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Insights intended to improve adaptation planning and reduce vulnerability at the local scale

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We live in a world of constant change, where multiple factors that generate vulnerability coincide, such as pandemics, climate change, and globalization, among other political and societal concerns. This demands the development of approaches capable of dealing with diverse sources of vulnerability and strategies that enable us to plan for and mitigate harm in the face of uncertainty. Our paper shows that the interpretation and conception that one gives to vulnerability in climate change can influence how decision-making solutions and adaptation measures are proposed and adopted. In this context, our approach integrates contextual vulnerability and decision-making planning tools to bolster the capacity to adapt at a local scale. We link our analysis to the evolution of vulnerability in climate change studies and some core articles and decisions on climate change adaptation and capacity building under the United Nations Framework Convention on Climate Change (UNFCCC) and the Conference of Parties throughout this study.

KEYWORDS

adaptive capacity, planning tools, vulnerability, climate change, adaptation

1 Introduction

The concept of vulnerability is relevant to research in several disciplinary fields, including areas such as political economy, natural hazards, food security, public health, and environmental change, for describing states of susceptibility to harm (Blaikie et al., 1994; Cutter, 1996; Adger, 2006; Smit and Wandel, 2006; Barnett, 2020). However, the treatment of the term "vulnerability" in climate change has been notoriously ambiguous. Understanding of the term has evolved as our understanding of the causes and complex feedback mechanisms associated with the impact of climate change has developed. Therefore, different epistemological orientations have influenced the term's use, giving rise to varying interpretations of vulnerability and ways in which it has been approached over time (Kelly and Adger, 2000; Füssel, 2007; Klein and Möhner, 2011).

This paper highlights that in a world full of constant and rapid changes, there is a pressing need to bolster the capacity of complex social-ecological systems to anticipate and respond to diverse adverse climate change-related exposure, political-economy relations and other societal concerns that generate vulnerability (Folke et al., 2002; Engle, 2011; Whitney et al., 2017; Cinner et al., 2018). In this study, we integrate contextual vulnerability with decision-making planning tools as a means intended to increase the capacity to adapt locally in light of diverse sources of exposure. This paper is divided into four sections. Section 2 outlines vulnerability due to climate change viewed from different perspectives, including the dimensions of outcome and contextual vulnerabilities. Based on these insights, we show how we integrate contextual vulnerability with some decision-making planning tools in Section 3. Section 4 shows the conclusions of this paper.

2 Notion of vulnerability in climate change interventions

Frequently, researchers define the term "vulnerability" as the "susceptibility of a system to adverse effects" or its "capacity to be wounded" (Turner et al., 2003; Ford and Smit, 2004; Füssel, 2007). However, the conceptualization of vulnerability in climate-change studies depends on the lens through which it is viewed and assessed (Ford and Smit, 2004; Eakin and Luers, 2006; Füssel, 2007). The word "vulnerability" means different things in different discourses (O'Brien et al., 2004a, 2007; Füssel, 2010). Therefore, the term's ambiguity has led to its indistinct use and triggered numerous diagnoses and cures regarding the climate-change problem (O'Brien et al., 2004a), influenced, among various circumstances, by theories on lack of entitlements and natural hazards (Sen, 1981; Turner et al., 2003; Adger, 2006; Füssel and Klein, 2006).

2.1 Vulnerability viewed through a risk-hazard perspective

Often, climate change has been understood and conceived as a scientific and technical problem in the scientific community. The risk-hazard research tradition has influenced assessments of climate change and continues to do so. This research tradition describes the hazard of a system of analysis as a dose-response relationship between an external hazard and its consequences for the system (Adger, 2006; Füssel, 2007; Tonmoy et al., 2014). This approach represents the classic conceptualization of vulnerability in engineering science, focusing on the physical elements of exposure and hazard impacts in terms of magnitude, rapidity of onset, duration, and frequency (Schröter et al., 2005; Füssel, 2007; McLaughlin and Dietz, 2008; Shitangsu, 2014). This view represents the most basic form in which climate-change discussions treat climate-change impacts at the onset of the problem through climate model projections. Influenced by Article 2 of UNFCCC, which calls on countries to reduce their greenhouse gas emissions to avoid dangerous anthropogenic interference in the climate system, adaptation was considered a defeatist option that climate-change negotiators did not accept at the time, as support for adaptation implied recognizing that mitigation would be insufficient to address climate change (Oppenheimer, 2005; Pielke et al., 2007; Schipper et al., 2020). Adaptation was absent in the global policy discourse. Therefore, climate-change assessments were focused primarily on the projected impacts of external factors of change on a system (Thomas et al., 2019).

