10] were among the first researchers to propose a framework for evaluating maladaptation. At least five pathways exist for categorizing maladaptive outcomes. These pathways can be considered initial criteria for screening potential maladaptation [10]. The aforementioned five pathways are mentioned as follows: (1) If adaptation leads to increased emissions, increased climate change would occur. (2) If adaptation actions meet the needs of one sector, system, or group but increase the vulnerability of those most at risk, disproportionate burdening of the most vulnerable would occur. (3) If economic, social, or environmental costs are higher than alternatives, the opportunity costs would be high. (4) If adaptation actions encourage unnecessary dependence on others, stimulate rent-seeking behavior, or penalize early actors, the incentives to adapt would decline. (5) If adaptation actions commit institutions and significant amounts of capital to trajectories that are difficult to change in the future, path dependency would occur. According to the literature reviewed in this study, the Pathways Framework is typically used to describe the outcomes of maladaptation. This framework recognizes the need to consider the effects of adaptations on spatiotemporal scales; however, the reviewed studies conducted ex post assessments and obtained feedback experience on a case-by-case basis.

Among the reviewed social science studies (n = 50), 28% used the Pathways Framework, probably because the Pathways Framework is advocated in AR5 and other frameworks. The most important property of the Pathways Framework is that it provides concrete scenarios of negative adaptation outcomes, which are widely used to assess and explain the circumstances of maladaptation. Other frameworks are relatively new and do not examine the risks of maladaptation but focus on minimizing the risks of maladaptation in advance. These frameworks had fewer citations than the Pathways Framework did in the reviewed social science studies. None of the reviewed spatial modeling studies adopted any framework. A main reason for this phenomenon is that research on maladaptation remains in its infancy. Disciplines of spatial modeling science have not yet been incorporated into the field of climate change adaptation [19].

Maladaptation must be analyzed in terms of the response process on spatiotemporal scales [14]. However, high uncertainty exists within the adaptation process. Societies may be affected by various risks of maladaptation over different timeframes [10][20]. The vulnerability also varies in different periods due to the changing climate and

maladaptation. Current discussions on maladaptation mostly focus on ex post evaluation. However, Magnan et al. [14] argued that climate change is a type of continuous variance and that maladaptive risk should be avoided before adaptation measures are implemented. Maladaptation exacerbates vulnerability; thus, identifying maladaptive risks is difficult in the initial stage of adaptation planning. Juhola et al. [18] suggested that the risk of maladaptation can be investigated by predicting the ex post results of adaptation initiatives.

The assessment frameworks adopted in the reviewed studies are suitable for analyzing specific climate risks. However, maladaptation must be considered within a comprehensive risk framework [21]. Maladaptive risks arise from initial climatic risks and increase vulnerability due to risk dynamics and substitution. This study preliminarily proposes the following dynamic characteristics of maladaptive risk to capture risk exhibition:

(a) Risk substitution: Risk substitution refers to actions that decrease the exposure of groups to one risk but increase their vulnerability to other risks. Thus, the original risk may decrease but new risks are generated.

(b) Risk transfer: Risk transfer refers to actions that do not decrease the overall risk but transfer it across different spaces. An adaptation initiative is considered maladaptation if it shifts risks existing in one space to other spaces. Risk transfer results in a vulnerability being relocated rather than reduced [15].

A lack of integrated studies to analyze the circumstance since that adapted specific climate risk but increasing original or inducing other risks. The aforementioned two dynamic characteristics of maladaptive risk are a convergence of spatiotemporal scales and should be basic elements of maladaptive risk assessment.

Various difficulties exist in quantifying maladaptive risks, such as the ambiguity of spatiotemporal scales, lack of risk thresholds, and spatial exhibition of various maladaptive risks. Existing spatial assessment techniques are unable to link the basic maladaptation theory with the four evaluation frameworks used in the reviewed studies. Information from multiple disciples must be integrated for designing suitable adaptation initiatives; otherwise, the likelihood of implementing maladaptive initiatives and decisions would increase [22]. The present study emphasizes that integrating relevant spatial modeling techniques and existing evaluation frameworks for maladaptation is crucial for accurate maladaptive risk assessment.

