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Disentangling climate change adaptation: A multi-site comparison of constraints and opportunities among Indigenous Peoples and local communities

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Abstract

Globally, Indigenous Peoples and local communities with nature-based livelihoods, such as small-scale agriculture, pastoralism, fishing, and foraging, face increasing climate change impacts. While implementing adaptive measures is urgently needed in such contexts, various constraints hamper their adoption. To understand these constraints and identify potential adaptation opportunities, this study adopts a multi-site comparative approach. We assessed commonalities and context-specific peculiarities of adaptation determinants among ten Indigenous Peoples and local communities across the globe. Data were collected using a mixed-method approach that included semi-structured interviews, focus group discussions, and household (n = 1,045) and individual surveys (n = 1,349).

The number of adaptive measures implemented by households is weakly correlated with the experienced severity of climate change impacts, suggesting that while cognitive factors could promote adaptation, other factors constrain it. Despite the complexity of adaptation and the relevance of context-specific adaptation determinants, we find common patterns across sites: Individuals who perceive severe climate change impacts and belong to households with low adaptation rates generally have fewer assets, lower social capital, and less access to sufficient and preferred food and freshwater sources compared to those who perceive less severe impacts and live in households with more adaptive measures implemented.

Effective adaptation planning and implementation should consider both commonalities across sites and context-specific peculiarities of adaptation constraints. Enhancing information exchange between local communities and institutions is crucial for the development of adaptation solutions across multiple scales.

1. Introduction

Climate change poses a major challenge for humanity, affecting safety, livelihoods, and food and water security globally (Caretta et al. 2022; Mbow et al. 2022). Risks associated with climate change impacts are especially acute for Indigenous Peoples and local communities with nature-dependent livelihoods, such as small-scale agriculture, pastoralism, fishing, and foraging (Morton 2007; Birkmann et al. 2022; Reyes-García 2024). To minimise adverse climate change impacts in these communities, the implementation of timely, effective, just, and sustainable adaptation strategies is needed (Adger and Barnett 2009). However, responding to climate change impacts is far from straightforward. Rather, it is a complex process simultaneously influenced by multiple factors beyond climate change itself and requiring resources at various scales (Eriksen et al. 2015). Scientific literature suggests that two key aspects play a major role in the process of implementing adaptive measures: motivation and adaptive capacity (Siders 2019; Van Valkengoed and Steg 2019; Thomas et al. 2021).

Motivation to adapt arises from people's recognition of the need to adjust to experienced or expected climate change risks and impacts (i.e., climate change risk and impact appraisal) and of people’s beliefs in and understanding of the benefits arising from the adaptation process (i.e., people’s appraisal of the efficacy of adaptation) (Grothmann and Patt 2005; Van Valkengoed and Steg 2019). Climate change risk and impact appraisals are highly shaped by people's place of residence and direct dependence on and relationship with nature (Morton 2007; Birkmann et al. 2022), but also by cognitive and psychological factors (Grothmann and Patt 2005). Studies highlight the important role of cognitive factors, including previous experiences with climate hazards and impacts, climate change risk awareness, and adaptation appraisal, in driving adaptation motivation (Dang et al. 2018; Khanal et al. 2018). For example, individuals who have personally experienced extreme events and consider an adaptive measure as effective against such events are more likely to adopt this measure than those who have not experienced extreme events (Wilson et al. 2020).

In addition to motivation, people’s adaptive capacity plays a major role in the adaptation process. The adaptive capacity is defined by the factors that facilitate, hamper, or impede the adaptation process, thus by the prevalence of adaptation opportunities, constraints (also referred to as barriers), and limits (Klein et al. 2014). Adaptation opportunities foster people’s adaptive capacities and facilitate the planning and implementation of adaptation strategies (Klein et al. 2014). On the contrary, adaptation constraints have been defined as the ‘subjective interpretation or collective understanding of sequential or simultaneously operating factors and conditions [...] which the actor values as having a negative influence on the process and reduce the chances of successful outputs, but that are manageable and can be overcome with concerted efforts’ (Biesbroek et al., 2013, p. 1127) and as ‘impediment[s] to specified adaptations for specified actors in their given context [...]’ (Eisenack et al., 2014, p. 686). An adaptation limit exists when no adaptation options are available to secure valued objectives from intolerable risks (Dow et al. 2013). We acknowledge that, in practice, the distinction between adaptation constraints and limits is not always clear and that, in certain contexts, constraints might turn into limits (Moser and Ekstrom 2010; Shackleton et al. 2015; Barnett et al. 2015). Adaptation constraints, including limits, and opportunities are complementary concepts, for which studying the former helps detect and support the latter (Biesbroek et al. 2013). Specifically, assessing how adaptation constraints and limits affect people’s adaptive capacity helps to understand why experiencing or expecting adverse climate change impacts and acknowledging the need for and benefits from adaptation does not automatically lead to adaptation actions (Spires et al. 2014; Shackleton et al. 2015; Piggott-McKellar et al. 2019).

To assess people's adaptive capacity, most studies refer to the sustainable rural livelihood approach and use access to different types of capitals as a proxy for adaptive capacity (Morse and McNamara 2013; Siders 2019). Several studies have found a positive association between people's adaptive behaviour and people's access to capitals, including financial and economic (e.g., income), physical (e.g., agricultural equipment), human (e.g., education, access to information), natural (e.g., secured land tenure, soil fertility), and social capital (e.g., access to agricultural extension, social group membership) (e.g., Deressa et al. (2009); Brown et al. (2019); Antwi-Agyei et al. (2021)).

However, assessments of adaptive capacity focusing on the access to different types of capitals that neglect cultural, cognitive, and psychological aspects in decision-making fall short in explaining adaptive behavior. Instead, understanding the complexity of adaptation determinants requires paying attention to both adaptation motivation (e.g., cognitive and psychological factors) and adaptive capacity (e.g., socio-economic factors) (Mortreux and Barnett 2017; Dang et al. 2019).

Empirical studies are important to understand context-specific biophysical, economic, political, and socio-cultural conditions for local adaptation planning (Shackleton et al. 2015). Yet, research on adaptation constraints and adaptive capacity remains fragmented and disconnected, and lacks a consistent application of concepts and methods (Siders 2019; Berkhout and Dow 2023). Specifically, case studies do not support the identification of common patterns of adaptation constraints beyond the local context. Therefore, they do not provide the type of generalisations that can support policy makers in formulating regional and global policies. To make insights from place-specific experiences transferable to other places, additional efforts in improved multi-site, cross-scale and cross-context assessments are needed (Siders 2019; Vallury et al. 2022). Such types of assessments, however, are largely lacking in literature on adaptation (see Berman et al. (2020) as an exception).

Our work contributes to filling these research gaps by assessing commonalities and context-specific peculiarities of adaptation determinants, including cognitive and socio-economic factors influencing the implementation of adaptive measures among Indigenous Peoples and local communities. Specifically, we draw on empirical evidence from ten nature-dependent communities to address three questions: 1) How does the experience of climate change impacts trigger the implementation of adaptive measures? 2) What are the locally relevant and context-specific adaptation constraints experienced by Indigenous Peoples and local communities? 3) How do socio-economic factors relate to experienced climate change impacts and implemented adaptive measures beyond the local context?

2. Methods

This study is part of a larger research project assessing knowledge of climate change impacts and adaptive measures among Indigenous Peoples and local communities (Reyes-García et al. 2024b). Primary data were collected by an international network of scientists with social-environmental research backgrounds. All participating researchers had either previously worked in their field site or planned a 12-month research stay. For the ten field sites featured, six collaborating researchers conducted research within their respective countries. The research protocol used in this project followed all ethical requirements of the European Research Council and was approved by the Ethics Committee of the Universitat Autònoma de Barcelona (CEEAH 4781). An external and independent ethical advisor oversaw the implementation of ethical procedures. Before data collection started, we obtained Free, Prior, and Informed Consents (FPIC) from community authorities, representatives, and all participating individual informants and survey respondents (Reyes-García et al. 2023).

2.1. Study sites

Data from ten sites located in sub-Saharan Africa, Latin America, and Central Asia were used. These sites vary in climatic, geographic, and socio-cultural conditions (Table 1). The sites cover tropical (four sites), arid (three sites), and temperate climate zones (three sites). Geographically, six sites are in lowlands, one in mid-mountains, and three in high mountains. The predominant livelihoods in the study sites are agropastoralism (four sites), agriculture (four sites), pastoralism (one site), and fishery (one site).

