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Scenario archetypes reveal risks and opportunities for global mountain futures

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Abstract

Mountain social-ecological systems (MtSES) are transforming rapidly due to changes in multiple environmental and socioeconomic drivers. However, the complexity and diversity of MtSES present challenges for local communities, researchers and decision makers seeking to anticipate change and promote action towards sustainable MtSES. Participatory scenario planning can reveal potential futures and their interacting dynamics, while archetype analysis aggregates insights from site-based scenarios. We combined a systematic review of the global MtSES participatory scenarios literature and archetype analysis to identify emergent MtSES archetypal configurations. An initial sample of 1,983 rendered 42 articles that contained 142 scenarios within which were 852 'futures states'. From these future states within the scenarios, we identified 59 desirable and undesirable futures that were common across studies. These 'common futures' were grouped into four clusters that correlated significantly with three social-ecological factors (GDP per capita, income inequality, and mean annual temperature). Using these clusters and their associated significant factors, we derived four MtSES scenario archetypal configurations characterized by similar key adaptation strategies, assumptions, risks, and uncertainties. We called these archetypes: (1) "revitalization through effective institutions and tourism"; (2) "local innovations in smallholder farming and forestry"; (3) "upland depopulation and increased risk of hazards"; and (4) "regulated economic and ecological prosperity". Results indicate risks to be mitigated, including biodiversity loss, ecosystem degradation, cultural heritage change, loss of connection to the land, weak leadership, market collapse, upland depopulation, increased landslides, avalanches, mudflows and rock falls, as well as climate variability and change. Transformative opportunities lie in adaptive biodiversity conservation, income diversification, adaptation to market fluxes, improving transport and irrigation infrastructure, high quality tourism and preserving traditional knowledge. Despite the uncertainties arising from global environmental changes, these archetypes support better targeting of evidence-informed actions across scales and sectors in MtSES.

Keywords decision support; desirable futures; participatory scenario planning; science policy interface; stakeholder participation; sustainability science

1. Introduction

Mountain social-ecological systems (MtSES) are experiencing severe challenges associated with global environmental change. Although MtSES are characterized by biophysical, cultural, and socioeconomic diversity, there are common characteristics that result in MtSES being highly exposed to interacting global change drivers. For example, climate warming is greater at higher elevations (Pepin et al., 2015), potentially exacerbating the impacts of multiple natural hazards, such as glacial outburst floods or shifting ranges of agricultural pests, that typify many MtSES (Zimmermann and Keiler, 2015; Klein et al., 2019*a*). Moreover, the sometimes physical isolation and peripheral nature of MtSES – combined with social challenges such as poverty, overstretched infrastructure, and exclusion from emergency preparedness – can increase MtSES' vulnerability to global changes (Körner, 2000; Vaidya et al., 2009; Körner et al., 2011; Klein et al., 2019*b*; Thorn et al., 2020). Impacts from these changes are already visible, as different MtSES are experiencing degradation of arable land and pastures, shifts in ground and surface water hydrology, demographic changes, socioeconomic transformations, soil erosion and desiccation, and reduced vegetation cover (Soliva et al., 2008; Simon and Etienne, 2010; Tzanopoulos et al., 2011). This complexity and diversity of MtSES presents an obstacle for local communities, researchers and decision makers seeking to reflect on and promote action towards sustainable MtSES.

Global environmental change impacts on MtSES present a situation where resilience, adaptability, and transformability are needed to sustain the structure and function of MtSES under rapid change. Resilience is the capacity of an SES to continually change but remain within critical thresholds; adaptability is the ability of system to adapt responses to changing external drivers and internal desired processes; transformability is the system's capacity to cross thresholds into new states and trajectories when ecological, economic, or social structures make the existing system untenable (Walker et al., 2004; Folke et al., 2010). Transformations can be unintended, resulting from uncontrolled change, or deliberately and actively managed in response to a perturbation or confluence of cross scalar change processes (Olsson et al., 2004; Thorn et al., 2015). For example, in Kenyan tropical montane cloud forests, unintended transformation can occur in response to changing fog capture levels if rare and endemic species are forced to move to lower elevations, thereby causing peoples who were reliant on these species to diversify their livelihoods (Los et al., 2019). In the Swiss Alps, tourism investors are responding to warming temperatures by transforming struggling winter ski resorts to health solariums (Sarkki et al., 2017).

Participatory Scenario Planning (PSP) has been a key tool of global change research in recent decades, providing a means for shifting adaptation planning so that it is less reactive and more anticipatory (van Notten et al., 2003; Kok et al., 2006; Capitani et al., 2019; Lavorel et al., 2019; Thorn et al., 2020; O'Neill et al., 2020). Scenarios are plausible descriptions of "how the future might develop, based on a coherent, internally consistent set of assumptions (or logic) about key relationships and their driving forces" (van Vuuren et al., 2012: 877). Embedded in every scenario are multiple desirable and undesirable visions of the future (Rosa et al., 2017). Participants imagine desirable futures as positive outcomes that can inspire change, while they see undesirable futures as having negative consequences that can serve as warnings of what to avoid (Oteros-Rozas et al., 2013). PSP differs from conventional scenario planning through the inclusion of a diverse array of relevant stakeholder views in the process (e.g., private industry, researchers, civil society, and municipal officials), which can improve the feasibility, validity, uptake, and concreteness of scenarios (van Vuuren et al., 2012; Vervoort et al., 2014; Vervoort et al., 2016; Lavorel et al., 2019; Thorn et al., 2020). PSP can help reveal that pathways to desired futures within a given scenario may not always be straightforward, and trade-offs can arise across spatial, institutional, or temporal scales, or among stakeholders (Haasnoot et al., 2013; Hermans et al., 2017; Lavorel et al., 2019). The aim of PSP is to ultimately engage in unconstrained deliberation of the future, rather than deliberation based purely on experiences of current paradigms or structures (Sarkki et al., 2017).

While the last decade has witnessed some developments in MtSES scenarios at regional (Soliva et al., 2008; Sarkki et al., 2017; Roy et al., 2019), and subnational levels (Wyborn et al., 2015; Capitani et al., 2016; Capitani et al., 2019), much room remains for local and regional processes to complement and contextualize global scenarios in particular places (Palazzo et al., 2017). Similarly, it remains challenging to scale up the insights derived from these highly localized or regionalized PSP processes. What is needed is a set of locally developed sustainability actions that can be adapted effectively to multiple locations, recognizing no single approach fits multiple locations in the same way.

Archetype analysis is increasingly used to identify patterns in the factors shaping the (un)sustainability of SES, making it a useful tool for aggregating insights from site-based scenarios (Oberlack et al., 2019; Sietz et al., 2019). Scenarios can be grouped into "archetypes", referring to "classes based on similarities in underlying assumptions, storylines, and characteristics, that can then be used to integrate visions, thus highlighting conflicts and convergences across scales" (Rosa et al., 2017: 1417). For example, one of the most widely cited sets of archetypes was developed by the Global Scenario Group (GSG), which identified over 450 distinct scenarios developed from 1997-2011 and aggregated them into three world end-states (Conventional, Barbarization, and Great Transitions). They further developed six scenario archetypes within those world end-states based on their inner logic, underpinning storylines, and other characteristics (Hunt et al., 2012). More recently, the International Panel on Biodiversity and Ecosystem Services developed regional archetypes on nature and natures' contributions to people (e.g., IPBES, 2018*abc*) using protocols that compared biodiversity and ecosystem services models, standardized land use, shared socioeconomic and climate scenarios, and stakeholder consultation (IPCC, 2014; 2018; Kim et al., 2018; O'Neill, et al., 2017). As diagnostic tools, archetypes provide insights into the processes that generate outcomes; as prospective tools, they suggest potential trajectories, and can help analyse how particular interventions may modify system behaviour leading to desired sustainability outcomes (Oberlack, et al. 2019).

Although there are a wide variety of appropriate qualitative and quantitative methods for identifying archetypes (e.g., meta-analysis (Messerli et al., 2016; Oberlack et al., 2016), statistical analyses (Václavík et al., 2013; Sietz et al., 2017), system dynamics modelling (Banson et al., 2016)), cluster analysis has emerged as a particularly effective and widely used approach for analyzing high dimensional data and a range of spatial and temporal scales (Kok et al., 2016; Sietz et al., 2017; Sietz et al., 2019). No attempt has been made to develop scenario archetypes in MtSES, despite considerable proliferation of the use of archetypes in the field of sustainability science (Oberlack et al., 2019), including explorations of how large scale land acquisitions affect rural livelihoods (Oberlack, et al., 2016), environmental degradation (Sietz et al., 2006), vulnerability (Sietz et al., 2011; 2017; Kok et al., 2016; Vidal Merino et al., 2019), impacts of climate change (van Vuuren et al., 2012), biodiversity and ecosystem services (Harrison, et al. 2019), land system types (Václavík et al., 2013), and teleconnections (Fragkias et al., 2017; Sitas et al., 2017).

In this paper, we draw on a systematic review of PSP in MtSES (Thorn et al., 2020) to conduct an archetype analysis of desired and undesired futures, with the aim of identifying common desired futures - and those that MtSES stakeholders seek to avoid - and to present risks and opportunities associated with those archetypal futures. First, we deconstructed scenarios from 42 PSP studies in MtSES to quantify the individual desirable and undesirable futures contained within them. We then used cluster analysis of desirable and undesirable futures to identify scenario archetypes, based on those clusters. We then identified which social, economic, and biophysical characteristics were associated with the scenario archetypes. Finally, we examined the strategies, innovations or practices identified in the archetype clusters to determine what adaptation responses might be common within or across these archetypes. In this analysis, we address the following questions:

1. What are the most common desirable and undesirable futures from PSP in MtSES?
2. What archetypes configurations emerge from the PSP process?
3. What opportunities arise from the archetypes for moving towards desirable futures? What risks are associated with the archetypes that need to be avoided or managed?

In the discussion, we explore the validity and limitations of the MtSES archetype approach and how MtSES archetypes compare to global archetypes. In view of risks and opportunities, we suggest ways to practically translate MtSES archetypes into outcomes and impacts. We conclude by examining the unique challenges and opportunities for future MtSES resilience and transformation. By developing MtSES scenario archetypes based on PSP processes, we seek to elevate local MtSES stakeholders' desired future states into a global conversation, facilitate sharing knowledge across MtSES that experience similar contexts, and contribute to a gathering momentum of collective action for MtSES sustainability science and policy that has local MtSES stakeholder perspectives of the future at its foundation.