## 3. Maladaptive Evaluation Pathways

Climate change causes pressures on land [23] because adaptation to climate change could be a potential driver force of spatial land change. For instance, if people decide to out-migrate to adapt to climate variability and change, increased land changes are likely to occur. Such changes may result in the loss of ecosystem goods and services in the medium-to-long term [24]. Adaptation and environmental change are likely to influence each other and developing policies for minimizing the unintended outcomes caused by implemented adaptation initiatives is crucial [24]. In addition, the effects of adaptation initiatives vary with space [25]. The spatial modeling of land changes is a fundamental step in adaptation planning because such modeling can indicate how to reduce the

effects of climate change and avoid maladaptation [26]. Spatial land management can play a crucial role in mitigating emissions and be used to store carbon at a relatively low cost [23].

The development of an adaptation initiative is an iterative continuous learning process. This study constructed maladaptation evaluation pathways (Figure 1) that combine spatial modeling and theoretical maladaptation frameworks to investigate maladaptive risk. These pathways include climate scenarios, adaptation initiative scenarios, spatial land modeling scenarios, the dynamic characteristics of maladaptive risk, functions for increasing vulnerability, the affected entity, and pathways of maladaptation.

**Figure 1.** Developed maladaptive evaluation pathways.

An adaptation initiative can increase risk and vulnerability in the long term [27]. The effectiveness of adaptation is dependent on how the future unfolds and can be assessed through scenario modeling. The modeling of different climate and adaptation scenarios can reduce uncertainty and provide proactive mechanisms for managing changing circumstances. For instance, Poussin et al. [28] examined the effectiveness of selected adaptation initiatives for flood risk reduction at the river Meuse by comparing different adaptation and flood risk scenarios. Gersonius et al. [12] conducted a case study that indicated that maladaptive decisions may result if uncertainty and flood risk flexibility are not considered in economic analysis and coastal management strategies. Planning long-term strategies according to the knowledge and experiences of recent climatic events is unreasonable [29]. Therefore, the most important aspects of adaptation planning involve systematically linking present challenges with future climate risks and examining the various timeframes of maladaptive risk [15]. In addition, to prevent adaptation initiatives from becoming maladaptation, adaptation planners may select multiple adaptation initiatives and consider several possible future climate scenarios to predict plausible medium-to-long-term situations. They may also examine the maladaptive and climate risks of implemented adaptation initiatives.

Stakeholders may have varying and conflicting considerations in adaptation initiatives. Spatial modeling can be used to predict future situations and to coordinate the activities of multiple stakeholders for producing long-term benefits [26]. Thus, the effect of climatic events on stakeholders can be determined. Climatic events may become disasters due to inadequate or inappropriate human intervention. Spatial land change is driven by a complex combination of natural, social, and economic factors [23], and adaptation to climate change is a vital driving force of spatial land change. Most adaptation studies focus on conceptual approaches for investigating vulnerability, climate risk, and adaptive capacity but do not consider stakeholders' adaptation preferences [19]. The present study advocates that capturing the preferences of stakeholders is essential for identifying plausible future maladaptive risks. Thus, for identifying maladaptive risks, real perspectives on the selected adaptation initiatives and climate awareness must be collected from adaptation decision makers and spatial land change prediction must be performed. According to Magnan [15], if an adaptation initiative increases a system's vulnerability to climate impacts in both the present and future, it may be considered maladaptation.

Numerous studies have focused on adaptation issues, and future studies on these issues should consider the use of spatial analysis and planning [26]. Spatial analysis is a key tool in adaptation planning. It can be used to predict the effects of climate change and indicate the effects of adaptation at local scales. Through appropriate modeling, the effects of various adaptation initiatives can be quantified and compared by calculating the area of land change. Spatial land changes can be considered actually or potentially beneficial in adapting to climate change or may be considered maladaptation if they cause environmental degradation [30]. For quantification with spatial analysis tools, the maladaptive risks can be divided as risk transfer and risk substitution. This study suggests that a spectrum of climate and adaptation scenarios for future timeframes should be considered for identifying adaptation initiatives with the highest robustness (Mitter et al. [31] defined robust strategies as low-regret strategies, that is, strategies that are beneficial even without significant changes in climatic conditions and can be reversed due to their low cost of maladaptation) for various plausible future scenarios.