Table 1
Site characterisation including socio-economic, climatic, and geographic features, along with sample details

Group	Site name	Country	Main livelihood	Climate	Topography*	Vegetation	Sample Households	Sample Individuals
Bassari	Bassari Country	Senegal	Agriculture	Tropical (Aw)	Low land	Savanna	138	177
Betsimisaraka	Vavatenina District	Madagascar	Agriculture	Tropical (Af)	Low land	Rainforest	37	40
Daasanach	Ileret Ward	Kenya	Agropastoralism	Arid (BWh)	Low land	Savanna	162	255
Dagomba	Kumbungu District	Ghana	Agriculture	Tropical (Aw)	Low land	Savanna	116	175
Farmers	Chiredzi District	Zimbabwe	Agriculture	Arid (BSh)	Low land	Savanna	120	145
Kolla-Atacameños	Puna	Argentina	Pastoralism	Arid (Bwk)	High mountains	Grass- & shrubland	114	151
Mam	Western Highlands	Guatemala	Agropastoralism	Temperate (Cwb)	High mountains	Coniferous forest	63	63
Mapuche	Lonquimay	Chile	Agropastoralism	Temperate (Cfb)	Mid-mountains	Mixed forest	74	75
Ribeirinhos	Juruá River	Brazil	Fishing	Tropical (Af)	Low land	Rainforest	98	127
Tibetans	Shangri-la County	China	Agropastoralism	Temperate (Cwb)	High mountains	Coniferous forest	123	141
Total							1,045	1,349
* Note: low land: <1.000 metres above sea level (masl), mid-mountains: 1.000-2.500 masl, high mountains: >2.500 masl								

HERE Table 1

2.2. Data collection

Primary data collection followed a standardised protocol intended for cross-site comparison (Reyes-García et al. 2023). In each field site, data collection took place in 3–8 villages with relatively homogeneous environmental and socio-cultural conditions. It comprised a two-step mixed-method approach, including semi-structured interviews and focus group discussions to collect qualitative data, followed by household and individual surveys to collect quantitative data. Insights from the semi-structured interviews and focus group discussions informed the survey design.

2.2.1. Semi-structured interviews and focus group discussions

Our sampling protocol for the semi-structured interviews and focus group discussions targeted community members with a long-standing connection to the area, specifically adults who grew up in the community and have not spent significant periods of time elsewhere. Participants were selected through convenience quota sampling to ensure a balanced representation across age groups, gender[1], and main livelihood activities.

Semi-structured interviews were used to assess local climate change impacts and respective adaptive responses locally implemented. Information saturation was normally achieved after 20–30 interviews. Interviews focused on changes observed in the local environment between the time when informants were young adults and the time of the interview. Reported changes that informants related to climatic drivers were categorised as 'local indicators of climate change impacts' according to the classification system developed by Reyes-García et al. (2019). For example, the observations 'Summers are now warmer' and 'Temperatures during the dry seasons are now higher' were both coded into the indicator *'Changes in the mean temperature in a given season'*. For each local indicator of climate change impacts, informants

were asked about adaptive responses locally implemented (hereafter referred to as 'local adaptive measures'). We specifically focused on adaptive measures adopted by households and not by external agents, such as NGOs or governments. To allow for cross-site comparison, local adaptive measures were categorised into groups, following the classification system proposed by Schlingmann et al. (2021) (Fig. SI1). For example, the reported site-specific local adaptive measures *'Planting new crops'*, *'Diversifying crops'*, and *'Shifting to maize cultivation'* were all coded into the adaptation category 'Changes in composition' of agricultural products. Similarly, collaborative activities such as *'Community-based fire brigades'*, *'Local farmers organisations'*, or *'Seed sharing networks'* were coded under the category 'Social networks & relations'.

In each site, we organised focus group discussions to assess the level of group consensus for controversial climate-related observations. Participation varied from four to 18 participants in a focus group. We considered a climate-related observation as controversial if i) less than three informants reported the observation in semi-structured interviews, ii) there were disagreements regarding the existence or the direction of the reported observation, or iii) it was not clear that the observed change was driven by climatic factors. As a result of the semi-structured interviews and focus group discussions, we obtained a site-specific and group-validated list of reported local indicators of climate change impacts and local adaptive measures.

2.2.2. Household and individual survey

A survey was used to collect data on individually experienced climate change impacts, household implementation rates of local adaptive measures (hereafter referred to as 'adaptation implementation rate'), perceived adaptation constraints, and individual and household socio-economic characteristics. We applied random sampling to select households and convenience sampling to select individuals within a household, aiming for gender and age balance in the selection of individuals. For the individual survey, we only targeted the male and/or the female household heads, recognised as the household representatives with authority, whether through formal or informal means. Our total sample includes 1,045 households and 1,349 individuals, as in some households two individuals were interviewed. In addition to socio-economic information (i.e., age, gender, livelihoods, and access to different types of capitals), the survey included questions on climate change impacts observed by the person interviewed and questions on adaptive measures implemented by the household. Specifically, from the site-specific and group-validated lists, we randomly selected 15 local indicators of climate change impacts and ten local adaptive measures to be included in the survey. For each of the 15 local indicators of climate change impacts, we asked household heads if they had observed the specific change and, if so, how this change had impacted their lives and livelihoods. We distinguished between two observation levels: 0 ('Not observed') and 1 ('Observed') and three levels of experienced severity: 0 ('Does not affect me at all'), 0.5 ('Affects me a little'), and 1 ('Affects me a lot'). Similarly, we asked whether the household had implemented any of the ten randomly selected local adaptive measures by distinguishing between 0 ('Not implemented') and 1 ('Implemented'). For each local adaptive measure that a household had not implemented, we asked for the reasons why they had not done so (i.e., reported adaptation constraints). Through this question, we obtained people's qualitative narratives on context-specific adaptation constraints (i.e., specific to the respective site and local adaptive measure).

2.3. Data transformation

2.3.1. Defining climate change impact and adaptation indices

To analyse how people's experiences with climate change impacts influence the implementation of adaptive measures, we developed two indices: 1) the individual Climate Change Impact index (CCI_{idx}) and 2) the household Climate Change Adaptation index (CCA_{idx}).

The individual Climate Change Impact index (CCI_{idx}) captures the level of experienced climate change impacts according to the household heads' appraisals. For each person interviewed, an $iCCI_{idx}$ was created by multiplying the numeric value of their reported observations of the 15 local indicators of climate change impacts by the numeric value of the experienced severity of each impact. The total sum across all indicators was then standardised (z-score) for cross-site comparison using equations (1) and (2).

(1) $$iCCI_{idx} = \frac{\sum_{k=1}^{15}(O_k \bullet S_k)}{15},\ O_k \in \{0,1\},\ S_k \in \{0,0.5,1\}$$

(2) $$CCI_{idx} = \frac{iCC\ I_{idx} - \overline{iCCI_{idx}}}{\sigma_{iCCI_{idx}}}$$

where O_k is the observation of the climate change impact k (0 – 'Not observed', 1 – 'Observed') and S_k is the severity level reported for the climate change impact k (0 – 'Does not affect me at all', 0.5 – 'Affects me a little', 1 – 'Affects me a lot').

Individuals with an above-average CCI_{idx} (> 0) were classified as *majorly impacted* (MI), while those with an average or below-average CCI_{idx} (≤ 0) were considered *minorly impacted* (mI).

The household Climate Change Adaptation index (CCA_{idx}) describes the household's adaptation implementation rate. The CCA_{idx} was created by transforming the sum of all local adaptive measures implemented by a household ($hCCA_{idx}$) into standard z-scores using equations (3) and (4).

(3) $hCCA_{idx} = \frac{\sum_{k=1}^{10} A_k}{10},\ A_k \in \{0,1\}$

(4) $CCA_{idx} = \frac{hCCA_{idx} - \overline{hCCA_{idx}}}{\sigma_{hCCA_{idx}}}$,

where Ak is the implementation of the local adaptive measure k (0 – 'Not implemented', 1 – 'Implemented').

Households with an above-average CCA_{idx} (> 0) were labelled as *(major) adapters* (MA), while those with an average or below-average CCA_{idx} (≤ 0) were termed *minor adapters* (mA).

For each interviewed household head, we assigned the respective CCI_{idx} and CCA_{idx}, resulting in a total of four *climate change impact - adaptation* (CCI_{idx} - CCA_{idx}) groups: 1) *majorly impacted adapters* (MI-MA); 2) *majorly impacted minor adapters* (MI-mA); 3) *minorly impacted adapters* (mI-MA); and 4) *minorly impacted minor adapters* (mI-mA).

2.3.2. Classifying adaptation constraints

We classified perceived adaptation constraints reported by survey respondents into four main categories, which were further divided into 14 sub-categories (Fig. 1).

HERE FIG. 1

Low adaptation need appraisal (low climate change risk and impact appraisal) includes responses that reflect people's assessments of low adaptation needs, including their low perception of and belief in climate change occurrence and damage potential (Grothmann and Patt 2005);

Low adaptation efficacy appraisal includes responses that reflect people's limited belief in the effectiveness or efficiency of local adaptive measures (Grothmann and Patt 2005);

Low self-efficacy appraisal regarding *access to capitals* includes responses that reflect people's perception of their low ability to carry out specific local adaptive measures due to limited access to different types of capitals (Grothmann and Patt 2005; Morse and McNamara 2013; Klein et al. 2014);

Low self-efficacy appraisal regarding *other trade-offs and inconveniences* includes responses that reflect people's perception of their low ability to carry out specific local adaptive measures because of trade-offs or inconveniences other than access to capitals (Grothmann & Patt, 2005).

2.3.3. Defining socio-economic individual and household indices

To assess potential relationships between socio-economic characteristics, climate change impact experience, and adaptation implementation rates across sites, four composite indices were developed, all with values ranging from 0 to 1 (Table 2).