2. Methodology

2.1. Systematic review: search strategy, screening, critical appraisal, and extraction

We conducted a systematic search of peer reviewed and non-peer reviewed literature to identify the state of evidence for PSP in MtSES between April-November 2017, with a repeat search in January 2021 in Web of Science. The second review found eight additional studies published from 2017-2021 (see list in Appendix A for future research). We searched five bibliographic databases, hand searched four key international e-journals, retrieved the first 200 search results from Google Scholar and searched 14 subject specific websites for reports, conference proceedings, policy briefs, book chapters, and individual research papers. To identify additional relevant studies, we made an open call online and consulted with researchers and stakeholders at a MtSES workshop, an advisory board, and an experienced environmental librarian. Six reviewers screened 1,983 studies according to a set of inclusion criteria: empirical research reporting on PSP with stakeholders living permanently or seasonally in MtSES, or upstream or downstream inhabitants affected physically, socially, or economically by MtSES; a primary focus on interactions of social and ecological systems and/or adaptive management; and full text available in electronic format and published in English. At title and abstract screening, Randolph's free marginal kappa coefficient was 0.72, indicating sufficient agreement among reviewers. Of the 44 studies that met the inclusion criteria, two did not meet our five quality assessment criteria (e.g., replicable methods, adequate sampling, and conclusions logically derived from evidence) and were removed. We extracted data from the final 42 studies using an evaluation tool (codebook) consisting of 86 questions, grouped into nine categories. The methodology is thoroughly described in Thorn et al. (2020), including the evaluation tool presented in Appendix 6.

2.2. Archetype analysis

We used analyses consistent with an archetype approach, which seeks to identify patterns across large numbers of cases, building on empirical data (Oberlack et al., 2019). The preconditions for archetype analysis were met in that multiple cases shared sufficiently similar defining features (i.e., all studies were defined as MtSES), and the cases (i.e., future states contained within scenarios) shared some attributes (i.e., desired, or undesired futures).

We used inductive, iterative coding to identify the desirable and undesirable futures contained within the scenarios in each of the 42 studies. The same six reviewers coded the studies, with 25% of the studies verified among coders for agreement. Here, a "case" or "future state" was defined as a particular "element" of a scenario (or an individual scene or development of events which represents one reality of multiple possibilities, with a temporal quality viewed as an extension of the present embedded in the future) (Spaniol and Rowland 2018). These "futures" had a normative quality, of "desirable", "good", or "positive" or "undesirable" or "feared" – representing an expression of human values (Durance and Godet, 2010). Whether the future was desirable, or undesirable was determined based on the coders' reading of the set of scenarios within a study. A total of 852 individual futures were identified, which were then grouped into 59 common futures by the first author – resulting in 32 desirable futures and 27 undesirable futures in MtSES. We ranked these futures according to their frequency across all studies to answer our first research question, using the most frequent futures (>75% of studies) in our subsequent analyses.

We acknowledge that potential biases may be embedded in the scenario components due to the worldview of the participants developing the scenarios, as well as in our analysis of the scenarios. Scenario developers may have cognitive biases such as overconfidence, optimism, or evaluating trends only within a certain geography or sector. Other biases might have arisen where developers assumed what the future will look like based on what is observed in the past or what is prominent in the present (i.e., stability bias) (Kahneman, 2010; Vervoort et al., 2015), or assigning low probability events with excessive weight or ignoring them entirely (i.e., probability neglect) (Erdmann et al., 2015). Similarly, there is the potential for bias in the coding of the desirable and undesirable futures – considering some scenarios were exploratory rather than normative, and so did not seek out, or avoided labelling scenario elements as "good" or "bad". We attempted to counter these biases by three reviewers coding 25% of the studies and discussing and agreeing on the categories chosen.

We then ran a hierarchical cluster analysis to group studies into clusters with similar desirable and undesirable futures (i.e., archetypes), using the ClustOfVar package in R (Chavant et al., 2010; R Development Core Team, 2019). To reduce aggregation bias and the ecological fallacy (Freedman et al., 2002), studies that included multiple sites in different countries (*n*=5 studies encompassing 19 countries) were excluded from the cluster analysis, resulting in 37 studies for this portion of the study. We used visual analysis of the scree plot and bootstrapping to aid the choice of the number of clusters. To display the results of the cluster analysis, we created a heat map using mix.heatmap from the CluMix package in R (Hummel et al., 2017) and highlighted the futures that were most frequently used in each cluster (>75% of studies). "Distinct" futures were denoted as those that were listed frequently in one cluster, but not in other clusters. We assigned each cluster a name that illustrates the archetype.

We explored differences between these clusters using eleven variables representing social, economic, and biophysical characteristics of the study sites. These variables were selected to represent conditions that could presumably influence the types of scenarios developed in each location (e.g., opportunities for income generation in areas with low GDP per capita). When available, we used site-specific data from global datasets with subnational resolution. For studies with multiple sites within a country, we calculated mean values across sites to obtain a study-level average. Site-level variables included: subnational gross domestic product per capita (Kummu et al., 2018); local net migration (difference of immigrants and emigrants) (de Sherbinin et al., 2012); minimum and maximum elevation; mean annual temperature and precipitation (Fick and Hijmans, 2017); a local indicator of drought conditions (Standardized Precipitation Evapotranspiration Index) (Vicente-Serrano, 2015); an indicator of human impact via population pressure, infrastructure, and other factors (Human Footprint Index) (WCS and CIESIN 2005); and local land use, including tourism/logging, crops/non-timber forest products, pastoral, agro-pastoral, and tourism/residential (Klein et al., 2019*a*). National-level data were used when site-level data were unavailable. National-level variables included: GINI coefficient (World Bank, 2015); annual, national, international, inbound tourists (overnight visitors) (World Tourism Organization, 2016); and average percentage of the population affected annually by droughts, floods, and extremes events (1990-2009) (Vos et al., 2010) (see Appendix B for detailed definitions). While national-level data cannot precisely represent the MtSES conditions within countries, the national parameters we included likely reflect pertinent conditions in mountains, where communities are often socially and economically marginalized, highly exposed to natural disasters and, in many cases, heavily dependent on tourism (Klein et al., 2019*a*; 2019*b*). We tested for differences in these variables among clusters using Fisher's exact tests for categorical variables and Kruskal-Wallis rank sum tests for continuous variables. For Kruskal-Wallis tests that produced significant ($p < 0.05$) and marginally significant ($0.05 < p < 0.10$) results, we conducted post hoc Dunn tests with a Benjamini-Hochberg adjustment for multiple comparisons to identify significant pairwise differences between clusters. Statistical analyses were conducted in R v. 3.6.2 (R Development Team, 2019).

The development of archetypes was both data driven, using the above cluster analysis based on stability of cluster partitions, and inductive, using scenarios' qualitative storylines and assumptions (Kok et al., 2016; Sietz et al., 2017). Thus, the resulting archetypes were complex narratives depicting the interwoven dynamics of the stakeholder defined futures of MtSES, highlighting both the prevalence of negative (e.g., collapse) and positive (e.g., intentional transformation) outcomes (Fergnani and Jackson, 2019).

Within each archetype group, we reviewed each case study narrative and drew from these studies examples of adaptation practices that can facilitate those futures, as well as risks, assumptions, and uncertainties. Here, assumptions are understood as the conditions that are set to be true for the future (Stevenson, 2010). Contrarily, uncertainties are those elements that are not certain, including elements in the narrative or scenario outputs, particularly for quantitative models. Considering the future of complex dynamic systems is highly uncertain – whether considering the effects of climate change, alternative human choices, price volatility or how landscapes undergo continuous and unpredictable change (Schermer et al., 2018). Reporting explicit uncertainties can therefore help produce information that is more useful for practical decision making and enhance the legitimacy of the information (Welling et al., 2019). Assumptions and uncertainties are common to all scenarios within an archetype (IPBES*a*, 2018).

3. Results

3.1. Study area

The 42 studies included in the systematic review encompassed 40 countries (Appendix C). Over half of the studies (54.8%) occurred in Europe, followed by Asia (19.0%) (Table 1). Most studies (52.4%) were located in temperate climates, and a fifth in dryland or semiarid climates (defined using the categories in Thorn et al., 2016). The dominant vegetation (as defined by Schultz, 1988) in these MtSES was forest, followed by grassland, shrubland, then savannah. Tourism and recreation comprised the largest proportion of land uses in the studies, followed by agro-pastoralism and timber/logging (Klein et al., 2019*a*; Thorn et al., 2020). Their elevations ranged from 0-8,848 masl, with a median of 2,469 masl. Appendix D contains names of scenarios in each study, and Appendix E contains the axes used in their development.

Table 1. Continents and MtSES ranges where PSP has been conducted. Elevation ranged from 0-8,848 masl, with a median of 2,469 masl.

Continent	**MtSES ranges**	**Number of studies**
Europe	Swiss Alps, Carpathians, Cairngorms, Fennoscandian, Iberian, Pindos, Pyrenees	23 (54.8%)
Asia	Hindu-Kush Himalaya, Mongolian Plateau, Liupan, Doi Tung, Luang Prabang	8 (19.0%)
Africa	Drakensberg, Eastern Arc, Rift	5 (11.9%)
North America	Rockies, Cascades, Adirondacks	4 (9.5%)
Oceania	Australian Alps	2 (4.8%)

3.2. Common desirable and undesirable futures in MtSES

We identified 59 common futures across most studies (from 852 individual futures across all the studies included in the review), resulting in 32 desirable futures and 27 undesirable futures in MtSES (see a comprehensive list of the desirable and undesirable futures in Appendix F). The four most common desirable futures were featured in over 70% of studies, while the four most common undesirable futures were featured in over 50% of studies. The four desired futures embraced (1) adaptive biodiversity conservation; (2) income diversification, improved market access, and adaptation to market fluxes; (3) cultural diversity and local and Indigenous knowledge; and (4) regulated, high quality tourism in cooperation with other sectors. The four undesired futures referred to (1) conversion, fragmentation, and degradation of productive lands; (2) biodiversity and habitat loss; (3) cultural erosion; and (4) climate induced hazards.