Spatial analysis involves integrating important factors across various spatiotemporal and governance scales. It can be used to simulate and predict plausible scenarios for implemented adaptation measures [32]. Spatial analysis provides opportunities to consider, assess, and select alternative future scenarios. It also facilitates the management and consideration of competing interests. The objective of using spatial modeling is to provide feedback regarding a predicted effect of a future state to the local environment and different stakeholders. The feedback mechanism and affected entity in the Feedback Framework are helpful for identifying conflicting interests among sectors or stakeholders from the spatial land change and risk distribution for the initial adaptation preferences and climate scenarios. After the identification of the conflicting interests, one can examine whether adaptation initiatives for a particular sector (or stakeholder) may drive maladaptation in other sectors (stakeholders) [33].

Proposed adaptation initiatives can be tested for maladaptation by examining the long-term effects of an implementation path [34]. Spatiotemporal scales cannot be identified using the original Pathway Framework, which enables outcome-oriented evaluation. However, the framework with concrete categories of maladaptive risks and suited for illustrating the specific states of risk when combined with spatiotemporal predicted modeling. This study compared the evaluation thresholds for different climate scenarios, socioeconomic conditions, and spatiotemporal scales. Maladaptation includes potential social and behavioral influences. For example, in Bihar, India, embankments were constructed to constrain rivers to their watercourses; however, when these embankments are breached, large areas of land are inundated with water that does not quickly return to river channels [35]. The maladaptive risks that may arise in different adaptation initiative scenarios at different timeframes and scopes should be explored.

The constructed maladaptation evaluation pathways are suitable for evaluating planned adaptation initiatives. A main reason for this phenomenon is that not all adaptation initiatives involve spatial allocation; thus, spatial analysis need not be conducted for some adaptation initiatives [25]. For example, in Australia, adopting refrigerant air conditioners may be a valid adaptation response to climate-related increases in temperature; however, this measure is a poor response from an electricity network perspective because it increases peak demand, network costs, carbon dioxide emissions, and finally, electricity prices, which disproportionately affects low-income

residents [36]. According to Juhola et al. [18], when analyzing maladaptive risk, autonomous adaptation initiatives should not be considered. However, adaptation is affected by changes in the behaviors or coping initiatives of stakeholders due to risk perception or past experiences of climate change. Not all autonomous adaptations have positive consequences [37]; some autonomous adaptations may cause negative outcomes and maladaptive states. This study advocates that one should focus on not only planned adaptation initiatives but also maladaptive risks of autonomous adaptation initiatives in the evaluation of maladaptive risks because autonomous and planned initiatives can affect each other. Maladaptive risk depends on the nature of the implemented adaptive initiatives, if any. The mechanisms and pathways of maladaptation that may undermine the adaptive capacity of sectors or stakeholders must be determined by investigating the cause-and-effect relationships between adaptation initiatives and implementing (or targeted) or external actors.

Finally, this study recommends that spatial modeling, dynamic mechanisms of maladaptive risk, the Feedback Framework [18] and the Pathways Framework [10] must be integrated as analytical bases for determining the mechanisms and pathways of maladaptation. By combining the Feedback Framework and Pathway Framework and using social science investigation methods, one can explore the interactions among the risks for stakeholders (winners and losers) and determine who or what was affected by maladaptation effects in what manner.

Adaptation initiatives enable vulnerability to be minimized but may have unintended maladaptive effects in the long term. Inappropriately framed adaptation initiatives have high maladaptive risks. Quantifying and comparing the benefits of adaptation initiatives and the environmental and socioeconomic effects of maladaptation are difficult tasks. If the spatiotemporal changes caused by adaptation and their effects on socioecological systems can be evaluated in advance at the adaptation planning stage, appropriate decisions can be taken to increase the adaptation efficacy and reduce maladaptive risk [38]. Finally, an increased number of experimental studies should be conducted on land spatial modeling to better incorporate such modeling into decision-making related to adaptation initiatives, identify maladaptive risks, and reduce uncertainties.

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