As a result of a robust mitigation-oriented view, much of the discussion surrounding vulnerability has relied on "climate-change impact assessments," through the use of greenhouse gas (GHG) scenarios and climate models derived from global circulation models (GCM) (Downing, 2003; O'Brien et al., 2004b; Ford et al., 2010). This linear interpretation of vulnerability has given rise to one group of vulnerability assessments of climate change, which the risk-hazard school of thought influences. It projects potential future conditions and assumes adaptations to estimate damages, ignoring internal characteristics that vary from place to place. The underlying point of this view is that it considers vulnerability as the residual impacts of climate change after speculating upon some adaptation measures (Dessai et al., 2004; Brooks et al., 2005; Eakin and Luers, 2006; Smit and Wandel, 2006; Prno et al., 2011). Commonly, this interpretation of vulnerability follows a sequence of steps beginning with GHG scenarios and climate projections, to estimate possible future impacts quantitatively, monetarily, or in terms of biophysical change. Then, it assumes some adaptation options aimed at reducing the adverse effects of climate change. Vulnerability is the last stage of this series of analyses (the end state of a system of interest) (Smit and Pilifosova, 2003; O'Brien et al., 2004a). In other words, vulnerability is the result of the projected net impacts of climate change on a system, offset by assuming adaptation options. Under this view of vulnerability autonomous adaptation options are undertaken in response to experiencing some climate-condition changes—i.e., one individual adopts some standalone adaptation options in response to experiencing some changing conditions in the environment. Essentially, the main focus and starting point of this view of vulnerability is the stimulus, i.e., the net impacts of climate change derived from climate-change scenarios (Brooks, 2003; Smit and Pilifosova, 2003). This linear way of thinking represents the classical approach to vulnerability, inherited from the initial Intergovernmental Panel on Climate Change (IPCC) guidelines and initial reports from the ceased United Nations Disaster Relief Office (UNDRO) to assess vulnerability (Burton et al., 2002; Cardona, 2004; Füssel and Klein, 2006; Thomas et al., 2019). Therefore, this approach has been particularly important in comprehending the potential impacts of climate change and raising public and political awareness of the adverse effects of climate change (Cardona, 2004; Ford and Smit, 2004).

Influenced by climate-change negotiations, the "first generation of vulnerability assessments" has been used for purposes such as meeting Article 2 of the UNFCCC, particularly when referring to the phrase "dangerous interference" (Smit et al., 2000; Burton et al., 2002), and to meet decision 11/CP.1, which divided adaptation work into three stages. Stage 1 was to carry out impact assessments to identify possible impacts of climate change and potentially vulnerable countries and regions (Adger et al., 2003; Burton, 2003; Füssel, 2004). In this context, the first-generation vulnerability assessments, which the literature also calls impact assessments (Smit and Pilifosova, 2003), outcome vulnerability assessments (O'Brien et al., 2007), top-down approaches (Dessai and Hulme, 2004), endpoint assessments (Kelly and Adger, 2000), or biophysical vulnerability assessments (Brooks, 2003), have played a significant role not only in meeting the objectives of the UNFCCC and resolutions under its auspices but also in generating the first IPCC reports, the first National Communications on Climate Change, the first Biennial Update Reports (BURs), and early research efforts in this field.

With this background, we note that climate-change vulnerability assessments have given considerable attention to the mismatch between the scale of GCMs and the local scale (Fowler et al., 2007). The use of climate models and scenarios derived from GCM, through statistical analysis and historical data, forecasts the potential effects of climate change on different scales. This linear form of approaching vulnerability locates the causality in climate hazards and not nearly enough on the social causation of vulnerability despite that they are both causal and have causes (Wisner, 1976; Wisner et al., 2003; Ribot, 2014). Systemic risks induced by climate change (e.g., the collapse of the local economy of a system of analysis due to diminishing agricultural production or diminishing tourism revenues) can trigger a cascade of detrimental effects on a system of analysis on social, ecological, political, and economic levels (Li et al., 2021). Therefore, vulnerability, defined as the projected impacts of external stressors on the exposed system of analysis, becomes one diagnosis rather than a way of identifying specific and actual vulnerability factors in systems of concern (Turner et al., 2003). In this context, it is significant that this technocratic view and rigid risk-hazard perspectives are shifting as our understanding of global dynamics and interactions evolves. Examples of this paradigm shift can be found, for instance, in the 5th assessment report (AR5) of the IPCC Working Group 2. AR5 is primarily focused on climate-related risks, taking into consideration human and natural systems and the Sendai Framework for Disaster Risk Reduction (SFDRR), a human-based approach rather than merely a technocratic view focused on risk reduction (Schipper et al., 2014; Räsänen et al., 2016; Busayo et al., 2020). Although still criticized from a political-economy perspective, these frameworks enable the integration of risk-hazard perspectives into climate change adaptation more coherently. In particular, the SFDRR's approach stresses the importance of vulnerability dimensions, disaster risk governance and stakeholders' participation in measures, strategies, and policy development during risk management processes (Lee and Chen, 2019; Matsuoka and Gonzales Rocha, 2021). As such, the SFDRR's approach has provided a platform to explore and integrate relationships and synergies between disaster risk reduction, climate change adaptation and other societal concerns at diverse levels and sectors in more depth, hand in hand with other significant frameworks, including the Sustainable Development Goals, the Paris Agreement (PA), and the New Urban Agenda (Wisner, 2020).