3.2.1. Desirable futures

The most frequently reported desired future (83.3%, n=35) is the creation of a dynamic system for **adaptive biodiversity conservation**, where a mosaic of multifunctional landscapes connect human and nonhuman species (Lebel, 2006; Carvalho-Ribeiro et al., 2010), often with adaptive governance support from public private partnerships and cooperation across local to international scales. Actors living and working in MtSES envision desirable futures with protections for valuable species and habitats (Lamarque et al., 2013; Wyborn et al., 2015), often through improved operational efficiency of national parks and stewardship of other protected areas (Tzanopoulos et al., 2011; Carlsson et al., 2015; Capitani et al., 2016), protected indigenous species and habitat corridors (Soliva et al., 2008; Oteros-Rozas et al., 2013), community wildfire protection plans (Reed et al., 2013), and limited water, soil, and air contamination (Enfors et al., 2018). Land is equitably distributed or pooled under communal agreements so that ecosystem goods and services are managed in the public interest, benefits are locally accrued and distributed (Wyborn et al., 2015; Allington et al., 2018), and smallholder farmers' bargaining power improves (Lamarque et al., 2013). Transboundary cooperation and negotiations, improved land use management, and better water use efficiency reduces conflict in MtSES (Jaeger et al., 2017). Local and national governments play a stronger role in regulating global markets (e.g., legislation incorporating externalities within the price of traded goods (Lebel, 2006)) and counter the negative impacts of unregulated markets on other sectors or land uses (Sarkki et al., 2017).

The second most frequently reported desirable future (78.6%, *n*=33) envisions MtSES communities with **diversified income sources, rapidly integrating into the market economy, and with the capacity to adapt to market fluctuations** (Fisher et al., 2011; Reed et al., 2013). People living in and around forests diversify income through multiple means, such as payments for ecosystem service schemes derived from reforestation, afforestation, and carbon- and biodiversity-efficient practices, such as sustainable charcoal production (Bourgoin and Castella, 2011; Capitani et al., 2016). Farmers diversify income by cultivating high value organic or novel products, strengthening agricultural value chains (Carvalho-Ribeiro et al., 2010), or shifting cultivation from subsistence to recreational purposes (e.g., leisure or hobby farming) (Enfors et al., 2008; Soliva and Hunziker, 2009). Pastoralists increase value added in direct herd sales to purchasers instead of intermediaries (Lamarque et al., 2013), manage pastures more sustainably with new mixtures of livestock species, and maintain practices to move between highlands and lowlands across seasons (Reed et al., 2013). In some cases, access to the local and traditional product markets implies a shift in the public attitude towards the product, such as transhumance artisan wool products in Spain (Oteros-Rozas et al., 2013). Ultimately, the gap in income inequality narrows, poverty declines, adaptive capacity is strengthened across all socioeconomic levels, and a strong, collaborative, entrepreneurial spirit is engendered (Malinga et al., 2013).

The third ranked desirable future (76.2%, *n*=32) is **the existence of cultural diversity and support for local and Indigenous knowledge**. MtSES communities envision functional institutions and cooperatives that incorporate a mixture of tradition, innovation, and contemporary living that conserves knowledge across generations (Malinga et al., 2013; Kohler et al., 2017). Leadership is built into formal and informal institutions, and over time, power devolves to local authorities (Daconto and Sherpa, 2015). Young people are socially and economically motivated to engage in customary, rural livelihoods (Brand, 2013). In this future narrative, academic progress supports a mixture of tradition and innovation, and scientific and local ecological knowledge is co-produced (Soliva et al., 2008; Plieninger et al., 2013; Palacios-Agundez et al., 2015; Roy, et al., 2019). Long term, embedded, and participatory engagement with local communities is truly valued and operationalized in policy and practice to better manage the commons (Bourgoin and Castella, 2011; Jaeger et al., 2017).

In the fourth desirable future (71.4%, *n*=30), MtSES communities capture the benefits of **regulated, high quality tourism in cooperation with other sectors**. Communities manage tourism, and it is integrated with other sectors, building markets for specialty niche MtSES products. Communities generate revenue from tourism that follows "environmentally friendly" guidelines, mobilizes capacity to preserve local food provisioning and biodiversity, and safeguards against the desecration of cultural heritage sites, thereby contributing to cultural and recreational value (Soliva and Hunziker, 2009; Bizikova et al., 2012; Oteros-Rozas et al., 2015; Capitani et al., 2016). Tourism companies step into the public sphere, playing a strong role in improving infrastructure and services in MtSES, particularly for ecotourism and holiday and retirement homes (Loibl and Walz, 2010; Mitchell et al., 2015). Tourism entrepreneurs pay pastoralists, park managers, and traditional users to co-manage areas and enhance the aesthetic quality of the landscape as a tourist destination (Lamarque et al., 2013). Domestic actors mitigate environmental pressures arising from mass tourism through subsidies and economic incentives for climate neutral and local production of resources tourists consume, and for solid waste and wastewater management. International mitigation of tourism's impacts occurs, through reductions in air travel and technological solutions to decarbonization (Sarkki et al., 2017). Coalitions of stakeholders reduce widening disparities among and within social groups through revenue sharing (Daconto and Sherpa, 2015), education, cross cultural dialogue and viewing ethnic minorities as flexible and mobile entrepreneurs as opposed to security threats (Sarkki et al., 2017).

3.2.2. Undesirable futures

When envisioning an undesirable future, MtSES actors (81%, *n*=34) are most critically concerned about the **conversion, fragmentation, or degradation of productive lands** (i.e., croplands, forests, and rangelands). In agricultural areas, soil erosion increases, compromising food self-sufficiency (Plieninger et al., 2013). In some forested lands, local populations' growing demand for fuelwood, charcoal, and building materials drives timber overextraction (Fisher et al., 2011; Jaeger et al., 2017), while elsewhere timber production declines as it becomes more capital- and technology-intensive (McBride et al., 2017). In rangelands, forage production decreases, while habitat fragmentation, poor soil fertility, and fire hazards increase, as does overstocking (Tzanopoulos et al., 2011; Oteros-Rozas et al., 2013). In some places, private and public actors exclude local communities from grazing rights or firewood collection, adversely impacting livelihoods, social dynamics, and environmental sustainability (Enfors et al., 2008). Long term land use planning is undervalued (Bogdan et al., 2016, Capitani et al., 2016).

High rates of biodiversity and habitat loss (64.3%, *n*=27), and **high rates of cultural heritage loss** (64.3%, *n*=27) are the next most undesirable futures. These futures present opposite trends of the first and third desirable futures described above; therefore, we do not elaborate on these undesired futures here.

The fourth most frequent undesirable future focuses on the adverse impacts of **climate induced natural hazards** (64.3%, *n*=27) such as droughts, floods, heat waves, increased climate variability and extreme events, as well as rock falls, storms, avalanches, and glacial lake outburst floods (Lebel, 2006; Murphy et al., 2016; Allington et al., 2018). Warming temperatures lead to stronger winds and changes in seasonality, including the onset and length of growing seasons and the timing of snowpack melt and permafrost thaw (UDSM IRA et al., 2016; Jaeger et al., 2017). Drier conditions result in more evapotranspiration, heat waves, and glacial melt (Malinga et al., 2013; McBride et al., 2017). Changes in frequency, extent, and intensity of wildfires damage soil structure, release carbon, and contaminate water (Lamarque et al., 2013). Increases in standing water or changes in humidity lead to outbreaks of infectious and waterborne diseases (Roy et al., 2019). These changes affect species distributions and composition, with certain species adapting and others becoming extinct (Wyborn et al., 2015) or invasive (Jaeger et al., 2017). Climate change introduces additional challenges for tourism markets in both summer (e.g., biking, angling, and hiking) and winter (e.g., skiing), with increased variability in rainfall, declining snow depth, and shorter snow seasons (Mitchell et al., 2015). MtSES actors were concerned that mitigation measures do not fit the aspirations for local self-sufficient economies, with limited government preparedness for compounding risks (Sarkki et al., 2017).

3.3. Emergent clusters of desired and undesired futures

Focusing on 37 of the 42 studies that occurred in individual, rather than multiple, countries, our cluster analysis identified four groups according to the presence or absence of desirable and undesirable futures (Fig. 1; Appendix F).