Table 2
Description of the socio-economic indices included in the study

Indices	Description	Values
Individual		
Age	Age of household head, in years	Numeric
Human capital	The *Individual Human Capital index* is defined as the average of two ordinal variables capturing 1) schooling and 2) language knowledge of the household head.	Numeric [0–1] with: 1) Schooling: 0 ('No schooling'), 0.25 ('Primary school'), 0.5 ('Middle school'), 0.75 ('High school'), and 1 ('Beyond high school'); 2) Second language knowledge: 0 ('No'), 0.5 ('A little'), and 1 ('Fluent').
Household		
Social capital	The *Household Social Capital index* is the mean value across three ordinal variables measured at the household level: 1) participation of household members in collective activities and organised groups, 2) access to NGO support, and 3) the number of adult family members living outside the community	Numeric [0–1] with: 1) Participation in collective activities and organised groups: 0 ('Rarely participating'), 0.5 ('Sometimes participating') and 1 ('Often participating'); 2) NGO support: 0 ('No') and 1 ('Yes'); 3) Number of adult family members living outside the community divided by the site's maximum value.
Asset ownership	The *Household Asset Ownership index* captures ownership of physical assets with market values.	Numeric [0–1] with: Asset ownership: Sum over the quantity of a set of ten physical assets owned by a household and multiplied by their respective local economic value in US dollars. Values are log-scaled and rescaled to values between 0 and 1.
Food and freshwater sovereignty	The *Household Food and Freshwater Sovereignty index* is the mean value of three ordinal variables capturing households' food and freshwater sovereignty: 1) quality, 2) quantity, and 3) preferences.	Numeric [0–1] with: 1) Food/Freshwater quality: 0 ('Quality was often not good'), 0.5 ('Quality was sometimes not good'), and 1 ('Quality was usually good'); 2) Food/Freshwater quantity : 0 ('Often we did not have enough'), 0.5 ('Sometimes we did not have enough'), and 1 ('We always had enough'); 3) Food/Freshwater preference: 0 ('I rarely/never had access to my preferred water sources', 'I rarely/never could eat the foods I like to eat'), 0.33 ('I mostly did not have access to my preferred water sources, but sometimes I did', 'I mostly ate foods I do not prefer, but sometimes I could eat the foods I like'), 0.66 ('I mostly had access to my preferred water sources, but not always', 'I mostly ate the foods I like, but sometimes had to eat something else'), and 1 ('I always had access to my preferred water sources', 'I always ate the foods I like to eat').

HERE Table 2

The *Individual human capital index* captures the level of schooling and language fluency, beyond the local language, of household heads.

The *Household Social Capital index* captures participation of household members in collective activities and organised groups but also access to NGO support and the number of adult family members living outside the community.

The *Household Asset Ownership index* captures ownership of physical assets with market values. Specifically, it is the sum over the quantity of a set of ten physical assets owned by a household and multiplied by their respective local economic value in US dollars.

The *Household Food and Freshwater Sovereignty index* captures households' access and use of sufficient, high-quality, and preferred food and freshwater sources, thereby comprising three aspects of sovereignty: quality, quantity, and preferences. For each household, we determine the mean value across the three categories for food and freshwater.

2.4. Data analysis

To test for significant correlation between the individual climate change impact appraisal level (CCI_{idx}) and the household adaptation implementation rate (CCA_{idx}), we applied Kendall's rank correlation coefficient (Kendall 1938). Then, non-parametric statistical analyses were used to assess socio-economic differences between the two climate change impact groups (i.e., *majorly impacted* vs. *minorly impacted*), the two adaptation groups (i.e., *(major) adapters* vs. *minor adapters*), and across the four *climate change impact - adaptation* groups. Non-parametric Wilcoxon sum rank tests were used for comparing the statistical significance of differences between two groups, i.e., between the

two impact groups and -separately- between the two adaptation groups (Wilcoxon et al. 1970). Non-parametric Kruskal-Wallis tests were employed for comparison across the four *climate change impact - adaptation* groups (Kruskal and Wallis 1952). Post-hoc procedures after the Kruskal-Wallis test involved the Dunn tests with adjusted p-values based on the Bonferroni method (Dunn 1964).

Data were analysed and visualised using R, version 4.1.2 (R Core Team 2021), and R Studio, version 2021.9.0.351 (RStudio Team 2021). Specifically, we used the *cor.test* function, the *wilcox.test* function, and the *kruskal.test* function of the *stats* package, version 4.1.2, and the *dunn.test* function of the *dunn.test* package, version 1.3.5 (Dunn 1964; Hollander et al. 2015; R Core Team 2021).

3. Results

3.1. Sample description

Survey respondents showed a balanced gender distribution (53% women). The average age of respondents was 46 years. Among the socio-economic individual and household indices, the Household Food and Freshwater Sovereignty index had the highest mean value (0.72), indicating that respondents generally confirm access to sufficient, high-quality, and preferred food and water sources. We found the lowest value and highest standard deviation for the Household Social Capital index, showing high discrepancies in the degree of social organisation with a tendency towards limited interaction among community members and/or with external agents (Table 3).

Table 3
Descriptive statistics of socio-economic variables included in the analysis

Indices	Description	Mean	Standard deviation
Individual (n = 1,349)			
Age	Age of household head, in years	46	16
Human capital [0–1]*	The human capital of the household head, including schooling and language knowledge	0.48	0.18
Household (n = 1,045)			
Social capital [0–1]*	Household social capital index, including participation in group activities, support by NGOs, and relatives outside the community [0–1]	0.37	0.25
Asset ownership	Household asset ownership index [0–1]	0.45	0.21
Food and freshwater sovereignty [0–1]*	A measure for a household's quantity, quality, access control and preferences of food and freshwater [0–1]	0.72	0.20
* With: 0 ('No access to capital') and 1 ('Full access to capital')			

HERE Table 3

On average, respondents observed 11 of the 15 local indicators of climate change impacts included in the survey. Across all sites, 18% of the respondents reported observing all the 15 local indicators of climate change impacts, while only 6% observed five or fewer. In most cases, respondents felt affected by climate change impacts in some way: in 45% of the answers, respondents reported feeling strongly affected by a specific climate change impact and in 15%, feeling somewhat affected. In 11% of the answers, respondents reported not feeling affected, and in 29%, they reported that they had not observed the specific indicator of change.

Despite the generally high observation rate of local indicators of climate change impacts, the adaptation implementation rate of households was considerably low. On average, households had implemented five of the ten local adaptive measures included in the survey. Less than 1% have implemented all ten local adaptive measures included in the survey.

3.2. Climate change impact appraisal and adaptation implementation

In examining the interplay between the Climate Change Impact (CCI_{idx}) and the Climate Change Adaptation (CCA_{idx}) indices, we observe a similar number of respondents falling into the four *climate change impact - adaptation* groups. *Majorly impacted adapters* (MI-MA) is the largest group, with 33% of the respondents (n = 443), followed by *minorly impacted minor adapters* (mI-mA), which include 27% of the respondents (n = 366). About 20% of respondents fall into the group of *minorly impacted adapters* (mI-MA) (n = 276) and into *majorly impacted minor adapters* (MI-mA) (n = 264), respectively. The results of the rank correlation indicate a positive and statistically significant but weak correlation between the CCA_{idx} and the CCI_{idx} indices (Kendall's tau = 0.161, $p = 2.2*10^{-16}$).

3.3. Reported context-specific adaptation constraints

An examination of the frequencies of implemented local adaptive measures shows disparities across sites and for different local adaptive measures, resulting from different adaptation needs and constraints (Fig. SI2).

Across sites, in 28% of the responses, survey respondents refer to the lack of need to adapt to a specific climate change impact because they feel not impacted by climate change. For example, Daasanach households in Ileret Ward (Kenya) feel differently affected by climate change impacts, depending on the household's main livelihood activity (i.e., agriculture, pastoralism or fishing). Similarly, the location of housings, especially the distances of houses to the river, defines whether Ribeirinhos in the Juruá River region (Brazil) feel directly exposed to and therefore threatened by increasing flooding events or not. In 15% of the answers, respondents evaluated an adaptive measure as little effective or even risky or expressed preferences for an alternative adaptive strategy (low adaptation efficacy). In another 13% of the answers, respondents referred to behavioural constraints such as habits, customs, and personal preferences that prevent them from adopting unfamiliar adaptive measures such as switching to new livelihood activities or changing diets. Other frequently reported constraints include limited access to different types of capital, especially natural (11%), financial (9%), and human capitals (7%).

The significant diversity of adaptation constraints within and across sites becomes apparent when comparing the reported constraints for local adaptive measures within the same adaptation category. For example, reported adaptation constraints for local adaptive measures related to social networks and relations have little in common across sites (Fig. 2a). For instance, Daasanach households generally lack access to seed (natural capital) to participate in seed exchange networks, whereas Mapuche agropastoralists in Lonquimay (Chile) often lack information (human capital) required to participate in community-based fire brigades, and Mam agropastoralists in the Western Highlands (Guatemala) are often constrained by limited time, making it difficult for them to engage in social groups. Similar deviations between sites exist for reported adaptation constraints in reforestation/afforestation efforts, with 'lack of information' being a frequently reported constraint by Mapuche, 'lack of time' being a major constraint reported by Dagomba farmers in Kumbungu District (Ghana), and 'lack of adaptation need' being reported by local farmers in Chiredzi District (Zimbabwe) (Fig. 2b). Two exceptions reveal similarities across sites in reported adaptation constraints. 'Lack of access to water' (natural capital) is a common constraint to adopting irrigation practices for both Kolla-Atacameños in the Puna region (Argentina) and local farmers in Chiredzi District (Fig. 2c) and 'lack of access to (fertile) land' (natural capital) is frequently cited by Mam and Daasanach agropastoralists as a constraint for changes in crop composition (Fig. 2d).