2.2 Vulnerability viewed through a social constructivism perspective

In contrast to impact assessments, climate change alone does not determine decision-making in current climate-change vulnerability studies. The social constructivism school of thought has influenced contemporary climate-change vulnerability assessments. The rationale of this research tradition is that social stressors (internal conditions) (e.g., vested interests, institutional factors, governance structures, unequal access to property and resources, corruption and nepotism, elite interests, marginalization, power relations, and other socio-economic and political factors) also determine the state of a system of analysis (Turner et al., 2003; Ford and Smit, 2004; Wisner et al., 2003; Füssel, 2005, 2007; Schröter et al., 2005; Füssel and Klein, 2006; Tonmoy et al., 2014; Pearse, 2016; Arifeen and Eriksen, 2019; Barnett, 2020; Mikulewicz, 2020; Scoville-Simonds et al., 2020; Eriksen et al., 2021).

This interpretation of vulnerability incorporates human dimensions and food-security studies have widely used it to explain the implications of both physical and socioeconomic circumstances in unfolding famines (Wisner, 1976; Sen, 1981; Watts and Bohle, 1993; Downing, 2003; Füssel, 2005). This rationale draws on the "wounded soldier perspective", in which pre-existing pressures (existing wound), rather than the effects of future external factors alone (future attacks), determine vulnerability (Kelly and Adger, 2000). The etymological foundations of this analogy link "vulnerability" with the Latin *vulnerabilis*, describing the state of an injured soldier on a battlefield, implying an army already at risk and vulnerable, regardless of a future attack (Kelly and Adger, 2000). This view of vulnerability contends that both climate and non-climate factors, not just external factors, can harm a system of analysis (Tschakert et al., 2013; Thomas et al., 2019; Eriksen et al., 2021). From this perspective, vulnerability is the starting point of the analysis rather than a sequence of steps. It is the result of the interaction of multidimensional factors spanning multiple scales and levels, from global to local, including both internal conditions (e.g., social, political, economic, environmental, institutional, urban and demographic) and external conditions (e.g., climatic and market conditions) (Neil Adger, 1999; Kelly and Adger, 2000; Smit and Pilifosova, 2003; O'Brien et al., 2004a; Eakin and Luers, 2006; Ford et al., 2006a,b; Garschagen and Romero-Lankao, 2015; Räsänen et al., 2016; Constable, 2017; Thomas et al., 2019).

This generation of climate-change vulnerability assessments is one of the applications used for meeting Article 4.4 of the UNFCCC, which commits developed countries to assist developing countries (particularly those most vulnerable to the adverse effects of climate change) in meeting the costs of adaptation (Füssel, 2004). The lack of specificity of Article 4.8 of the UNFCCC (i.e., potentially sensitive places) has appeared, from the perspective of developing countries, as an opportunity to get international funds and, from the developed countries' perspective, as a way to identify vulnerable locations for assigning resources. Commonly referred to as "second-generation vulnerability assessments," the literature variously identifies these as vulnerability assessments (Smit and Pilifosova, 2003), contextual vulnerability assessments (O'Brien et al., 2007), bottom-up approaches (Dessai and Hulme, 2004), starting-point assessments (Kelly and Adger, 2000), and social vulnerability assessments (Brooks, 2003). This generation of climate-change vulnerability assessments has played and does play a significant role in the development of recent IPCC Assessment Reports, contemporary National Communications on Climate Change Reports, Biennial Update Reports, National Adaptation Programmes of Action (NAPAs), National Adaptations Plans (NAPs), Nationally Determined Contributions (NDCs), and current research efforts in the field.

2.3 Embracing contextual vulnerability interventions

Although numerous vulnerability interventions have attempted to measure vulnerability across different sectors of interest, remembering that it is a theoretical concept that reflects a dynamic state, not an outcome, is crucial (Adger, 2006). The contextual approach to vulnerability assessment often identifies indicator-based approaches as the dominant method of measuring vulnerability to determine and prioritize vulnerable areas and groups (Eriksen and Kelly, 2007). In doing so, indicator-based approaches often seek to operationalize vulnerability by combining socioeconomic and biophysical data to then aggregate them into an overall measure to quantify vulnerability (Tonmoy et al., 2014; Gaworek-Michalczenia et al., 2022). The construction of these indicators has often followed the relationship: Vulnerability = Exposure + Sensitivity – Adaptive capacity. However, while the policy arena has valued the use of the vulnerability-indices arena because it enables a straightforward interpretation of the results of indices, allowing the synthesis of complex relationships into numeric results that facilitate rapid decision-making (Hinkel, 2011), intense criticism has confronted indicator-based approaches' methods and calculations. Much of this criticism arises because they do not capture the specific socio-political economy relations that generate vulnerability in complex social–ecological systems, and the selection and creation of indices depend heavily on the availability of physical and socioeconomic data variables, generally gathered from national censuses or national and international datasets (Brooks et al., 2005; Klein and Möhner, 2011; El-Zein and Tonmoy, 2015; Eriksen et al., 2021).