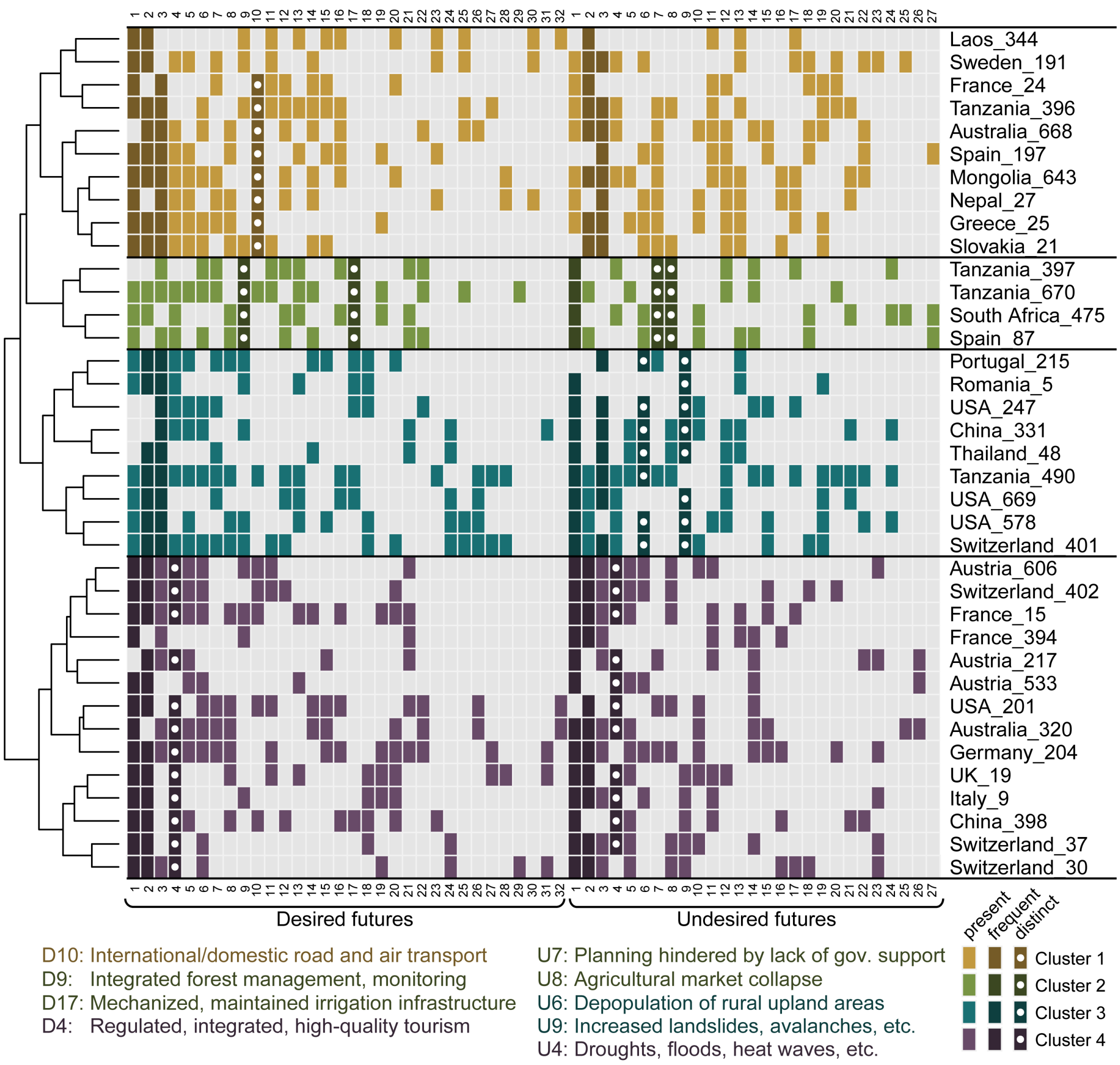

Fig. 1. Heat map showing four clusters of case studies based on the similarity of their desired and undesired futures. Studies are shown in rows and labelled with their country and study ID number. Desirable futures are numbered according to the descriptions in Appendix F. Futures are shown in columns and are coloured for each study in which they were listed. Darker colours indicate futures that were listed frequently within a cluster (>75% of studies). Futures that were listed frequently in one cluster but not frequently in any other are marked as "distinct" and described at the bottom of the figure. Desired and undesired futures are each sorted from most to least frequently mentioned across all studies when reading from left to right across the figure and labelled by number across the bottom of the figure.

Fisher's exact tests and Kruskal-Wallis rank sum tests indicated that there were significant ($p<0.05$) and marginally significant ($0.05<p<0.10$) differences among clusters in terms of land use ($p=0.01$), GDP ($p=0.008$), Gini coefficient ($p=0.02$), tourism ($p=0.05$), and mean annual temperature (MAT, $p=0.09$) (Appendix G). However, subsequent Dunn tests revealed that only three variables showed significant pairwise differences between clusters: GDP per capita, Gini coefficient, and MAT (Fig. 2).

Fig. 2. Variables with significant or marginally significant differences among clusters ($p < 0.05$ for GDP per capita, $p < 0.10$ for Gini coefficient and mean annual temperature). Median values for each cluster are indicated by dots.

Studies within Cluster 1 were characterized by frequently reported (> 75%) desirable futures of adaptive biodiversity conservation (D1), economic resilience (D2), and cultural diversity and local and Indigenous knowledge (D3). Distinct from other clusters, studies in this cluster frequently reported (>75%) preferences for improved road and air transportation (D10). Studies in this cluster occurred in Europe (*n*=5), Asia (*n*=3), Africa (*n*=1), and Oceania (*n*=1), and were characterized by lower GDP per capita, on average, than cluster 4 (adj. $p = 0.02$) and less income inequality (i.e., low Gini) than clusters 2 and 3 (adj. p=0.06 and 0.07).

Studies within Cluster 2 frequently reported (>75%) two distinct desirable futures: integrated forest management (D9) and well-maintained irrigation infrastructure (D17). Studies frequently cited (>75%) the conversion, fragmentation, or degradation of productive lands (U1) as an undesirable future. Distinct from other clusters, studies in this cluster frequently reported (>75%) a lack of long term planning due to weak leadership (U7) and collapse of local agricultural markets due to free market competition (U8) as undesirable futures. Unlike other clusters, studies within this cluster were less likely (≤50%) to desire income diversification (D2), and none were concerned with high rates of cultural heritage loss (U3). Studies in this cluster occurred in Africa (*n*=3) and Europe (*n*=1) and were characterized by lower GDP per capita than those in cluster 4 (adj. p=0.04) and higher income inequality than those in cluster 1 (adj. p=0.06). Studies also tended to be in places with higher MAT, but only differed from cluster 4 in this regard (adj. p=0.07).

Studies within cluster 3 frequently reported (>75%) desired futures focused on income diversification and market access (D2) and the preservation of cultural diversity or local and Indigenous knowledge (D3). Studies also tended to report (55.6%) flood prevention (D18) and restoration of steep degraded lands (D24) as desirable futures, whereas other clusters were considerably less (0–29%) interested in these futures. Generally, studies in this cluster emphasized a greater number of undesirable futures (>75%) including the conversion, fragmentation, or degradation of productive lands (U1) and high rates of cultural heritage loss (U3). Distinct from other clusters, these studies were frequently concerned (>75%) about the depopulation of rural areas (U6) and increased landslides or avalanches (U9). Studies in cluster 3 occurred in North America (n=3), Europe (n=3), Asia (n=2) and Africa (n=1). GDP per capita in cluster 3 varied across a wider range and had higher income inequality than clusters 1 and 4 (adj. p=0.07).

Studies within Cluster 4 frequently reported (>75%) adaptive biodiversity conservation (D1) and income diversification and market access (D2) as desirable futures. Futures to avoid (>75%) included the conversion, fragmentation, or degradation of productive lands (U1) and high rates of biodiversity loss (U2). Distinct from other clusters, these studies frequently reported (>75%) regulated, high quality tourism (D4) as a desirable future, while climate induced natural hazards (U4) were a distinct undesirable future. Studies in this cluster were largely unconcerned (7%) with growing water demand or uncertainty around water quality and quantity (U12), compared to other clusters (≥50%), and fewer studies (57%) emphasized the preservation of cultural diversity or local and Indigenous knowledge (D3) compared to other clusters (≥70%). Finally, land abandonment due to loss of agricultural subsidies (U5) was a more common undesired future (71%) compared to other clusters (≤ 33%). These studies occurred in Europe (n=10), North America (n=1), and Oceania (n=1), and were characterized by significantly higher GDP per capita than clusters 1 and 2 (adj. p < 0.05) and cooler temperatures than studies in cluster 2 (adj. p=0.07). Studies in this cluster also displayed somewhat lower income inequality compared to cluster 3 (adj. p=0.07).

3.3. MtSES archetypes

In this section, we present four proposed MtSES scenario archetypal configurations (Fig. 3) based on the clusters described above, which incorporate key risks to be managed, adaptation responses, assumptions, and uncertainties.

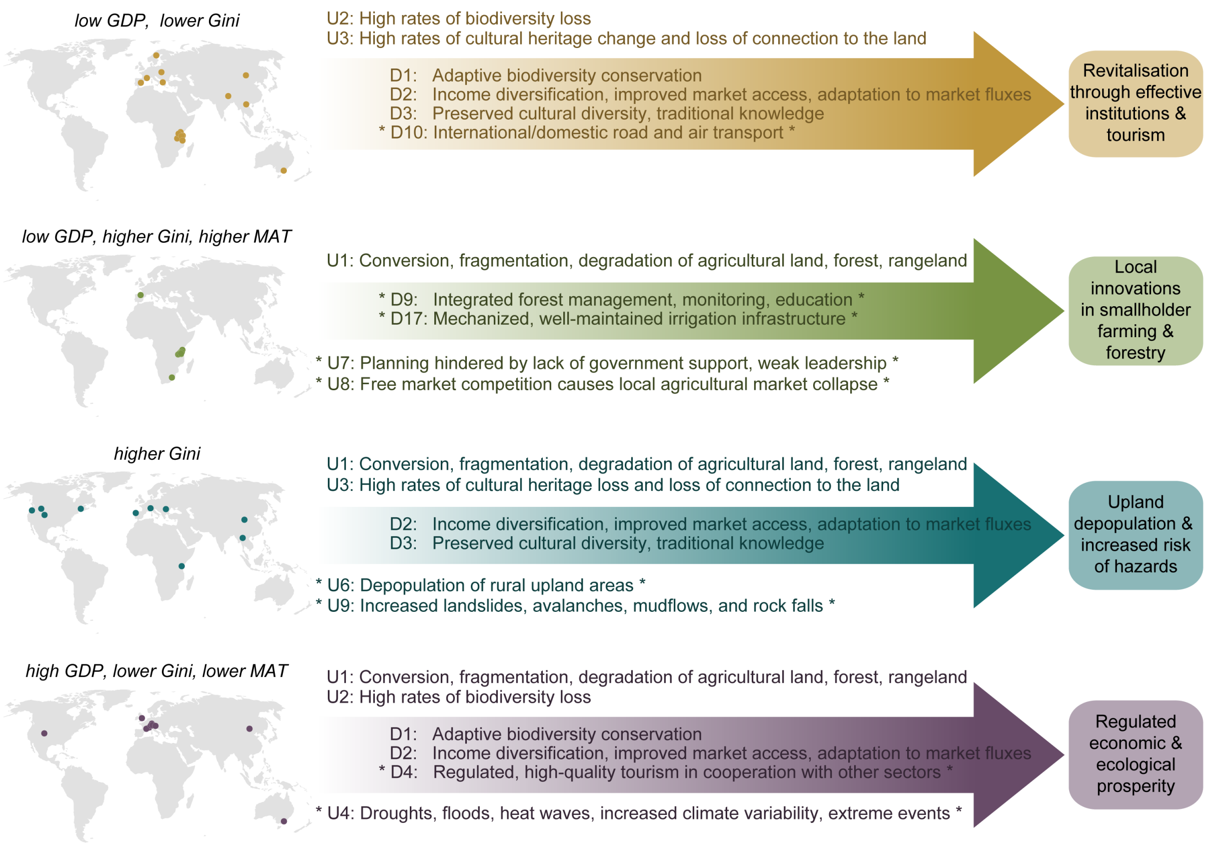

Fig. 3. Desired futures (inside arrows) and undesired futures (outside arrows) within each cluster where D= desired future and U=undesired future. Distinct futures for a particular cluster are denoted with

asterisks. Coloured points on the maps indicate where studies were located (Thorn et al., 2020). Social-ecological factors associated with each cluster are represented by text above the maps. “Low” and “high” denote explanatory variables with significant differences across clusters, while “lower” and “higher” indicate marginally significant differences.