HERE FIG. 2

Across sites, respondents reported as much as 5.6 (SD = ± 1.5) adaptation constraints per local adaptive measure. Specifically, for Kolla-Atacameños in the Puna (Argentina), Tibetans in Shangri-la County (China), Betsimisaraka in Vavatenina District (Madagascar), Bassari in Bassari Country (Senegal), and local farmers in Chiredzi District (Zimbabwe), the reported reasons for not implementing local adaptive measures are so varied that we could not identify any general patterns regarding site-specific adaptation determinants (Fig. 3a-e).

HERE FIG. 3

Although the diversity of reasons explaining the lack of implementation of local adaptive measures is high in all the sites, in a few there are some recurrent reasons. For example, in Kumbungu District (Ghana), 55% of the answers provided by Dagomba farmers refer to economic factors that impede households from implementing adaptive measures. Frequent responses are that the lack of job opportunities prevents households from complementing main livelihood activities with off-farm work, while insufficient financial resources hinder adaptation efforts such as rainwater harvesting and modifying buildings to cope with warmer temperatures (Fig. 3f).

For Daasanach agropastoralists in Ileret Ward (Kenya), low adaptation implementation frequently refers to perceived low adaptation needs, which correspond to the primary livelihood practised by each household, cited in 39% of the responses (Fig. 3g). Specifically, the importance of farming, livestock rearing, or fishing for each household influences how households experience climate change impacts (i.e., climate change sensitivities) and, consequently, the need to adopt local adaptive measures tailored to agricultural or fishing activities. Additionally, 37% of the responses from Daasanach agropastoralists relate to behavioural constraints, such as entrenched habits and customs. For example, traditional customs and social taboos prevent Daasanach from switching to new activities, such as fishing or camel rearing, or from relying on external information. For instance, fishing has traditionally been considered by the Daasanach as a subsistence activity associated with a low social status and fit only for 'poor people with no livestock'. Similarly, many Daasanach households are hesitant to modify their diets by adopting unfamiliar food products during food-scarce periods such as droughts.

Similarly, Ribeirinhos fishers in the Juruá River region (Brazil) frequently cite low experienced impacts, leading to a perceived low need for local adaptive measures (31%) or behavioural constraints (27%), especially habits and customs, as reasons for not implementing adaptive measures (Fig. 3h). Common responses from this site include expressing that there is no need for local adaptive measures and continuing activities as they have always been.

In the Western Highlands of Guatemala, 28% of responses from Mam agropastoralists refer to limited access to natural capital, such as lack of access to farmland and limited available water for irrigation, as major constraints to implement adaptive measures (Fig. 3i). Limited access to

natural capital is a frequently reported constraint for adopting local adaptive measures such as forest preservation, fruit tree planting, crop cultivation during the dry season, use of greenhouses, cultivation of new crops, and crop diversification in general.

In Lonquimay (Chile), 21% of responses from Mapuche agropastoralists refer to the lack of human capital, especially access to information, as a factor that hinders the adoption of several local adaptive measures, such as protecting water sources, working in the tourism sector, and participating in community-organised reforestation and fire protection activities (Fig. 3j).

3.4. Relationships between socio-economic factors, experienced climate change impacts, and adaptation

Comparing socio-economic characteristics between the *majorly impacted* (MI) and the *minorly impacted* (mI) groups, as well as between the (*major) adapters* (MA) and the *minor adapters* (mA), and across the four *climate change impact - adaptation* groups reveals significant differences. Specifically, differences across groups were observed in age, human capital, asset ownership, social capital, and food and freshwater sovereignty (Table 4 and Fig. SI3).

Table 4
Parameter estimates of the analysis of variance according to the non-parametric Wilcoxon rank-sum test, Kruskal-Wallis test, and Dunn tests. Significance levels are indicated at 5% (*), 1% (**) and 0.1% (***) probability levels

Response variables	**Wilcoxon rank-sum test**		**Kruskal-Wallis test**	**Dunn test**					
	MI-mI	**MA-ma**	**all groups**	**MI-MA/MI-mA[1.1)]**	**MI-MA/mI-MA[1.2)]**	**MI-MA/mI-mA[1.3)]**	**MI-mA/mI-MA[1.4)]**	**MI-mA/mI-mA[1.5)]**	**mI-MA/mI-mA[1.6)]**
	Coef. (W)	**Coef. (W)**	**Coef (Chi²)**	**Coef. (z)**	**Coef. (z)**	**Coef. (z)**	**Coef. (z)**	**Coef. (z)**	**Coef. (z)**
Individual									
Age	**255070*** **	233654	**16.941*** **	-0.227	**-2.830***	**-3.397****	-2.315	**-2.755***	-0.294
Human capital	225823	**240752***	7.243	-	-	-	-	-	-
Household									
Asset ownership	**200692*** **	231066	**25.774*** **	**-3.344****	0.501	2.034	**3.467****	**4.997*** **	1.322
Social capital	223694	**247603****	**10.612***	**-2.818***	0.187	-1.568	**2.712***	1.342	-1.569
Food & freshwater sovereignty	**200588*** **	**240702***	**28.261*** **	**-4.165*** **	0.918	0.713	**4.575*** **	**4.625*** **	-0.249

[1.1)] Comparison between *majorly impacted adapters* (MI-MA) and *majorly impacted minor adapters* (MI-mA);

[1.2)] Comparison between *majorly impacted adapters* (MI-MA) and *minorly impacted adapters* (mI-MA);

[1.3)] Comparison between *majorly impacted adapters* (MI-MA) and *minorly impacted minor adapters* (mI-mA);

[1.4)] Comparison between *majorly impacted minor adapters* (MI-mA) and *minorly impacted adapters* (mI-MA);

[1.5)] Comparison between *majorly impacted minor adapters* (MI-mA) and *minorly impacted minor adapters* (mI-mA);

[1.6)] Comparison between *minorly impacted adapters* (mI-MA) and *minorly impacted minor adapters* (mI-mA)

HERE Table 4

First, the two groups differently affected by climate change significantly differ regarding age, asset ownership, and food and freshwater sovereignty. Specifically, individuals in the *majorly impacted* (MI) group were generally older, owned fewer assets, and had less access to sufficient and preferred food and freshwater sources than individuals in the *minorly impacted* (mI) group. Second, households falling into the two adaptation groups significantly differ in their human and social capital and in their food and freshwater sovereignty. In particular, households in the group of *minor adapters* (mA) show significantly lower access to human and social capital and to sufficient and preferred food and freshwater sources compared to households in the group of (*major) adapters* (MA). Third, the four *climate change impact - adaptation* groups significantly differ in age, asset ownership, social capital, and food and freshwater sovereignty. Households in the group of

majorly impacted minor adapters (MI-mA) have significantly fewer assets, lower social capital, and lower access to sufficient and preferred food and freshwater sources than households in the group of *majorly impacted adapters* (MI-MA). Additionally, households in the group of *majorly impacted minor adapters* (MI-mA) also had significantly fewer assets, lower social capital, and less access to sufficient and preferred food and freshwater sources than households in the group of *minorly impacted adapters* (mI-MA).

4. Discussion

This study adopts a multi-site comparative approach to assess commonalities and context-specific peculiarities of adaptation determinants among Indigenous Peoples and local communities. We found highly diverse and context-specific adaptation constraints, but also common patterns of association between socio-economic factors, experienced climate change impacts, and the implementation of local adaptive measures.

Before discussing our results, we acknowledge the limitations and caveats of the work presented, from which we derive recommendations for future research. First, while this study detects common patterns of adaptation determinants across sites, it does not assess in detail how local adaptation constraints and opportunities link to, or arise from, the broader socio-economic and political contexts they are embedded in, a topic addressed in other studies (Porcuna-Ferrer et al. 2024a). A deeper understanding of such cross-level interrelations could improve the identification of structural vs. local adaptation determinants, thereby supporting the development of transformative solutions (Ribot 2014; Vallury et al. 2022). Second, this study does not assess adaptation efficacy nor people's satisfaction with local adaptive measures. Such information is often neglected in current research but would improve prioritisation processes in adaptation planning by complementing feasibility with efficacy (Adger et al. 2005; Dilling et al. 2019; Singh et al. 2020, 2022; Berrang-Ford et al. 2021). Third, our study lacks a systematic assessment of the role of cultural and behavioural factors (i.e., customs and habits) for risk perception and adaptation across sites. While the study offers meaningful insights on how to systematically assess climate change impact appraisal levels, adaptation implementation rates, and households' access to different types of capitals, the development of a systematic approach for cultural and behavioural aspects would enrich the analysis of common patterns of adaptation determinants across sites.