We refer to vulnerability more accurately in terms of assessment than measurements (Leichenko and O'Brien, 2002; Downing, 2003; Hinkel, 2011; Nguyen et al., 2016). The term "vulnerability" refers to particularly vulnerable situations (Brooks, 2003). This means that it does not presume variables. It seeks to identify empirically the different underlying conditions driving vulnerability in one system of analysis regardless their geneses (Belliveau et al., 2006; Fazey et al., 2010; Ford et al., 2010; Hopkins, 2015; McCubbin et al., 2015). Exploring the root causes of vulnerability and possible adaptation measures requires context-specific and cultural-specific investigations (Mills-Novoa, 2023). Decisive action in one place may lead to maladaptation or reinforce power relationships in another place or other groups (Eriksen et al., 2015, 2021; Antwi-Agyei et al., 2018; Work et al., 2019). This can be observed, for instance, in Victoria del Portete, a local community in Ecuador where adaptation interventions intended to provide irrigation systems ultimately only benefitted those with the financial resources to replace broken pipes, leaving the poorest within the association without access to the project (Mills-Novoa, 2023).

Any system of concern involves different social, institutional, environmental, cultural, and political-economy conditions, which can vary significantly from place to place, regardless of their closeness (Turner et al., 2003; Ford et al., 2008; Nightingale, 2017). As such, the ability of vulnerability assessments to capture the climate-society dynamics of a particular system of concern decreases as distance increases (Thomas et al., 2019). Assuming a relation of behaviors and features across locations will inevitably lead to wrong decisions. Therefore, if vulnerability interventions aim to extrapolate outcomes from nearby areas, they will not capture the specific variables and the dynamics that make people vulnerable (Atteridge and Remling, 2018). Mindful of such constraints, many scholars in this context employ ethnographic techniques such as semistructured interviews, focus groups, participant observation, walking transects, seasonal calendars, climate diaries, and hazard mapping, considering the local experience from the beginning of the research to prevent inconsistencies and biased outcomes (Schröter et al., 2005; Belliveau et al., 2006; Ford et al., 2008; van Aalst et al., 2008; Pearce et al., 2009; Fazey et al., 2010; Hopkins, 2015; McCubbin et al., 2015; Mills-Novoa, 2023).

3 Contextual vulnerability and decision-making planning tools

Bearing in mind that within a new architecture of climate governance under the PA, the global adaptation goal centers on enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development (see Article 7 of PA). We argue that if we integrate the planning tools and strategies (described below) to address the specific underlying sources of vulnerability in a system of interest, these strategies serve as means to enhance adaptive capacity at a local scale.

3.1 No-regrets adaptation options

Political instability often influences systems of analysis, particularly in developing countries where political positions are variable in the short term, and political disputes might render previous decisions invalid (Helmke, 2020; Warsame et al., 2022; Asfaw et al., 2023). Although it is not considered to be transformational or the best option for strengthening the capacity of a system to adapt, the "no-regrets" adaptation option is a method worth mentioning for decision-making in such a scenario. This approach involves actions thought wise regardless of climate change, which, if implemented, improve the adaptive capacity of a system of analysis in light of climate-change effects (Dessai and Hulme, 2007; Hallegatte, 2009). Significantly, no-regret actions can reduce the "adaptation deficit"—also called "development deficit" and "wounded soldier" (i.e., minimize exploitation, raise prices on primary goods, allow access to markets and to representation and rights for all ethnic and religious groups, abolish racial hierarchies, patriarchy norms and skewed cultural norms, diminish job and education segregation, protect water resources, and enhance the public health system among other societal concerns) (Táíwò, 2022), underlying issues and sources of vulnerability in developing countries usually identified after carrying out contextual vulnerability assessments.

3.2 Climate-change mainstreaming

Climate change and development concerns have often been dealt with separately, creating a gap between development agendas and local realities (Adam, 2015; Smucker et al., 2015). Evidence shows that adaptive capacity and adaptation strategies are linked to different societal concerns and factors of vulnerability, usually stemming from underdevelopment, including such social demands as electricity and water supply, access to adequate public health services, better purchasing power, access to quality education, and infrastructure and technology improvement (Smit and Pilifosova, 2003; Agrawala, 2004; Ayers et al., 2014; Milman and Arsano, 2014; Abrahams and Carr, 2017; Robinson, 2019; Braunschweiger and Pütz, 2021; Kundo et al., 2021). Therefore, analyzing climate change and development separately not only increases vulnerability but also has the potential to generate ineffective responses to tackling the underlying factors that make people vulnerable (maladaptation) (Antwi-Agyei et al., 2018). There is broad agreement that current problems, such as climate change or novel pandemics such as the 2019 novel coronavirus or COVID-19, can potentially worsen present socioeconomic factors and needs that make people vulnerable, a priori. Therefore, development is and has been the primary concern [see decision 2/CP.17; (2011)], and the best form of adaptation is in places that still face issues related to underdevelopment (Milman and Arsano, 2014; Robinson, 2019; Schipper et al., 2020). Mainstreaming adaptation into development enables formulating long-lasting actions across various sectors, by including climate-change issues and development priorities (underlying drivers of vulnerability) together. Therefore, separating progress and responses to climate change makes no sense, bearing in mind that Article 4.1(f) of the UNFCCC call countries to include climate change adaptation into their development programs and that the majority of international financial cooperation destines to support development in developing countries (Smit and Pilifosova, 2003; Ayers et al., 2014; Milman and Arsano, 2014).