3.3.1. Archetype 1: Revitalization through effective institutions and tourism

This scenario archetype shows an orientation towards environmental conservation and cultural regeneration, facilitated through effective and credible institutions that persist across all levels. To mitigate key risks of cultural assimilation and biodiversity loss, education systems are restructured to recognize Indigenous culture and the value of protected areas in MtSES. Town centres market and host local cultural events. Adaptive biodiversity conservation is prioritized and supports income diversification, particularly through ecotourism that supports small businesses. International and domestic transportation upgrades allow people and goods to move more easily between lowlands and uplands, generating new employment opportunities, and the ability to live and work in different places. Concurrently, there is the risk that better education leads to outmigration and thus a reduced labour force and brain drain of talented individuals. There is also a risk that investors are external, so benefits are not accrued by local communities. Yet commitments in revitalizing MtSES and investing in local development actively reduce these risks.

This archetype envisions a transformative MtSES future that transcends current paradigms and embraces new values in pursuit of a more equitable, sustainable future. Ultimately, large scale, systemic adaptation occurs through land reform that protects marginalized groups. Cross scalar institutions, international agreements and public private partnerships promote effective national and regional cooperation to prevent environmental damage and social inequality. In the long term, participatory engagement in decision making with underrepresented MtSES stakeholders and communities is embedded in policy making and implementation, together with supportive political will and program longevity, thereby increasing overall prosperity, and future oriented management of commons. Arising cooperation strengthens social safety nets and adaptive capacity to respond to frequent natural disasters.

Key assumptions in this archetype are that education and information lead to behaviour change, cultural heritage maintenance slows outmigration, and effective and credible institutions persist across all levels. Key uncertainties relate to the extent and impact of climatic variability and change, particularly wildfires and changing precipitation regimes.

3.3.2. Archetype 2: Local innovations in smallholder farming and forestry

This scenario archetype shows an orientation towards small scale farming and forestry. Key risks emerge from rising temperatures, poverty, and various forms of inequality. Local producers in MtSES will likely experience frequent market fluxes and associated vulnerabilities.

To overcome these risks, adaptation largely occurs at the local level, achieved by knowledge sharing (e.g., peer to peer and information communication technology), loans and pooling assets so that climate smart technology is more equally distributed and context appropriate. Smallholder production intensifies (e.g., from gradual improvements to on farm surface irrigation technologies). Off farm income and remittances increasingly contribute to farmers' resilience, particularly against climate shocks. Meanwhile, foresters diversify livelihoods from timber or charcoal harvesting to tourism. This reduces risks of natural resource depletion, and contamination from watershed sedimentation due to deforestation in MtSES.

Yet, sustainable agriculture and forestry at the individual and household level are insufficient to build long term resilience. Transformative adaptation arises when extra local institutions (*sensu* Thorn et al., 2015) foster a supportive, enabling environment working in partnership with local communities. Heterogenous mosaics of open space, combined with integrated, agroecological management of land, water, and wildlife, contribute to overall landscape resilience. Interactions between people and nature are radically restructured. For example, hydropower companies make payments to downstream water users for practicing retention forestry, paying attention to equitable distribution of compensation. Strict forest regulations are enforced, and those responsible for encroaching into or harvesting illegally from protected areas are arrested. Smallholder farmer cooperatives play a much stronger role in decision making processes, incorporating a mixture of tradition and innovation, and accessing private and public finance for sustainable resource management. Systemwide change is supported by improving efficiency and reducing inequalities (e.g., water use) between smallholder and commercial farmers.

Key assumptions are that technological and infrastructural development improves agricultural, forest and agro-pastoral livelihoods, and that government control is effective, with regulations enforced. Key uncertainties relate to how successful markets perform, and how local leadership impacts sustainability.

3.3.3. Archetype 3: Upland depopulation and increased risk of hazards

This scenario archetype represents a high risk situation in which MtSES experience the complex interaction of undesirable futures and both maladaptation (i.e., actions that are more harmful than helpful) and adaptation. Ultimately, this worst case scenario archetype leads to the depopulation of the uplands (mountains). Key risks are realized from growing inequality, dependence on ambiguous property rights, eventual collapse of local agricultural MtSES markets, declining food sovereignty, and increased hazards such as landslides, avalanches, mudflows and rockfalls, which damage infrastructure and create direct and indirect financial losses. Political conflict erupts with increasing elite capture of scarce resources, as does land use conflict, particularly associated with inevitable trade-offs that occur between conservation and food security (e.g., converting arable land into forests) and energy production (e.g., biofuels). Water scarcity, erosion, and unpredictable growing seasons, amongst other global environmental (change) stresses and shocks, lead to widespread crop and livestock loss. Producers cannot recover and move away from agricultural and transhumant lifestyles. As young people adopt a more modern life, cultural and historical heritage is lost, as is elderly people's authority. As countries industrialize and transition away from agriculture, demand for food increases. Consequent regional grain shortages are met by imports from other regions, depending on access to railways and roads.

Some of these risks are managed by localized adaptation, although with limited success. For example, transhumance communities recognize the need to shift livestock seasonally to new areas where forage is available, due to changing climatic conditions. Communal agreements manage ecosystem goods and services in the public interest, with benefits locally accrued. Specialized markets create new opportunities for viable livelihoods and profitable firms in MtSES, such as direct livestock sales and service sector development, including call centres. Transformation arises when MtSES communities reclaim and revegetate marginal agricultural land retired from use on steep slopes or heavily degraded land for forests and moorlands found in upland temperate grasslands. Reduced population pressure and shifts in consumer behaviours and lifestyle patterns reverse patterns of landscape degradation from unsustainable production to light impact recreational and wilderness areas. New markets arise around farm products (e.g., local slow food markets and alternative agri food networks) that encourage people to remain (or resettle) in rural areas. In the long term, transboundary cooperation and negotiations reduce conflicts. Nevertheless, without innovation and revitalization, MtSES are among the most vulnerable across all archetypes.

Key assumptions are that the wider economic framework remains broadly as it is at present - with benefits accrued by a few, and widespread environmental damage as an externality. Another key assumption is that increased education or livelihood abandonment leads to deepened income disparities. Key uncertainties include the extent and intensity of climatic variability and change, and the impacts that technological and communication innovation could have.

3.4.4. Archetype 4: Regulated economic and ecological prosperity

This archetype shows an orientation towards markets that continue to drive stable growth in GDP, accompanied by MtSES leadership advocating for a greener, cleaner future. Key risks arise from climate variability and change, and growing populations in uplands.

For MtSES to benefit from the potential of markets, a key component of adaptation in this archetype is strict spatial planning and rationing of land, which reforms the relation between sustainable land management, agricultural production, and urban expansion. Government plays a stronger role in clarifying ambiguous property rights and monitoring and enforcing protected area boundaries. With warming temperatures, farmers diversify the elevation in which crops are grown, produce new mixes of livestock and crops to sell, and expand their roles to not only be food producers, but also biodiversity managers. With rising prosperity in MtSES, in-migration is driven by interest in secondary residences, homes for the elderly, holiday apartments, real estate developments, and climate migration. Local actors experiment and respond flexibly to market fluctuations.

Transformation occurs with cross scalar spatial planning. For example, authorities utilize technical measures, hazard maps, restriction zones, and historic information to reduce disaster risk in areas of urban expansion. MtSES landscapes are restructured as climate change leads to new land uses (e.g., glacial retreat opens previously unused areas). Policy reforms incentivize long term emission reductions (e.g., by utilizing diverse, local sources of clean energy) and agricultural land use with conservation targets and regenerative practices. New legislation advances basin-wide water rights and use and establishes regional water conservancies and community wildlife protection plans. Businesses adopt circular economy models aimed at eliminating waste and decoupling growth from the consumption of finite resources.

Key assumptions are that markets have the potential, if well managed, to improve ecological prosperity. Key uncertainties lie in how rapid temperature increases, extreme rainfall or snowfall lead to more mass wasting in MtSES (e.g., due to permafrost thaw, floods and avalanches), how bioclimatic shifts will lead to land cover change, and how alternative land uses will compete with food production.

4. Discussion

While there has been increased application of global and regional archetype analysis in recent years (Sietz et al., 2019), analyses at local scales - and with local stakeholder input - are lacking (Oberlack, et al., 2019). We used scenario archetypes to compare how local stakeholders envision desired and undesired futures in mountains, strategies to move towards them, and risks to avoid along the way. Such archetypes enabled us to characterize processes that operate under identifiable conditions across MtSES contexts. This constitutes a forward looking, flexible, inclusive approach that can be used to inform global debates and local-to-regional implementation of strategies (Hunt et al. 2012; Van Vuuren et al. 2012; Vervoort et al., 2016; Rosa et al., 2017; UNEP, 2019). Here, we discuss the validity and limitations of the MtSES archetypes, how they compare to global archetypes, and some avenues to practically translate MtSES archetypes into outcomes and impacts. We conclude by discussing the unique challenges and opportunities for future MtSES sustainability.

4.1. Validity of the MtSES archetypes

The design and quality of archetypes can be considered in terms of their internal and external validity (*sensu* Eisenbeck et al., 2019). Internal validity pertains to the evidence base; specifically, the quality of included studies in the systematic review (i.e., adherence to methodological standards used in scenario studies). The archetypes are internally valid for two key reasons. First, we devised five criteria to assess whether studies were of sufficient quality for inclusion, following Rodríguez et al., (2016) (i.e., methods and analysis thoroughly explained, sample size was representative, results and conclusions were logical and confounding factors were considered). Second, common attributes were subject to intercoder validity to ensure consistency with Randolph's free-marginal Kappa coefficient of 0.72 - indicating that there was sufficient agreement among reviewers (Thorn et al., 2020).

External validity depends on the extent to which we can generalize and extrapolate our findings across the suite of archetypes to other MtSES not included in the review (Sietz et al. 2011, 2017; Kok et al., 2016). Qualitatively, the recurrent desirable and undesirable futures informing these archetypes indicate strong potential for generalizability and transferability beyond the 42 study cases (although the MtSES archetypes do not need to apply to all cases to be valid). MtSES archetypes also have good geographic coverage (Fig. 3). All archetypes span multiple continents (i.e., archetype one spans three continents, archetype two spans two continents, archetype three spans three continents and archetype four spans four continents) and therefore, biophysical, socioeconomic, and political contexts, which suggests generalizability. Nevertheless, more research is needed to explore whether aspects of these archetypes are idiosyncratic to these 42 studies. To this end,developers of new scenarios could map their results to the four MtSES archetypes, and if not congruent, propose additional types. This could also make it easier for users to integrate information from different assessments (van Vuuren et al., 2012). A useful example is how the shared socioeconomic pathways have been linked with the Special Report on Emission Scenarios, Millennium Ecosystem Assessment, and IPBES scenarios (Akçakaya and Pereira, 2016; Harrison et al., 2019). Furthermore, archetypes could be refined by building sub archetypes and by exploring interregional, historical, or cultural differences (Oberlack et al., 2016).