4.1. The association between climate change impact appraisal and adaptation implementation is positive but weak

Our first important finding is that there is a significant, positive, but weak association between people's climate change impact appraisal levels and households' adaptation implementation rates, suggesting that a household's adaptation implementation rate is shaped by other factors beyond the climate change impact appraisal level of the household head(s). This finding dovetails with previous studies that emphasise the importance of climate change experience and risk awareness as drivers for adaptation motivation, as well as with studies emphasising the relevance of (perceived) adaptation constraints in explaining the difference between adaptation motivation and action (Adger et al. 2009; Van Valkengoed and Steg 2019; Van Valkengoed et al. 2023).

We also found evidence that local adaptive measures are not only adopted when climate change impact appraisal levels are high. A considerable number of households display a high adaptation implementation rate, despite their low climate change impact appraisal level. We can think of three possible explanations. First, a sampling mismatch may explain the high share of households in the group of *minorly impacted adapters*. We assessed experienced climate change impacts at the individual level but adaptation implementation at the household level. This mismatch might have led to a lack of correspondence between the reported severity levels of experienced climate change impacts and a household's adaptation implementation rate, particularly for households where adaptive decision-making is not in the hands of the interviewed household head (Niemann et al. 2024). Second, the implementation of local adaptive measures normally occurs in a broad socio-environmental context, so many adaptive measures might respond to pressures other than climate change, such as socio-economic, demographic, and cultural changes, as for example, market integration (Ensor et al. 2019; Porcuna-Ferrer et al. 2024b). Third, it might also be that adaptive measures were implemented preventively (i.e., proactively) and/or that their implementation had already reduced experienced climate change impacts.

In addition, we found that high climate change impact appraisal levels do not always lead to higher adaptation levels, as reflected in a non-negligible number of households that implement few adaptive measures despite feeling strongly impacted by climate change. Previous research suggests that Indigenous Peoples and local communities are aware of ongoing climatic changes and experienced impacts (Savo et al. 2016, 2017; Reyes-García et al. 2024a), although research also highlights that these impacts are often experienced in a context of multiple stressors (McDowell and Hess 2012; Nyantakyi-Frimpong and Bezner-Kerr 2015). Consequently, many communities are hindered in the adoption of local adaptive measures by constraining factors at various scales and levels, which often reinforce one another (e.g., Fayazi et al. (2020); McNamara et al. (2017)). In line with previous studies (Van Valkengoed and Steg 2019), our findings provide nuances to the somehow simplified assumption that fostering climate change awareness would result in increased adaptation action (McNamara 2013; Burnham and

Ma 2017; Antwi-Agyei et al. 2021). Rather, our results support the idea that increasing awareness is unlikely to lead to the implementation of local adaptive measures on its own, unless existing adaptation constraints are identified, addressed and overcome (Thomas et al. 2021).

4.2. Reported adaptation constraints are diverse and context-specific

Addressing adaptation constraints can be challenging, as suggested by the results of this study underscoring that adaptation constraints are highly diverse, complex, subjective, and often context-specific (Biesbroek et al. 2013; Eisenack et al. 2014). In this sense, our results show that the implementation of adaptive measures is not only restricted by access to different types of capitals, but they also highlight the important role of personal habits, often linked to cultural and traditional bonds, in motivating or hindering adaptation action (Adger et al. 2009, 2013). As in the case of Daasanach in Ileret Ward (Kenya) and of Ribeirinhos in the Juruá River region (Brazil), reported adaptation constraints reveal the importance of habits and customs in adaptation decision-making, linked to traditional diets and livelihood activities. A similar finding was reported in a study on successful community-based adaptation in which Piggott-McKellar et al. (2019) found that reluctance to implement unknown technologies and resistance to development projects that contrasted community cultural and religious values were among the most frequently reported constraints. Understanding the complexity of climate change adaptation is the first step towards acknowledging the need for diverse, plural, and interdisciplinary solution approaches (Schipper et al. 2021).

4.3. Low adaptation rates, despite high climate change impact appraisals, are associated with limited access to capitals

Our third finding reveals common patterns across sites, despite context-specific differences. Specifically, we found that above-average levels of climate change impact appraisal and below-average rates of adaptation implementation are associated with lower access to certain capitals (i.e., asset ownership, social capital) and lower food and freshwater sovereignty. In contrast, below-average climate change impact experience and above-average adaptation implementation rates are associated with higher access to such capitals. The finding could be interpreted as low access to different types of capitals might (directly or indirectly) act as an adaptation constraint, whereas high access to multiple capitals presents an adaptation opportunity.

These results align well with other studies that emphasise the importance of access to physical and financial capitals for climate change adaptation (Deressa et al. 2009; Williams et al. 2021). The relationship between access to social capital and adaptation implementation is also consistent with previous research findings (Adger 2003; McNamara and Buggy 2017). Indeed, many traditional practices and adaptive measures based on Indigenous and local knowledge, such as agrobiodiversity, build on social ties between family and community members (Labeyrie et al. 2021; Fenzi et al. 2022; Galappaththi and Schlingmann 2023). Due to their potential to promote organisation and learning and to compensate for the lack of other capitals, in some contexts exchange, sharing, reciprocity, social ties, and networks may be more relevant for adaptation than direct access to financial assets (Barnes et al. 2020). Relationships with external actors, such as extension services and NGOs, may have positive effects and support the implementation of local adaptive measures (Khanal et al. 2018). However, research also shows that external support and interventions can also carry the risk of maladaptive outcomes by reinforcing, redistributing, or creating new sources of vulnerability (Eriksen et al. 2021). For example, the introduction and promotion of high-yielding, marketable but water-demanding crops by agricultural extension services and NGOs in south-eastern Senegal has led to new vulnerabilities in an increasingly water-scarce environment (Porcuna-Ferrer et al. 2024a). Findings of this study also show that households with higher levels of climate change impact appraisals and lower adaptation implementation rates also experience significantly lower access to sufficient and preferred food and freshwater. These results suggest that increased climate change impacts and limited adaptive capacities directly threaten existential common goods (Kirchhoff et al. 2016; Sam et al. 2019).

Our findings on socio-economic patterns relate to the understanding of climate change risks and impacts not as an outcome of climatic stressors alone but as a process derived from or entangled within the context of existing political, institutional and socio-economic structures at various scales (O'Brien et al. 2007). In other words, our results highlight how climate change impacts intersect with multiple forms of inequities and vulnerabilities (Otto et al. 2017). In this sense, imbalanced power dynamics at international and national levels reinforce inequities at the local level by determining access to crucial resources, such as different types of capitals as well as food and freshwater resources, thereby defining who has the lowest capacities to reduce adverse climate change impacts through adaptation and who is most affected by them (Lahsen and Ribot 2022). Therefore, it is crucial to detect which constraints arise from local conditions and which are embedded in a broader context (Ribot 2014). This suggests that adaptation can only be successful when planned in a broader political and socio-economic context and based on sustainability and justice criteria targeting the reduction of structural inequities at all scales (Bhatasara and Nyamwanza 2018; Fuso Nerini et al. 2019).

5. Conclusion

Results from our work exploring common and context-specific adaptation constraints and opportunities among ten Indigenous Peoples and local communities across three continents show how experienced climate change impacts, adaptation opportunities, and constraints are inextricably linked with underlying social issues that shape inequities across scales.

Our work makes important contributions to two aspects of adaptation planning. First, the identification of adaptation constraints and opportunities could facilitate decision-making during planning and preparation because it helps to prioritise feasible adaptation options over those that are more challenging or 'costly' because of their numerous and/or diverse adaptation constraints. Second, by assessing both general and context-specific constraints, our findings provide clear indications of relevant impediments that need to be addressed urgently. This is a crucial step for developing solution-oriented approaches that devise hands-on strategies for adaptation.

Based on these results, we offer three policy recommendations. First, there is no 'one-size-fits-all' approach to overcoming adaptation constraints. Instead, efforts must employ diverse and holistic strategies that address context-specific and multiple constraints simultaneously. Second, socio-economic inequities within and between communities play a critical role in the successful implementation of local adaptive measures. Therefore, attention should be given to the heterogeneous patterns of vulnerability (i.e., experienced climate change impacts and adaptive capacities), with a priority placed on reducing existing inequities within and between communities. Third, adaptation constraints arise from different contexts at various levels. Addressing these constraints necessitates close coordination and secure information flows between communities and policy makers at various institutional levels, ensuring that adaptation constraints are addressed where they are most effectively tackled - at the local level for some and at higher political levels for others to overcome structural vulnerability. These policy recommendations highlight the urgent need to increase the representation of Indigenous Peoples and local communities in adaptation planning, including regular consultation with different vulnerable groups within communities. This is essential not only to align adaptation planning and implementation with local concerns, needs, and worldviews but also to identify and address the diverse and context-specific constraints faced by different vulnerable groups.

Declarations

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Statements and Declarations

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Competing Interests

The authors declare that they have no known competing financial or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Compliance with Ethical Standards

The research protocol used in this project followed all ethical requirements of the European Research Council and was approved by the Ethics Committee of the Universitat Autònoma de Barcelona (CEEAH 4781). An external and independent ethical advisor oversaw the implementation

of ethical procedures. Before data collection started, we obtained Free, Prior, and Informed Consents (FPIC) from community authorities, representatives, and all participating individual informants and survey respondents.