This method of creating policy coherence allows the inclusion of climate-vulnerability concerns in ongoing decision-making structures at various scales, and eliminates unnecessary double efforts and conflicts between priorities and strategies (Agrawala, 2004; Ayers et al., 2014; Rauken et al., 2015). For example, initiating such development programs as climate-smart agriculture indirectly encourages concrete adaptation actions and monitoring processes. Using the Pru District in Ghana as an empirical case, Ahenkan et al. (2021) show that through Mobile Weather Alert Messaging training, farmers can learn to use their mobiles phones to obtain daily weather forecasts. This gives them insight into when to plant their crops and when not to, thus increasing their productivity.

In the agriculture sector, a vital area for many developing countries, mainstreaming allows the inclusion of development and climate-change concerns in decision-making policies (e.g., through subsidies). Mainstreaming influences farmers to choose crop varieties better adapted to drier or more saline conditions, considering the prospect of damages and losses. The cost of a sudden reduction in agricultural production could be devastating for a local community in terms of economic or food security, for both the short and the long term. These unexpected events not only create environmental damage but also exacerbate poverty and other social problems, due to the high dependency of countries considered vulnerable to climate change on climate-dependent sectors (e.g., agriculture and livestock, fisheries, tourism). In that regard, the incorporation of adaptation into development policies in the agriculture sector, through the implementation of subsidies for seed that is more tolerant of drier conditions, could decrease damages and losses from drought. Sorghum bicolor, for example, is a climate-smart crop that is widely grown throughout the world, particularly in Africa (Pixley et al., 2023). We must bear in mind that Article 8 of the PA formalizes Loss and Damage within the climate regime. This Article calls on countries to avert, minimize and address loss and damage associated with the adverse effects of climate change in vulnerable developing countries [see, also, decision 2/CP.19 regarding the Warsaw International Mechanism for Loss and Damage; (2013)].

Although some adaptation interventions may seem highly successful initially, after project closures, local actions and strategies intended to foster the adaptive capacity of a system have uncertain futures (Mills-Novoa, 2023). Therefore, mainstreaming is a vital planning tool for creating a coherent umbrella of policies to bridge adaptation and ongoing development efforts across different sectors and levels (horizontally and vertically). Given that the causes of vulnerability of one system of analysis are location-specific, mainstreaming is an approach that contributes to ensuring that development efforts aim at reducing the root causes of vulnerability and, therefore, achieve actual tangible adaptation measures aimed at building adaptive capacity. This mainstreaming has been referred to as "mainstreaming plus," a vulnerability-based focus rather than a technology-based view, known as a "mainstreaming minimum" (Ayers et al., 2014). Mainstreaming plus aims to incorporate specific drivers of the vulnerability of a system of analysis into ongoing decisions on development in short and medium timeframes, particularly significant in countries characterized by political instability, where the political will and direction can change on short (or no) notice. This can be observed, for instance, in Latin America, where around 15 Presidents from different countries in the region (including Honduras, Bolivia, Ecuador, Peru, Paraguay, Brazil, and Argentina, among others) have been overthrown or forced to end their presidential mandates due to impeachments through parliaments, economic crises, civil protests, and social riots in the last 20 years (Helmke, 2020).

3.3 Adaptation pathways

Similarly, we deem "adaptation pathways" (AP) to be another planning approach, the features of which might contribute to the adaptive capacity of socio-ecological systems at a local scale if they incorporate specific drivers of the vulnerability into the analysis. Following the analogy that Mitchell (2019) uses, any road will take one to a destination if one is unsure about where to go. AP provides different pathways, each of which uses different strategies, to achieve a common desired future (Haasnoot et al., 2019). Central to AP is the identification of tipping points (Haasnoot et al., 2013, 2019). To achieve this, possible trajectories are set, which can change direction depending on defined tipping points (Barnett et al., 2014; Wise et al., 2014). Using the language of Haasnoot et al. (2013), in a manner similar to a metro map, the AP presents different alternative routes to get to the same desired point in the future. If an action no longer meets one specific criterion (tipping point or terminal station), a new action becomes necessary (transfer to a new station or a new action); therefore, decision-makers can change to an AP (Haasnoot et al., 2013). The exact date of a tipping point is not rigid; it might be reached within 30, 40, or 50 years, or