4.2. Limitations of MtSES scenarios and archetype paradigms

There are limitations for any type of classification, and identifying common patterns is highly challenging, given the complicated local contexts in which MtSES scenarios are developed. Despite employing a pluralist approach, inviting actors from multiple sectors, disciplines, and geographical scales to participate in the scenario development processes (Vervoort et al., 2015), underlying biases and fundamental differences in epistemologies and worldviews could have influenced the assumptions implicitly made about how futures evolve and what is a “good” endpoint in the scenarios that informed the archetypes. The nature of PSP requires a small group of stakeholders unavoidably making decisions to select the most interesting scenarios (which represent a fraction of the potential ecosystem of possible scenarios). These choices may not necessarily reflect the diverse views of audiences commonly found in public policy debates, who may see the chosen scenarios as arbitrary or biased towards some particular policy outcome (Groves and Lempert, et al., 2007). For instance, scenarios may reflect the visions of more environmentally minded stakeholders that tend to participate in many PSP studies, while non environmentally minded viewpoints may have been underrepresented (Oteros-Rozas et al., 2015). The lack of MtSES PSP application in developing countries and a bias towards European MtSES may have resulted in lack of representation of non-European and Global South views, values, and contexts (Thorn et al., 2020). It is also possible that subnational statistics are unable to capture locally significant differences, for example, across elevational gradients or distributional access (e.g., tourism revenue).

To address these limitations, more empirical research is needed that broadens the stakeholder expertise involved, including specialists or practitioners in gender, health, atmospheric science, anthropology, water, sanitation, and hygiene. Future work may strive not only for greater expertise, but also for a wider range of worldviews and MtSES contexts. This can help shed light upon problems which have been overlooked in MtSES futures work, overcome existing geographic gaps in our understanding, and enhance likely utilization and translation. As archetypes are created, they should be shared, tested for relevance and validity, evaluated, and adapted in a continuous iterative development model.

4.3. How do MtSES scenario archetypes compare to global scenario archetypes?

The four MtSES archetypes that emerged offer some well-suited matches to global challenges and six change themes in the global archetypes’ literature (Wardropper et al., 2016). We chose the Global Scenario Group (GSG) archetypes as an international benchmark because it is one of the most widely applied archetypes, and its long history has created a legacy for other scenarios produced in the last decade (Hunt et al., 2012). For example, MtSES archetype 1 (revitalization through effective institutions and tourism) supports the theme of collaborative decision making and local governance, as also shown in the GSG's world end-state of *Great transitions*. This end-state is underpinned by a scenario variant of a *New sustainability paradigm*, where social values-led change catalyses new development approaches. Archetype 1 also relates to *Conventional - Policy reform* because sustainability in MtSES is driven by policy rooted in human solidarity and universal access to services. However, more attention is paid to cultural diversity and preservation in the MtSES archetype than in the GSG. Archetype 2 (local innovations in smallholder farming and forestry) supports the GSG world end-state of *Great transitions* and the scenario variant *Eco-communalism*, because local stewardship, co management, common property institutions such as cooperatives, and intensive production dominate. Archetype 3 (upland depopulation and increased risk of hazards) resonates with *Barbarization - Fortress world,* where in response to the threat of breakdown, elites control critical natural resources. Inequality and conflict prevail, brought about by environmental, climate and socioeconomic stress. Archetype 4 (regulated economic and ecological prosperity) supports the GSG scenario of *Conventional - Market forces,* because competitive markets are used to address global challenges. However, this MtSES archetype differs to that of the GSG in that governments employ economic regulation to avoid profound inequality and enhance environmental sustainability. On the other hand, no MtSES archetypes resemble *Barbarization - Breakdown*. The closest match is archetype 3, with its undesired futures of deagrarianization, outmigration, and depopulation. However, income diversification in MtSES could help to prevent a total collapse. Clearly, the scenario archetypes presented in this study are comparable to global archetypes and may have relevance to global transitions and adaptation challenges beyond MtSES.

An important, innovative aspect of this approach, different from global archetypes, is that the presented archetypes are mainly "archetypes of futures". This means a subtle shift in focus, away from addressing similarities of assumptions or setting conditions (e.g., the potential of markets to improve ecological health, or the impact of education on inequality), towards considering similarities of the desired or undesired end-points. This better responds to the needs of agendas on "where should we head or not" (UN General Assembly, 2015). Moreover, the heterogeneity among MtSES (as for other SES) means that a bottom-up approach, that seeks to find commonalities among diverse sites, may lead to more relevant insights at the global scale than top-down, international efforts (Bennett et al., 2016).

4.4. Archetypes present unique challenges and opportunities for MtSES sustainability

The suggested archetypes indicate at least three unique challenges and opportunities for the future of MtSES sustainability. First, in the future, multiple forms of inequality are likely to increase in MtSES, not only income inequality due to wealth accumulation, but also related to technology infiltration, changes to education, insertion of new social groups into labour markets, and transitions into new sectors, among other factors (Bayfield et al., 2008). Cultural heritage and local knowledge are often the fabric of social cohesion within MtSES communities, and there are many diverse groups that exhibit these dynamics in their own ways (Bizikova et al., 2012). Archetypes indicate that in the future, participatory representation (archetype 1), benefit sharing mechanisms (archetype 2), and strengthened institutions and property rights (archetype 4) will likely play important roles in the evolution of equity (Fisher et al., 2006; Reed et al., 2013; Tzanopoulos et al., 2011). Greater equality not only reduces conflicts and strengthens social safety nets that provide stability in the face of natural disasters (Allington et al., 2018). Reduced inequalities also increase the potential for leapfrog growth imperatives and thus decarbonization, carbon neutrality, clean and resource efficient technologies (Roy et al., 2019), and environmental safeguards (Capitani et al., 2016).

Second, ecosystem services research in MtSES appears to be increasing and becoming more policy relevant. Yet, less research has focused on institutional responses, such as payment for ecosystem service schemes, protected area, or community-based management (Martin-Lopez et al., 2019). Meanwhile, nature-based solutions have recently gained popularity as an integrated approach that could address the twin crises of climate change and biodiversity loss (Cohen-Shacham et al., 2016; Seddon et al., 2021). Although more research is needed, a growing body of evidence also shows nature-based solutions support a wide range of sustainable development goals (Gómez Martín et al., 2020; Maes et al., 2019) and if well designed can deliver multiple benefits (Seddon et al., 2020). Our research shows that communities themselves desire nature- and community-based approaches that enhance climate resilience, with co-benefits of poverty alleviation and slowing trends of urbanization by making rural livelihoods viable, particularly through tourism (archetype 1) and recreation (3), income generation for environmental protection, and sustainable product chains and product quality control for farmers and foresters (2), pastoralists (3) and agricultural subsidies (4) (Loibl and Walz, 2010; McBride et al., 2017). For example, in the United States, stakeholders envision improving landscape management - connecting ecologically sensitive forests to mitigate disasters, combined with value shifts on the part of residents to support conservation (McBride et al., 2017). In Slovakia, stakeholders envision developing educational courses for multiethnic MtSES communities focusing on nature protection and community cultural events (Bizikova et al., 2012). In MtSES of Greece and the United States, stakeholders envision nature-based solutions channelled through land use, water management or nature conservation planning, and avoiding development along riparian zones and outside of designated "regrowth zones" (Tzanapoulous et al., 201; McBride et al., 2017). By contrast, stakeholders in the United Kingdom envision taking greater advantage of the amenity value of upland national parks, sequestering and storing carbon through peatland restoration or revegetating bare or eroding peat – while countering the loss of habitats and species elsewhere in the landscape (Reed et al., 2013). On the other hand, nature-based solutions can lead to undesirable outcomes or trade-offs among the benefits ecosystem services provide to some people. For instance, scenarios of tourism that aim to reduce grazing intensity in pastoral landscapes in Spain explored trade-offs between provisioning services (i.e., food and fibre from livestock and agriculture); regulating services (i.e., fire prevention, connectivity, seed dispersal, maintenance of soil fertility); and cultural services (i.e., aesthetic value, recreational hunting) (Oteros-Rozas et al., 2013). Carefully implemented nature-based solutions crafted at the local level in a participatory manner are not only critical in MtSES, but also for other remote communities that rely directly on their environment for ecosystem services (Oteros-Rozas et al., 2013).

Third, a warming world will significantly influence the future of MtSES, as climate change is one of the top undesired futures, in that it cuts across all MtSES archetypes. Mean annual temperature is expected to rise globally, along with droughts and reduced water availability, although at different rates (Reed et al., 2013; Jaeger et al., 2017). This will lead to impacts on biodiversity, growing water demand, resource overextraction, and changes in land use (Tappeiner et al 2008). Beyond any individual climate parameter, greater unpredictability will be a key future challenge for planning in MtSES. Unless appropriate policies and strategies are adopted and effectively implemented, this will put immense pressure and demand for services for and from MtSES, undermining adaptive capacity (Roy et al., 2019).

4.5. How can MtSES archetypes be practically translated into outcomes and impacts?

Despite the usefulness of MtSES archetypes, there remains a significant gap between current scenario practice and its potential contributions both in MtSES and more broadly (Briggs 2006; Parson et al., 2006; van Vuuren et al., 2012; Banson et al., 2016; Eisenbeck et al., 2019; Oberlack and Eisenbeck, 2018; Oberlack, et al. 2019). Considering that decision making is complex, often selective of information used, and is a political process, structures and incentive schemes could be created to encourage the use of scenario archetypes for building science-policy relationships. Approaches include dialogues of why the MtSES scenario archetypes would be valued, compared to other forms of evidence, or funding networking events of actors who use scenario archetypes (Steger et al., 2021). When applying these archetypes to specific MtSES contexts, it is important to engage relevant decision makers at the project conceptualization stage to frame research priorities (Young et al., 2014). Communication requires consideration of timing (Sitas et al., 2019), and specifying the target end users to determine what information and formats are appropriate (van Vuuren et al., 2012). To maintain efficacy, communication strategies need to be revisited periodically (Thorn et al., 2020).