Data Availability

The datasets generated and analysed during the current study are available in the Supplementary Information (SI) of the study.

References

1. Adger WN (2003) Social capital, collective action, and adaptation to climate change. Econ Geogr 79:387–404. https://doi.org/10.1111/j.1944-8287.2003.tb00220.x
2. Adger WN, Arnell NW, Tompkins EL (2005) Successful adaptation to climate change across scales. Glob Environ Chang 15:77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005
3. Adger WN, Barnett J (2009) Four reasons for concern about adaptation to climate change. Environ Plan A 41:2800–2805. https://doi.org/https://doi.org/10.1068/a42244
4. Adger WN, Barnett J, Brown K et al (2013) Cultural dimensions of climate change impacts and adaptation. Nat Clim Chang 3:112–117. https://doi.org/10.1038/nclimate1666
5. Adger WN, Dessai S, Goulden M et al (2009) Are there social limits to adaptation to climate. change? Clim Change 93:335–354. https://doi.org/10.1007/s10584-008-9520-z
6. Antwi-Agyei P, Wiafe EA, Amanor K et al (2021) Determinants of choice of climate change adaptation practices by smallholder pineapple farmers in the semi-deciduous forest zone of Ghana. Environ Sustain Indic 12:100140. https://doi.org/10.1016/J.INDIC.2021.100140
7. Barnes ML, Wang P, Cinner JE et al (2020) Social determinants of adaptive and transformative responses to climate change. Nat Clim Chang 10:823–828. https://doi.org/10.1038/s41558-020-0871-4
8. Barnett J, Evans LS, Gross C et al (2015) From barriers to limits to climate change adaptation: path dependency and the speed of change. Ecol Soc 20:5. https://doi.org/10.5751/ES-07698-200305
9. Berkhout F, Dow K (2023) Limits to adaptation: Building an integrated research agenda. Wiley Interdiscip Rev Clim Chang 14:e817. https://doi.org/10.1002/wcc.817
10. Berman M, Baztan J, Kofinas G et al (2020) Adaptation to climate change in coastal communities: findings from seven sites on four continents. Clim Change 159:1–16. https://doi.org/10.1007/s10584-019-02571-x
11. Berrang-Ford L, Siders AR, Lesnikowski A et al (2021) A systematic global stocktake of evidence on human adaptation to climate change. Nat Clim Chang 11:989–1000. https://doi.org/10.1038/s41558-021-01170-y
12. Bhatasara S, Nyamwanza A (2018) Sustainability: a missing dimension in climate change adaptation discourse in Africa? J Integr Environ Sci 15:83–97. https://doi.org/10.1080/1943815X.2018.1450766
13. Biesbroek GR, Klostermann JEM, Termeer CJAM, Kabat P (2013) On the nature of barriers to climate change adaptation. Reg Environ Chang 13:1119–1129. https://doi.org/10.1007/s10113-013-0421-y
14. Birkmann J, Liwenga E, Pandey R et al (2022) Poverty, Livelihoods and Sustainable Development. In: Pörtner H-O, Roberts DC, Tignor M,. (eds) Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK and New York, NY, USA, pp 1171–1284
15. Brown PR, Afroz S, Chialue L et al (2019) Constraints to the capacity of smallholder farming households to adapt to climate change in South and Southeast Asia. Clim Dev 11:383–400. https://doi.org/10.1080/17565529.2018.1442798
16. Burnham M, Ma Z (2017) Climate change adaptation: Factors influencing Chinese smallholder farmers' perceived self-efficacy and adaptation intent. Reg Environ Chang 17:171–186. https://doi.org/10.1007/s10113-016-0975-6
17. Cameron JJ, Stinson DA (2019) Gender (mis)measurement: Guidelines for respecting gender diversity in psychological research. Soc Personal Psychol Compass 13:e12506. https://doi.org/10.1111/SPC3.12506
18. Caretta MA, Mukherji A, Arfanuzzaman M et al (2022) Water. In: Pörtner H-O, Roberts DC, Tignor M et al (eds) Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp 551–712
19. Dang H, Le, Li E, Nuberg I, Bruwer J (2018) Vulnerability to climate change and the variations in factors affecting farmers' adaptation: A multi-group structural equation modelling study. Clim Dev 10:509–519. https://doi.org/10.1080/17565529.2017.1304885
20. Dang H, Le, Li E, Nuberg I, Bruwer J (2019) Factors influencing the adaptation of farmers in response to climate change: a review. Clim Dev 11:765–774. https://doi.org/10.1080/17565529.2018.1562866

21. Deressa TT, Hassan RM, Ringler C et al (2009) Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob Environ Chang 19:248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002
22. Dilling L, Prakash A, Zommers Z et al (2019) Is adaptation success a flawed concept? Nat Clim Chang 9:572–574. https://doi.org/10.1038/s41558-019-0539-0
23. Dow K, Berkhout F, Preston BL et al (2013) Limits to adaptation. Nat Clim Chang 3:305–307. https://doi.org/10.1038/nclimate1847
24. Dunn OJ (1964) Multiple comparisons using rank sums. Technometrics 6:241–252. https://doi.org/10.1080/00401706.1964.10490181
25. Eisenack K, Moser SC, Hoffmann E et al (2014) Explaining and overcoming barriers to climate change adaptation. Nat Clim Chang 4:867–872. https://doi.org/10.1038/nclimate2350
26. Ensor JE, Wennström P, Bhatterai A et al (2019) Asking the right questions in adaptation research and practice: Seeing beyond climate impacts in rural Nepal. Environ Sci Policy 94:227–236. https://doi.org/10.1016/j.envsci.2019.01.013
27. Eriksen S, Nightingale AJ, Eakin H (2015) Reframing adaptation: The political nature of climate change adaptation. Glob Environ Chang 35:523–533. https://doi.org/10.1016/J.GLOENVCHA.2015.09.014
28. Eriksen S, Schipper ELF, Scoville-Simonds M et al (2021) Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance? World Dev 141:105383. https://doi.org/10.1016/J.WORLDDEV.2020.105383
29. Fayazi M, Bisson IA, Nicholas E (2020) Barriers to climate change adaptation in indigenous communities: A case study on the mohawk community of Kanesatake, Canada. Int J Disaster Risk Reduct 49:101750. https://doi.org/10.1016/J.IJDRR.2020.101750
30. Fenzi M, Rogé P, Cruz-Estrada A et al (2022) Community seed network in an era of climate change: dynamics of maize diversity in Yucatán, Mexico. Agric Hum Values 39:339–356. https://doi.org/10.1007/s10460-021-10249-3
31. Fuso Nerini F, Sovacool B, Hughes N et al (2019) Connecting climate action with other Sustainable Development Goals. Nat Sustain 2:674–680. https://doi.org/10.1038/s41893-019-0334-y
32. Galappaththi EK, Schlingmann A (2023) The sustainability assessment of Indigenous and local knowledge-based climate adaptation responses in agricultural and aquatic food systems. Curr Opin Environ Sustain 62:101276. https://doi.org/10.1016/J.COSUST.2023.101276
33. Grothmann T, Patt A (2005) Adaptive capacity and human cognition: The process of individual adaptation to climate change. Glob Environ Chang 15:199–213. https://doi.org/10.1016/J.GLOENVCHA.2005.01.002
34. Grothmann T, Reusswig F (2006) People at risk of flooding: Why some residents take precautionary action while others do not. Nat Hazards 38:101–120. https://doi.org/10.1007/s11069-005-8604-6
35. Hollander M, Wolfe DA, Chicken E (2015) In: Balding DJ, Cressie NAC, Fitzmaurice GM et al (eds) The two-sample location problem, 3rd edn. John Wiley & Sons, Ltd, New Jersey, pp 115–150
36. Kendall MG (1938) A new measure of rank correlation. Biometrika 30:81–93. https://doi.org/10.1093/BIOMET/30.1-2.81
37. Khanal U, Wilson C, Hoang VN, Lee B (2018) Farmers' adaptation to climate change, its determinants and impacts on rice yield in Nepal. Ecol Econ 144:139–147. https://doi.org/10.1016/j.ecolecon.2017.08.006
38. Kirchhoff CJ, Lara-Valencia F, Brugger J et al (2016) Towards joint consideration of adaptive capacity and water security: lessons from the arid Americas. Curr Opin Environ Sustain 21:22–28. https://doi.org/10.1016/J.COSUST.2016.10.003
39. Klein RJT, Midgley GF, Preston BL et al (2014) Adaptation opportunities, constraints, and limits. In: Field CB, Barros VR, Dokken DJ et al (eds) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 899–943
40. Kruskal WH, Wallis WA (1952) Use of ranks in one-criterion variance analysis. J Am Stat Assoc 47:583–621. https://doi.org/10.1080/01621459.1952.10483441
41. Labeyrie V, Antona M, Baudry J et al (2021) Networking agrobiodiversity management to foster biodiversity-based agriculture. A review. Agron Sustain Dev 41:1–15. https://doi.org/10.1007/S13593-020-00662-Z
42. Lahsen M, Ribot J (2022) Politics of attributing extreme events and disasters to climate change. Wiley Interdiscip Rev Clim Chang 13:e750. https://doi.org/10.1002/wcc.750
43. Mbow C, Rosenzweig C, Barioni LG et al (2022) Food security. In: Shukla PR, Skea J, Calvo Buendia E et al (eds) Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Cambridge University Press, pp 437–550
44. McDowell JZ, Hess JJ (2012) Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate. Glob Environ Chang 22:342–352. https://doi.org/10.1016/j.gloenvcha.2011.11.002
45. McNamara KE (2013) Raising awareness about climate change in Pacific communities. Environ Educ Res 19:864–871. https://doi.org/10.1080/13504622.2013.769046