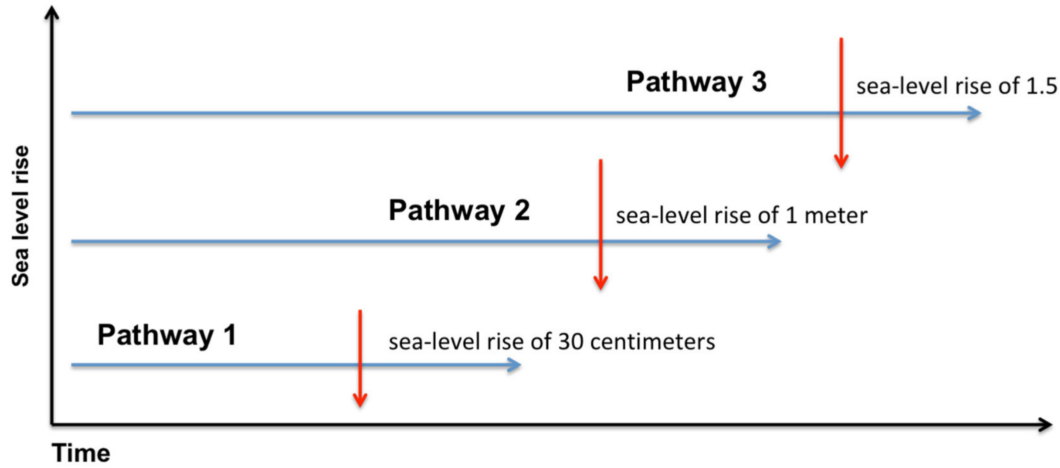

FIGURE 1
Adaptation pathways. The blue arrow indicates different Pathways to achieve a desired future (e.g., avoid saltwater intrusion in a common-pool livelihood). The red arrow indicates the tipping points (thresholds) set for each path (e.g., Pathway 1: a sea-level rise of 30 centimeters, Pathway 2: a sea-level rise of 1 meter and Pathway 3: a sea-level rise of 1.5 meters). If sea level rise reaches the tipping points (thresholds) set for each path, moving to a new alternative (Pathway) is necessary. Often, Pathway 1 starts with planned actions focused on a short time frame vision, including policy-making measures and the construction of natural structures such as mangroves. In contrast, Pathway 2 and Pathway 3 focus on planned strategies in more extended time frames, including dune constructions and the relocation of critical infrastructure (Barnett et al., 2014). The materialization of planned actions designed for each Pathway can be considered good tipping points (e.g., Pathway 1: construction of natural structures such as mangroves).

more, which enables decision-makers to adjust measures as events unfold (Haasnoot et al., 2013). Developed initially in infrastructure projects, to recognize the influence of sea-level rise (Thames 2100 Project/The Thames Barrier), the AP approach helped decision-makers to identify a set of possible adaptation pathways (or, in Haasnoot et al.'s language, different routes), each with specific measures and thresholds (or, using Haasnoot et al.'s language, terminal stations). Decision-makers can switch directions (or, using Haasnoot et al.'s words, transfer to a new station) if tipping points are reached, depending on the water-level rise to keep the risk low (Ranger et al., 2013). We argue that this approach is significant in systems at the local level, with the capacity to positively transform common-pool resources management. For example, if the desired future is to avoid saltwater intrusion in a common-pool livelihood (an underlying factor of vulnerability identified in a contextual vulnerability assessment), and one path encounters difficulties impossible to overcome (tipping points such as a sea level rise of 30 centimeters), decision-makers can switch from that route to another (e.g., a path on which the tipping point is a sea-level rise of 1 meter) to achieve the same desired future (Figure 1) (Barnett et al., 2014; Wise et al., 2014). An example of the adoption of adaptation pathways for sea-level rise is the Delta Programme in the Netherlands. This is a low-lying, country prone to flooding, and the implementation of an adaptation path approach has enabled decision-makers to incorporate uncertainty pertaining to the future by considering climatic and social developments in decision-making structures (Bloemen et al., 2019). The Delta Programme applies different measures across different time frames, with the aim of protecting the country in case of extreme weather events and providing sufficient freshwater until 2050 and 2100 (Restemeyer et al., 2017; Bloemen et al., 2019). Another example of the application of adaptation pathways for sea-level rise can be found in Lakes Entrance, Australia, a coastal town in eastern Victoria where the conception of adaptation pathways has enabled decision-makers to work at the community level (Barnett et al., 2014). The approach applies different paths and actions across diverse timeframes ranging from immediate low-cost actions (e.g., stringent controls over new developments) to actions that other generations should determine as future adaptation pathways as other socio-ecological circumstances unfold (Barnett et al., 2014).