5. Conclusion

Future MtSES sustainability requires distinguishing where a sustainable solution is context dependent for a particular scale or sector, or where it can be generalized to different MtSES areas (Rocha et al., 2020). Through a systematic review of MtSES scenarios globally, we identified 59 futures common across all studies (from 852 individual futures), resulting in 32 shared desirable futures and 27 shared undesirable futures in MtSES. Then we identified four MtSES archetypes by clustering desirable and undesirable futures and building on the narratives behind the clusters and the explanatory factors which explain these clusters. These archetypes enable end users to explore the possibilities of achieving their objectives through different adaptation responses, while sharpening awareness about anticipated challenges and uncertainties. Thus, the archetypes can guide the design of better decision support systems in the science-policy interface. Results can further be used to monitor progress, for example, towards the Sustainable Development Goals or the African Union Development Agenda, and ultimately, interventions for equitable, resilient, social-ecological futures for mountains and those beyond the mountains who rely on them.

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Supplementary material

Scenario archetypes reveal risks and opportunities for global mountain futures

Jessica P. R. Thorn, Julia A. Klein, Cara Steger, Kelly A. Hopping, Claudia Capitani, Catherine M. Tucker, Robin S. Reid, Robert A. Marchant

Appendix A. Eligible studies identified in search on the 25th of January 2021.

Blancas, A. N. I., La Toree-Cuados, M. A. and Carrera, G. A. M. (2018) Using foresight to gain a local perspective on the future of ecosystem services in a mountain protected area in Peru. Mountain Research and Development 28(3):192-202.

Burton, V., Metzger, M. J., Brown, C. and Moseley, D. (2019) Green gold to wildwoodlands; understanding stakeholder visions for woodland expansion in Scotland. Landscape Ecology 34:1693–1713.

Capitani, C., van Soesbergen, A., Mukama, K., Malugu, I., Mbilinyi, B., Chamuya, N., Kempen, B., Malimbwi, R., Mant, R., Munishi, P., Njana, M. A., Ortmann, A., Platts, P.J., Runsten, L., Sassen, M., Sayo, P., Shirima, D., Zahabu, E., Burgess, N.D. and Marchant, R. (2019) Scenarios of land use and land cover change and their multiple impacts on natural capital in Tanzania. Environmental Conservation 46:17–24.

Capitani, C., Garedew, W., Mitiku, A., Berecha, G., Hailu, B. T., Heiskanen, J., Hurskainen, P., Platts, P. J., Siljander, M., Pinard, F., Johansson, T. and Marchant, R. (2019) Views from two mountains: exploring climate change impacts on traditional farming communities of Eastern Africa highlands through participatory scenarios. Sustainability Science 14:191–203.

Huber, L., Rüdisser, J., Meisch, C., Stotten, R., Leitinger, G. and Tappeiner, U. (2021) Agent-based modelling of water balance in a social-ecological system: A multidisciplinary approach for mountain catchments. Science of the Total Environment 755:142962.

Schermer, M., Stotten, R., Strasser, U., Meißl, G., Marke, T., Förster, K. and Formayer, H. (2018) The role of transdisciplinary research for agricultural climate change adaptation strategies. Agronomy 8(237):1-18.

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Appendix B. Definitions of social and environmental explanatory variables used to characterize the futures clusters

Biome: Biomes included were grasslands, shrub lands, savanna; protected forests; unprotected forests; peri-urban or urban settlements; and tundra – which were defined according to the authors of the study. Biomes were based on the broadest biogeographic division of the Earth's land surface, based on distributional patterns of terrestrial organisms (Schultz, 1988). If biome was not reported in the study, biome was determined using the study coordinates.

Droughts, floods, and extreme temperatures (mean percent of the population affected annually, 1990-2009): Annual average percentage of the population affected by natural disasters (i.e., drought, flood, extreme temperature). Population affected includes the number of people injured, left homeless, evacuated, displaced, or requiring immediate assistance during a period of emergency (Vos et al., 2010). Data were extracted at the national level.

Elevation: The minimum and maximum elevations of each study area (meters above sea level) were used as defined by the study when these details were given, or else located for the mountain range included in the study.

Gini coefficient: The Gini coefficient measures the extent to which the distribution of income among individuals or households within an economy deviates from a perfectly equal distribution. A Gini coefficient of 0 represents perfect equality, while a coefficient of 100 indicates perfect inequality. It measures relative, rather than absolute wealth at a national level (World Bank, 2015).

Gross domestic product (GDP) per capita (USD): Average GDP per capita by subnational administrative unit (e.g., state, province, prefecture, converted to 5-arc-min resolution) (Kummu et al., 2018). Values are calculated for 2010 and given in 2011 international U. S. dollars. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources (World Bank, 2016; OECD, 2016).

International inbound tourists (overnight visitors) nationally per annum: Number of tourists who travel to a country in which they do not have their usual residence, for a period not exceeding 12 months and whose main purpose is visiting, and not remuneration (World Tourism Organization, 2016). Data were extracted at the national level.

Human Footprint index: An indicator of the amount of human influence on an area, estimated as a measure of human population pressure (density), land use, infrastructure, and human access (via coastlines, roads, railroads, and navigable rivers), and normalized by biome (WCS and CIESIN, 2005). Data are available as an estimate for 1995-2004 at 30 arc-second resolution.

Land use: Land use categories are those used by the Mountain Sentinels Collaborative Network, i.e., tourism/recreation; agro pastoral; timber/logging; pastoral; crops and non-timber forest products (Klein et al., 2019*a*).

Mean annual precipitation (mm): 30 arc-seconds (~1 km^2) for 1970-2000 (Fick and Hijmans, 2017). Data were extracted at the site level.

Mean annual temperature (°C): 30 arc-seconds (~1 km^2) for 1970-2000 (Fick and Hijmans, 2017). Data were extracted at the site level.

Net migration: The estimated net total of number of migrants between 1990-2000 at 0.5-degree resolution during five-year estimates (2008-2013) (de Sherbinin et al., 2012). Migrants are the total number of annual immigrants less emigrants, including both citizens and noncitizens (UNDESA, 2013).

Data were extracted at the site national level. These estimated site-level values may not be reliable for local level analyses (de Sherbinin et al., 2012), but we found that we obtained qualitatively similar patterns for national-level migration data (UNDESA, 2013) and thus proceeded with the site-specific data.

Standardized Precipitation-Evapotranspiration Index (SPEI) Global Drought Monitor: An index of drought conditions with 0.5-degree spatial resolution (Vicente-Serrano, 2010). The index is calculated by subtracting the potential evapotranspiration from precipitation, using precipitation and temperature data as inputs. This value each is then standardized relative to the long-term mean for each 0.5-degree pixel to give an indication of site-specific drought conditions. At the location of each study, the mean annual SPEI from 1990-2018 was calculated with data from SPEI base v2.6, using the 12-month periods ending in December each year. Considering this time frame, we are not inferring causality between this index and explanatory variables, but rather a general site characterization.

Appendix C. Study ID numbers, clusters, and regions.
Clusters are indicated by the number used to depict them in Fig. 1-3.

ID	Citation	Cluster	Country	Specific region
668	Mitchell et al., 2015	1	Australia	Australian Alps
24	Griffon et al., 2011	1	France	Pic Saint-Loup Region, Department of Hérault
25	Tzanopoulos et al., 2011	1	Greece	Vikos–Aoös National Park and periphery, Zagori Region
344	Bourgoin and Castella, 2011	1	Laos	Nam Et–Phou Loey National Biodiversity Conservation Area, Viengkham
643	Allington et al., 2018	1	Mongolia	Sükhbaatar Province (aimag)
27	Daconto and Sherpa, 2010	1	Nepal	Sagarmatha National Park and Buffer Zone
21	Bizikova et al., 2012	1	Slovakia	Eastern end of Slovenský Raj National Park
197	Oteros-Rozas et al., 2013	1	Spain	Conquense Drove Road, Castilla La Mancha
191	Carlsson et al., 2015	1	Sweden	Vilhelmina municipality
396	Capitani et al., 2016	1	Tanzania	Arusha
475	Malinga et al., 2013	2	South Africa	Upper Thukela
87	Palacios-Agundez et al., 2015	2	Spain	Biscay
397	UNDSM IRA et al., 2016	2	Tanzania	Iringa
670	Fischer et al., 2011	2	Tanzania	Sigi Basin and Usambara Mountains
331	Zhen et al., 2014	3	China	Guyuan District, Ningxia Hui Autonomous Region
215	Carvalho-Ribeiro et al., 2010	3	Portugal	Peneda-Gerês National Park
5	Bogdan et al., 2016	3	Romania	Râul Târgului Catchment, Arges
401	Brand et al., 2013	3	Switzerland	Visp-Saastal Region
490	Enfors et al., 2008	3	Tanzania	Makanya Catchment, South Pare Mountains, Kilimanjaro
48	Barnaud et al., 2007	3	Thailand	Mae Salaep village, Chiang Rai Province
247	Murphy et al., 2016	3	USA	Grand County, Colorado
578	McBride et al., 2017	3	USA	New England/Acadian forests
669	Jaeger et al., 2017	3	USA	Willamette river basin, Oregon
320	Mitchell et al., 2015	4	Australia	Australian Alps
606	Loibl and Walz, 2010	4	Austria	Montafon region
533	Tappeiner et al., 2008	4	Austria	Stubai valley (Stubaital)
217	Kohler et al., 2017	4	Austria	Stubai valley (Stubaital)
398	Allington et al., 2018	4	China	Xilingol League
394	Simon and Etienne, 2010	4	France	Larzac (Causse du Larzac)
15	Lamarque et al., 2013	4	France	Écrins National Park, Villar d'Arène
204	Plieninger et al., 2013	4	Germany	Swabian Alb Biosphere Reserve
9	Malek and Boerboom, 2015	4	Italy	Friuli Venezia Giulia
402	Walz et al., 2014	4	Switzerland	Alps
37	Walz et al., 2007	4	Switzerland	Davos
30	Soliva and Hunziker, 2009	4	Switzerland	Surses Valley
19	Reed et al., 2013	4	UK	Peak District National Park
201	Wyborn et al., 2015	4	USA	Grand County, Colorado

Appendix D. Examples of names given to scenarios

Australia: “R.I.P. – Take the (retirement) package now”, “Multi use park”, “We care, but is it too late?”, “Alpine dreaming” (Mitchell et al., 2015)

European mountain landscapes: “Status quo”, “Reduce area-based support”, “Rural diversification” (Bayfield et al., 2008)

European treeline areas: “Global markets”, “Self-sufficient economies”, “Tyranny of climate governance”, “Sustainable use of ecosystem services” (Sarkki et al., 2017)

Germany: “Less is more”, “AlbGAU” (GAU = German abbreviation for “worst-case scenario”), “Spirit of invention”, “Energy silo” (Plieninger et al., 2013)