46. McNamara KE, Buggy L (2017) Community-based climate change adaptation: A review of academic literature. Local Environ 22:443–460. https://doi.org/10.1080/13549839.2016.1216954
47. McNamara KE, Westoby R, Smithers SG (2017) Identification of limits and barriers to climate change adaptation: case study of two islands in Torres Strait, Australia. Geogr Res 55:438–455. https://doi.org/10.1111/1745-5871.12242
48. Morse S, McNamara N (2013) The theory behind the sustainable livelihood approach. Sustainable Livelihood Approach. Springer, Dordrecht, pp 15–60
49. Morton JF (2007) The impact of climate change on smallholder and subsistence agriculture. Proc Natl Acad Sci 104:19680–19685. https://doi.org/10.1073/pnas.0701855104
50. Mortreux C, Barnett J (2017) Adaptive capacity: exploring the research frontier. Wiley Interdiscip Rev Clim Chang 8:e467. https://doi.org/10.1002/wcc.467
51. Moser SC, Ekstrom JA (2010) A framework to diagnose barriers to climate change adaptation. Proc Natl Acad Sci 107:22026–22031. https://doi.org/10.1073/pnas.1007887107
52. Niemann J, El-Mahdi M, Samuelsen H et al (2024) Gender relations and decision-making on climate change adaptation in rural East African households: A qualitative systematic review. PLOS Clim 3:e0000279. https://doi.org/10.1371/JOURNAL.PCLM.0000279
53. Nyantakyi-Frimpong H, Bezner-Kerr R (2015) The relative importance of climate change in the context of multiple stressors in semi-arid Ghana. Glob Environ Chang 32:40–56. https://doi.org/10.1016/j.gloenvcha.2015.03.003
54. O'Brien K, Eriksen S, Nygaard LP, Schjolden A (2007) Why different interpretations of vulnerability matter in climate change discourses. Clim Policy 7:73–88. https://doi.org/10.1080/14693062.2007.9685639
55. Otto IM, Reckien D, Reyer CPO et al (2017) Social vulnerability to climate change: A review of concepts and evidence. Reg Environ Chang 17:1651–1662. https://doi.org/10.1007/s10113-017-1105-9
56. Piggott-McKellar AE, McNamara KE, Nunn PD, Watson JEM (2019) What are the barriers to successful community-based climate change adaptation? A review of grey literature. Local Environ 24:374–390. https://doi.org/10.1080/13549839.2019.1580688
57. Porcuna-Ferrer A, Calvet-Mir L, Faye NF et al (2024a) Drought-tolerant indigenous crops decline in the face of climate change: A political agroecology account from south-eastern Senegal. J Rural Stud 105:103163. https://doi.org/10.1016/J.JRURSTUD.2023.103163
58. Porcuna-Ferrer A, Guillerminet T, Klappoth B, Schlingmann A (2024b) Agricultural adaptation to multiple stressors in a climate change context: a case study in south-eastern Senegal. In: Reyes-García (ed) Routledge Handbook of Climate Change Impacts on Indigenous Peoples and Local Communities. Routledge, Abingdon, Oxon, UK, pp 227–243
59. R Core Team (2021) R: A language and environment for statistical computing
60. Reyes-García V (2024) Routledge handbook of climate change impacts and adaptation strategies on indigenous peoples and local communities. Routledge, Abingdon, Oxon, UK
61. Reyes-García V, Álvarez-Fernández S, Benyei P et al (2023) Local indicators of climate change impacts described by indigenous peoples and local communities: Study protocol. PLoS ONE 18:e0279847. https://doi.org/10.1371/JOURNAL.PONE.0279847
62. Reyes-García V, García-del-Amo D, Álvarez-Fernández S et al (2024a) Indigenous Peoples and local communities report ongoing and widespread climate change impacts on local social-ecological systems. Commun Earth Environ 5:1–10. https://doi.org/10.1038/s43247-023-01164-y
63. Reyes-García V, García-del-Amo D, Benyei P et al (2019) A collaborative approach to bring insights from local observations of climate change impacts into global climate change research. Curr Opin Environ Sustain 39:1–8. https://doi.org/10.1016/j.cosust.2019.04.007
64. Reyes-García V, García-del-Amo D, Porcuna-Ferrer A et al (2024b) Local studies provide a global perspective of the impacts of climate change on Indigenous Peoples and local communities. Sustain Earth Rev 7:1–11. https://doi.org/10.1186/S42055-023-00063-6
65. Ribot J (2014) Cause and response: vulnerability and climate in the Anthropocene. J Peasant Stud 41:667–705. https://doi.org/10.1080/03066150.2014.894911
66. RStudio T (2021) RStudio: Integrated Development Environment for R
67. Sam AS, Abbas A, Surendran Padmaja S et al (2019) Linking food security with household's adaptive capacity and drought risk: Implications for sustainable rural development. Soc Indic Res 142:363–385. https://doi.org/10.1007/s11205-018-1925-0
68. Savo V, Lepofsky D, Benner JP et al (2016) Observations of climate change among subsistence-oriented communities around the world. Nat Clim Chang 6:462–473. https://doi.org/10.1038/nclimate2958
69. Savo V, Morton C, Lepofsky D (2017) Impacts of climate change for coastal fishers and implications for fisheries. Fish Fish 18:877–889. https://doi.org/10.1111/FAF.12212
70. Schipper ELF, Dubash NK, Mulugetta Y (2021) Climate change research and the search for solutions: rethinking interdisciplinarity. Clim Change 168:1–11. https://doi.org/10.1007/s10584-021-03237-3

71. Schlingmann A, Graham S, Benyei P et al (2021) Global patterns of adaptation to climate change by Indigenous Peoples and local communities. A systematic review. Curr Opin Environ Sustain 51:55–64. https://doi.org/10.1016/J.COSUST.2021.03.002
72. Shackleton S, Ziervogel G, Sallu S et al (2015) Why is socially-just climate change adaptation in sub-Saharan Africa so challenging? A review of barriers identified from empirical cases. Wiley Interdiscip Rev Clim Chang 6:321–344. https://doi.org/10.1002/wcc.335
73. Siders AR (2019) Adaptive capacity to climate change: A synthesis of concepts, methods, and findings in a fragmented field. Wiley Interdiscip Rev Clim Chang 10:1–18. https://doi.org/10.1002/wcc.573
74. Singh C, Ford JD, Ley D et al (2020) Assessing the feasibility of adaptation options: methodological advancements and directions for climate adaptation research and practice. Clim Change 162:255–277. https://doi.org/10.1007/S10584-020-02762-X
75. Singh C, Iyer S, New MG et al (2022) Interrogating 'effectiveness' in climate change adaptation: 11 guiding principles for adaptation research and practice. Clim Dev 14:650–664. https://doi.org/10.1080/17565529.2021.1964937
76. Spires M, Shackleton S, Cundill G (2014) Barriers to implementing planned community-based adaptation in developing countries: a systematic literature review. Clim Dev 6:277–287. https://doi.org/10.1080/17565529.2014.886995
77. Thomas A, Theokritoff E, Lesnikowski A et al (2021) Global evidence of constraints and limits to human adaptation. Reg Environ Chang 21:1–15. https://doi.org/10.1007/s10113-021-01808-9
78. Vallury S, Smith AP, Chaffin BC et al (2022) Adaptive capacity beyond the household: a systematic review of empirical social-ecological research. Environ Res Lett 17:063001. https://doi.org/10.1088/1748-9326/ac68fb
79. Van Valkengoed AM, Perlaviciute G, Steg L (2023) From believing in climate change to adapting to climate change: The role of risk perception and efficacy beliefs. Risk Anal 44:553–565. https://doi.org/10.1111/RISA.14193
80. Van Valkengoed AM, Steg L (2019) Meta-analyses of factors motivating climate change adaptation behaviour. Nat Clim Chang 9:158–163. https://doi.org/10.1038/s41558-018-0371-y
81. Wilcoxon F, Katti SK, Wilcox RA (1970) Critical values and probability levels for the Wilcoxon rank sum test and the Wilcoxon signed rank test. In: Selected tables in mathematical statistics. pp 171–259
82. Williams P, Simpson N, Team GAMI et al (2021) Feasibility assessment of climate change adaptation options across Africa: an evidence-based review. Environ Res Lett 16:073004. https://doi.org/10.1088/1748-9326/ac092
83. Wilson RS, Herziger A, Hamilton M, Brooks JS (2020) From incremental to transformative adaptation in individual responses to climate-exacerbated hazards. Nat Clim Chang 2020 103 10:200–208. https://doi.org/10.1038/s41558-020-0691-6

Footnotes

1. We identified informants as men or women according to the socio-cultural expression of their gender. We acknowledge that our binary gender variable does not necessarily reflect the gender identities of our informants (Cameron and Stinson 2019).