3.4 Scenario planning

Similarly, we deem "Scenario Planning" (SP) to be another planning approach, the features of which might contribute to the adaptive capacity of socio-ecological systems at a local scale if they incorporate specific drivers of the vulnerability into the analysis. SP enables the incorporation of uncertainty about future conditions into decisions, in extended time frames (Rounsevell and Metzger, 2010; Star et al., 2016). Initially developed for military and business purposes and explored in depth by the Royal Dutch Shell oil company for strategic planning (a "what if" planning approach) (Schoemaker and van der Heijden, 1993; Rounsevell and Metzger, 2010; Star et al., 2016). SP is an approach that identifies specific drivers of vulnerability to explore how they likely might unfold in the future (Haasnoot et al., 2013; Wise et al., 2014). Significantly, SP provides a framework that entertains a vision of multiple long-term potential futures (Figure 2), allowing us to think more about anticipatory measures than reactive ones and providing a foundation for discussions of policy development and adaptive strategies (Rounsevell and Metzger, 2010; Cairns et al., 2013; Haasnoot et al., 2013; Wise et al., 2014;

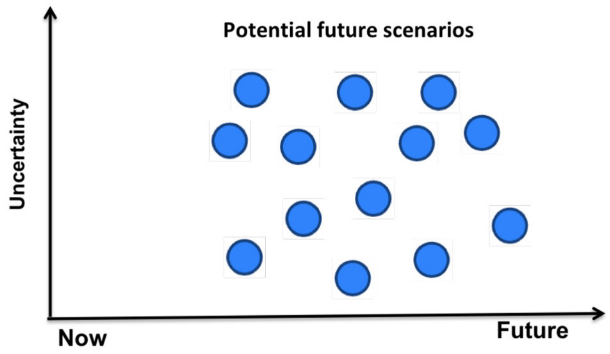

FIGURE 2
Scenario planning (SP). SP is a planning tool that creates images of potential futures under uncertainty and complexity (Star et al., 2016; Serrao-Neumann et al., 2019). Blue circles indicate multiple potential long-term futures. Data and insights used to construct these possible scenarios should include, among other information, local priorities, information from contextual vulnerability assessments, and desirable future scenarios from community stakeholders through participatory approaches. Although the future is uncertain, SP provides decision-makers a way to plan actions and be better prepared. Integrating SP with recent computational intelligence techniques, like machine and deep learning, can help decision-makers handle uncertainties and achieve more accurate outcomes.

Star et al., 2016). SP has often been used primarily for large-scale strategic business planning, where the causes of change are relatively well-known and can be selected by following broad categories. Examples include the STEEP approach—Social, Technological, Economic, Environmental, and Policy Governance, developed by Metzger et al. (2010) and shown in Rounsevell and Metzger (2010)—or the drivers used to show Shared socioeconomic pathways (SSPs), discussed by O'Neill et al. (2014). Yet, we believe that SP has the potential to enable decision-makers and planners to assess and estimate more closely the implications of current context-specific factors of vulnerability so that a system seeks a desirable future and avoids adverse ones (Rounsevell and Metzger, 2010; Haasnoot et al., 2013; Wise et al., 2014). An example of the adoption of SP can be found in Baan Talae Nok, a coastal community in Thailand that has been shifting away from traditional livelihoods (e.g., fisheries) toward new livelihoods, including tourism and agriculture (Bennett et al., 2015). SP has enabled decision-makers to prioritize local actions and desirable future scenarios for livelihoods in Baan Talae Nok and the community's environment. These desirable future scenarios include adequate infrastructure for tourism, better community water and risk management, healthy habitats, forests and mangrove areas managed by the community, productive agriculture areas, and reduced coastal erosion, among others (Bennett et al., 2015).

3.5 Collaborative governance

Bolstering the capacity of a system to adapt at the local scale requires addressing the multiple sources of vulnerability, affecting various sectors alike (e.g., agriculture, health, energy, tourism, and food security) (Bullock et al., 2022). Today, the extent of sources of vulnerability can affect various livelihoods and alter the socio-economic dynamics of different productive sectors together (i.e., systemic risks). For example, in the Galapagos Islands in Ecuador, climate variability, in combination with the adverse effects of COVID-19, has affected the archipelago's tourism sector. This has prompted a cascade of negative consequences on the other sectors of the islands, including fishing and conservation (Escobar-Camacho et al., 2021; Cáceres et al., 2022; Viteri Mejía et al., 2022). Systemic risks triggered in the tourism, fishing, and conservation sectors included a disruption of food supply, the closure of national borders, the prohibition of all national and international tourist arrivals, drastic changes in consumer demands, the closure of restaurants, and requests to use banned fishing techniques (e.g., longlining), among others (Cáceres et al., 2022; Viteri Mejía et al., 2022; Castrejón et al., 2024).

Contrary to the conceptualization of government that refers to elected people at different levels or to the various governmental institutions responsible for delivering goods and services to people in a society, collaborative governance facilitates multilevel participation beyond the state, involving in decision-making the public sector, the private sector, and civil society, from local to broader scales (Kooiman, 2003a; Mitchell, 2019). Following Kooiman's (2003b) work, collaborative governance involves the totality of interactions, in which the whole range of institutions, networks, and linkages that are part of decision-making processes, including formal and informal actors, public and private actors, non-governmental organizations (NGOs), Local and Indigenous peoples, interest groups, and corporations, participate in solving societal problems and in creating societal opportunities (Kooiman, 2003a; Lemos and Agrawal, 2006; Armitage et al., 2009; Keskitalo, 2009; Plummer and Armitage, 2010; Mitchell, 2019).