Figures

CATEGORY	SUB-CATEGORY	EXAMPLES
LOW ADAPTATION NEED APPRAISAL (LOW CLIMATE CHANGE RISK & IMPACT APPRAISAL)	I. Low climate change probability & intensity II. Low climate change sensitivity & exposure	I. No/Little changes in local climate observed II. Feeling little impacted by climate change
LOW ADAPTATION EFFICACY APPRAISAL	I. Low adaptation effectiveness & efficiency (low benefits) II. Preference for other adaptation III. Potential risks	I. Low adaptation success II. Other adaptation measure preferred III. Fear of potential risks associated with adaptation measure
LOW SELF-EFFICACY APPRAISAL (LOW ACCESS TO CAPITALS)	I. Financial & economic constraints (‘financial capital’) II. Techno-physical constraints (‘physical capital’) III. Constraints related to human resources (‘human capital’) IV. Biophysical & natural resource constraints (‘natural capital’) V. Social & cultural constraints (‘social capital’) VI. Political constraints (‘political capital’)	I. High investments costs, low income II. Low access to materials, tools, technology III. Low education, low access to information IV. Low access to land or water V. Low participation in local groups, low access to extension services, cultural taboos VI. Low influence in decision-making (legislation, governance)
LOW SELF-EFFICACY APPRAISAL (OTHER TRADE-OFFS)	I. Habits, customs & personal preferences II. Time constraints III. Other constraints	I. Preference towards traditional practices over modifications II. Limited available time III. Other constraints

Figure 1

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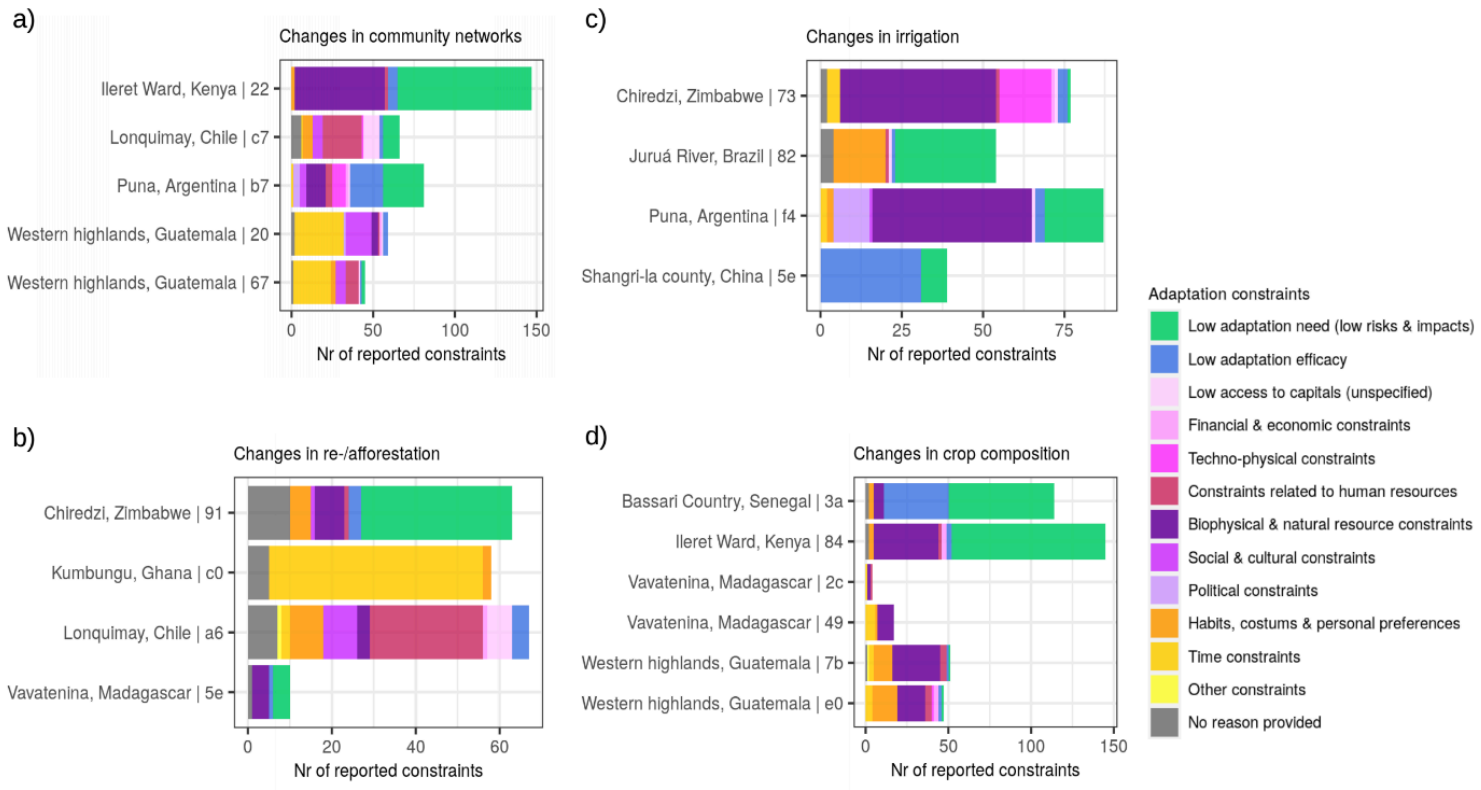

Figure 2

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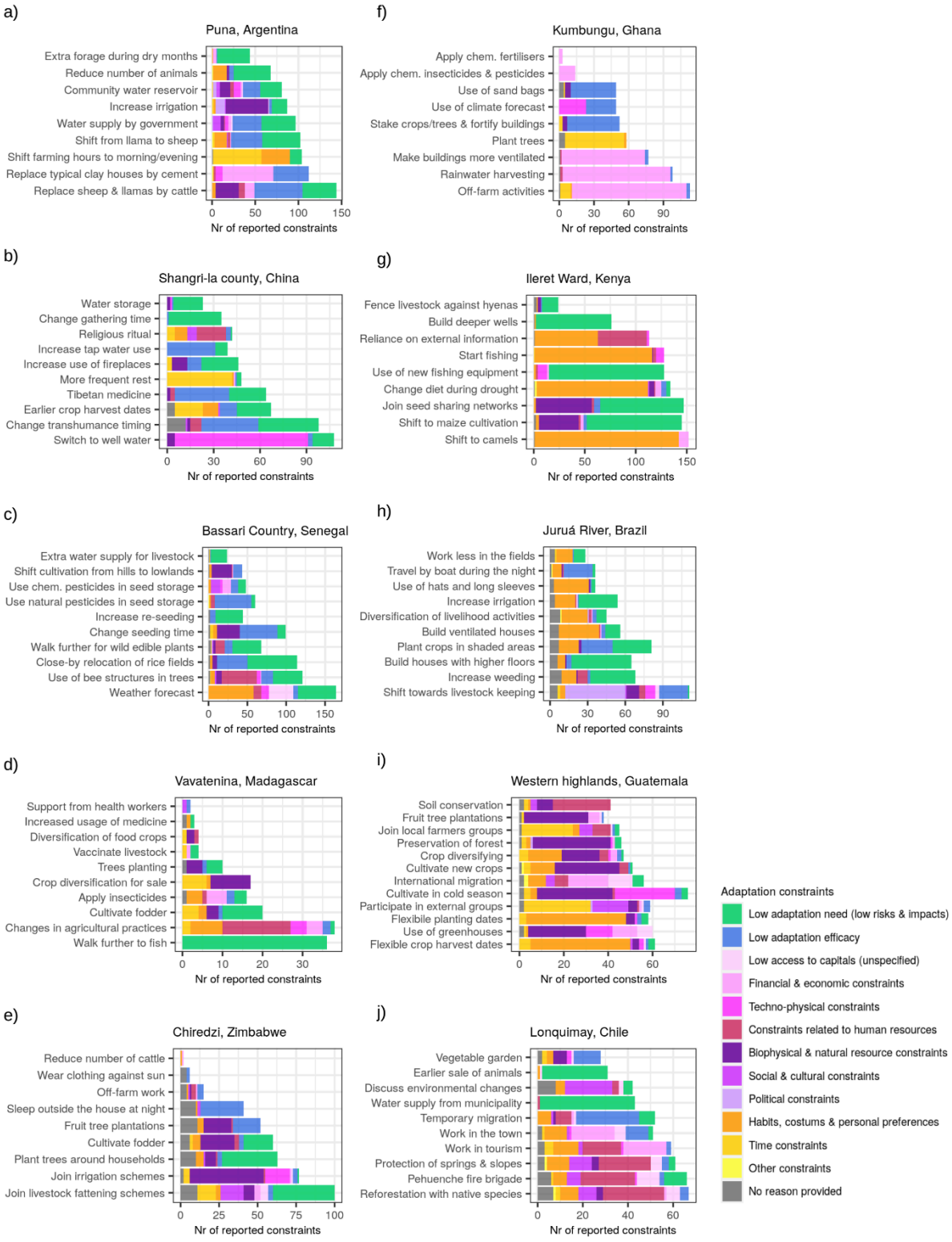

Figure 3

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