Even though not all civil society represents society and governance systems tend to be marked by participation disputes and power relations, we argue that how governments, local users and civil society in general address societal problems is crucial in responding to vulnerability factors (Thomas et al., 2019; Mudaliar, 2020). Actors formulate innovative solutions on many geographical and administrative scales, such as within local communities, at subnational levels, and among business sectors, advocacy groups, and private companies, which generates different niches of knowledge and expertise (Ostrom, 2010; Tran et al., 2020). Therefore, participants in collaborative governance have the advantage of learning from others (Ostrom, 2010; Bullock et al., 2022). For example, Local and Indigenous peoples have a close relationship with their environment that allows them to see and feel what the scientific community or decision-making structures usually cannot capture and from whom there is much to learn (Zurba et al., 2018; Bullock et al., 2022, 2023). They are on the front lines of change and know first-hand the dynamics that make a particular place vulnerable (Zurba et al., 2018; Mehta et al., 2019; Eriksen et al., 2021; Bullock et al., 2022). This relationship with the environment has enabled them to have linkages in multiple sectors, including farming, fisheries, tourism, and forestry (Nilsson et al., 2012; Leonard et al., 2013; Ford et al., 2020; Bullock et al., 2022). Consistent with Article 7.5 of PA (2015), the latter considerations are central features in building adaptive capacity at a local scale. In particular, if we keep in mind double-loop learning, change that points to correcting errors by adjusting behaviors and attitudes rather than correcting mistakes by adjusting resource management strategies and actions, e.g., modifying harvesting techniques (single-loop learning) (Armitage et al., 2007, 2008).

Among the different strands of collaborative decision-making (e.g., participatory appraisal and integrated conservation), we argue that co-management is one of the leading management strategies that formalize linkages among local resource stakeholders and governments to share management rights and responsibilities (Armitage et al., 2007). Usually defined as a power-sharing approach, co-management gives rise to cross-sectoral interactions. Therefore, collaborative and power-sharing links across sectors under a co-management context, including partnerships with multilevel stakeholders groups, allow the understanding of local vulnerability and traditional values, the development of shared actions, redistribution of rights and responsibilities, and a co-production of knowledge, adding fundamental considerations to reduce vulnerability and bolster the governance systems capacity to adapt at the local level (Armitage et al., 2007, 2011; Plummer and Armitage, 2007; Plummer, 2013; Andrachuk et al., 2019; Zurba et al., 2022).

4 Conclusion

While the possible adaptation strategies to climate change are numerous in the literature, they often fail to capture the underlying nature of sources of vulnerability, making them insufficient to bolster the adaptive capacity at a local scale. This paper shows that the interpretation and understanding that one gives to vulnerability can lead to diverse adaptation measures and likely ill decisions. Therefore, we remark on the importance of consolidating vulnerability as a dynamic and unmeasurable concept often embedded in political economy matters to capture underlying sources of exposure. Adaptation and vulnerability to climate change are subject to grants, political visibility aspirations, and power relations involving actors with specific interests and agendas. Therefore, we echo the claims by Eriksen et al. (2021), who showed that a limited understanding of contextual vulnerability dimensions, including socio-political relations, might lead to exacerbating, reallocating, or creating new sources of vulnerability.

Our study contributes to the growing vulnerability and climate change adaptation literature. This contribution integrates contextual vulnerability with decision-making planning tools to foster the capacity to adapt and improve decision-making processes on a local scale. We apply context-specific perspectives with different planning horizons at a local scale, a geographical and administrative scale that often lacks the necessary tools, as occurs in developing countries. Our approach shows a series of planning strategies, which, if they rely on political economy factors and other societal concerns that shape people's vulnerabilities, are powerful planning tools that might guide practitioners to work at a local scale. Notably, with the rapid changes and uncertainties within social-ecological systems driven by complex factors, all strategies and decisions must deal with uncertainty. Thus, our approach incorporates flexibility into decision-making and provides scholars and policymakers with avenues to plan in the face of uncertainty.

Notably, the insights presented throughout this paper may help practitioners and decision-makers decentralize adaptation programs often conceived from top-down approaches and institutions with power, authority, and control over decision-making regarding natural resources, including solutions for climate change vulnerability and adaptation agendas. Within the contemporary research on climate change, decentralizing and downsizing the scale of adaptation programs are critical to depoliticizing the programs and approximating decision-making processes and policy-making solutions—shifting closer to the actual sources of vulnerability at the local scale—including socio-political causes of vulnerability and other societal concerns.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

RC: Conceptualization, Validation, Visualization, Writing—original draft, Writing—review & editing. JW: Supervision, Writing—review & editing. JP: Funding acquisition, Supervision, Writing—review & editing. PD: Supervision, Writing—review & editing.

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Conflict of interest

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

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