Hindu Kush Himalaya: “Downhill”, “Muddling through”, “Prosperity” (Roy et al., 2019)

Mainland South Asia: “Ruralization”, “Food bowl”, “Glocalization”, “Services park” (Lebel, 2006)

Mongolia: “Grassland paradise”, “Grassland pendulum”, “Desertification”, “Proactive adaptation” (Allington et al., 2018)

South Africa: “Equal environment”, “Diverging climate”, “Adaptive collaboration” (Malinga et al., 2013)

Spain: “Oppressed Biscay”, “Global delicatessen”, “Techno Faith”, “Cultivating social values” (Palacios-Agundez et al., 2015)

Switzerland: “Business as Usual”, “Agricultural Liberalization”, “Managed Change for Biodiversity” (Soliva and Hunziker, 2009)

Switzerland: “Growth and convergence, “Regional centers, “Green growth”, “Local sustainability” (Walz et al., 2014)

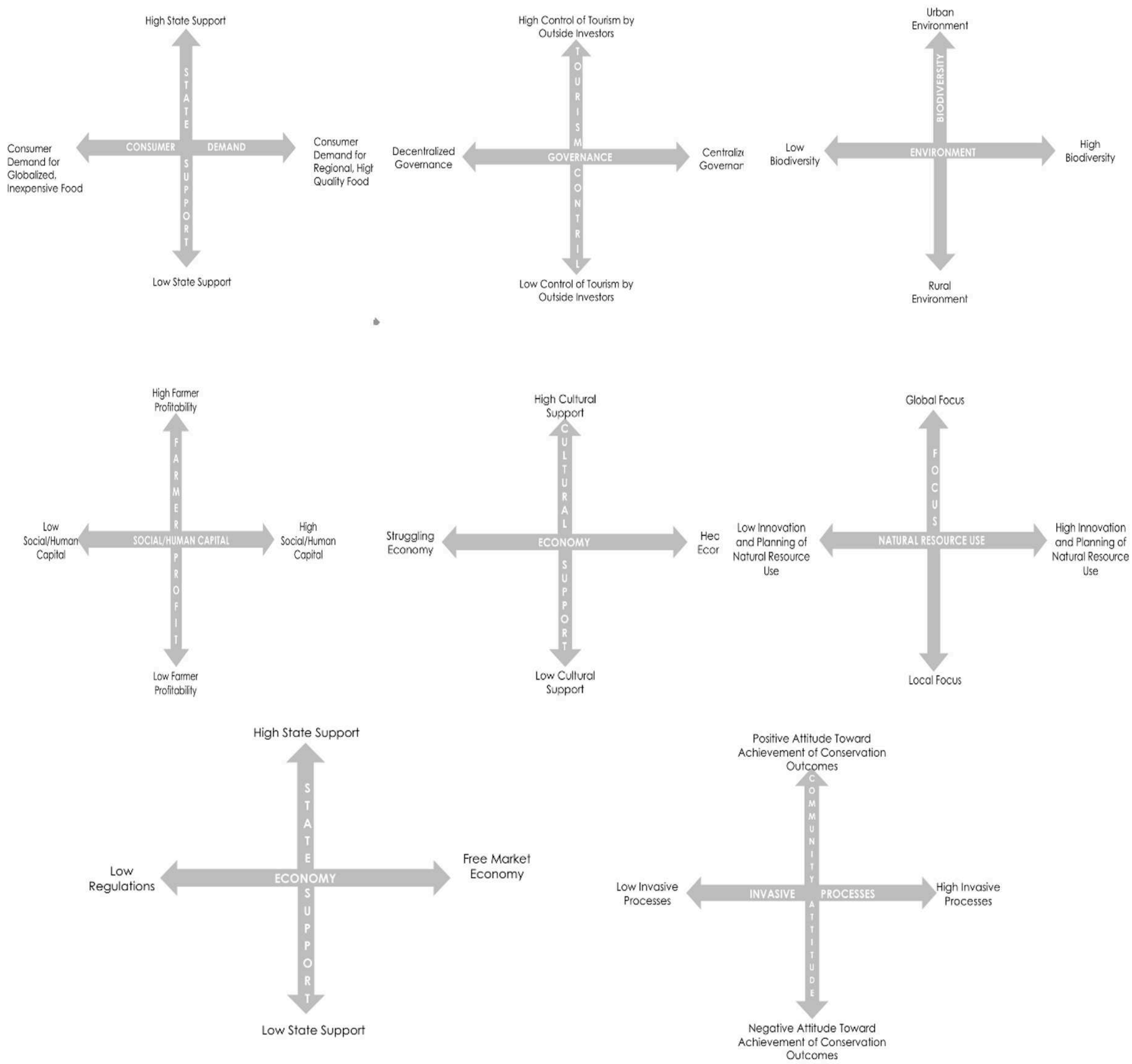
Tanzania: “Agricultural advance”, “Managing on the margins”, “Community cohesion”, “Industry imperial” (Enfors et al., 2008)

Tanzania: “Hopeful expectations”, “Business as Usual” (Fischer et al., 2011)

USA: “Community connectedness”, “Yankee cosmopolitan”, “Go it alone”, “Growing global” (Mitchell et al., 2015)

USA: “Some like it hot”, “The seasons are a changing”, “Feast or famine” (Murphy et al., 2016)

Appendix E. Examples of MtSES scenario axes provided by stakeholders. Multiple methods represented business-as-usual to ideal future scenarios, such as narratives (*n*=29, 69%) and arranging the content against four extremes of uncertainties (i.e., using morpho-matrices: 2x2 boxes of axes and endpoints) (30.9%, *n*=13). Thirteen studies (38.1%) used four diverse futures, 13 studies (30.1%) used three diverse futures, and 15 studies (35.7%) used two.



Appendix F. Desirable and undesirable futures ranked by frequency across studies and clusters. The rank of each future is determined based on the number of studies that included the future in a scenario. The percent of overall studies that included this future is given, as well as the percent of studies in each cluster. The prefix "D" indicates desirable futures, "U" undesirable futures, and "C" for clusters of scenarios.

ID	**Rank**	**Desirable future**	**% of studies**	**% C1**	**% C2**	**% C3**	**% C4**
D1	1	Adaptive biodiversity conservation, with public and private, national and international support	83.3	90	75	67	93
D2	2	Income diversification, improved market access, and adaptation to market fluxes	78.6	80	50	78	86
D3	3	Cultural diversity and local indigenous knowledge	76.2	80	75	100	57
D4	4	Regulated, high-quality tourism in cooperation with other sectors	73.8	70	75	67	86
D5	5	Rural re-population through policy, legislation, and market reform	61.9	60	25	67	57
D6	6	Efficient technologies for agricultural intensification	57.1	50	75	44	64
D7	7	Regional cooperation for multifunctional catchment management	45.2	50	50	67	21
D8	7	Education promotes market specialization and participation in decision-making	45.2	50	50	44	43
D9	8	Integrated forest management that promotes community education and monitoring and halts illegal harvesting	42.9	40	100	56	29
D10	9	International/domestic road and air transportation	40.5	80	25	11	36
D11	10	Renewable energy sources and sustainable building design	38.1	50	50	11	36
D12	10	Proactive climate change mitigation/adaptation policy development	38.1	50	75	33	14
D13	10	Payments for ecosystem services including carbon, water, soil, and biodiversity	38.1	30	75	44	21
D14	11	Public interest protected by private/communal and institutional/customary land use agreements	35.7	70	50	22	21
D15	12	Scientists, policy makers, and communities collaboratively adapt agendas via deliberation	33.3	50	0	22	29
D16	13	Rangelands well managed according to the lands' carrying	31	50	50	22	29

		capacity and livestock fodder needs					
D17	14	Mechanized, well-maintained irrigation infrastructure	28.6	0	100	56	7
D18	14	Flood prevention via restriction zones, habitat restoration, or connectivity and infrastructure	28.6	0	0	56	29
D19	14	Agricultural policy reform tied to stricter agro environmental regulations	28.6	20	50	0	36
D20	14	Spatial planning managed by both formal and informal organizations	28.6	30	0	22	50
D21	15	Soil nutrient management and erosion control for higher, less variable yields	26.2	0	75	22	43
D22	16	Invasive species management	21.4	10	75	11	21
D23	17	Increased social harmony and acceptance of ethnic minorities	19.1	40	0	11	7
D24	17	Steep or degraded land restoration and rehabilitation to prevent natural hazards	19.1	0	0	56	14
D25	18	Clarified, secured, and strengthened property regimes including land tenure, resource rights, and intellectual property rights	16.7	40	25	22	0
D26	18	Fire management and protection	16.7	10	0	44	14
D27	19	Agro ecological, precision agriculture and preservation of indigenous varieties of crops	14.3	10	0	22	14
D28	19	Investments in public and private primary healthcare, elderly retirement, and day care	14.3	20	0	22	7
D29	20	Increased gender equity via female engagement in labour markets and consultative decision-making processes	11.9	0	25	0	7
D30	21	Decentralized, polycentric, and multi-layered governance	9.5	30	0	0	0
D31	21	Consumer patterns demand high-quality food and self-sufficiency	9.5	0	0	11	21
D32	22	Long-term funding and policy cycles	7.1	10	0	0	14

ID	Rank	Undesirable future	% of studies	% C1	% C2	% C3	% C4
U1	1	Conversion, fragmentation, degradation of productive lands (agricultural land, forests, and rangelands)	81.0	70	100	89	93
U2	2	High rates of biodiversity and habitat loss	64.3	80	50	44	79
U3	2	Cultural erosion (High rates of cultural heritage change and loss connection to the land)	64.3	80	0	78	71
U4	3	Climate-induced hazards (Droughts, floods, heatwaves, increased climate variability, and extreme events)	57.1	40	50	44	79
U5	4	Reduced state agricultural subsidies lead to de-agrarianization and land abandonment	47.6	20	25	33	71
U6	4	Depopulation of rural upland areas	47.6	50	50	78	36
U7	5	Long-term planning hindered by lack of government support and weak leadership	45.2	70	100	22	21
U8	6	Free market competition causes local agricultural markets to collapse	42.9	20	100	33	50
U9	7	Increased landslides, avalanches, mudflows, and rock falls	38.1	0	0	89	36
U10	7	Underdeveloped or declining tourism sector	38.1	30	50	33	43
U11	7	Decline in forage availability for livestock grazing	38.1	60	0	11	50
U12	7	Growing water demand, uncertainty associated with water supply, and contamination related to energy and economy	38.1	70	50	56	7
U13	8	Increased insecurity in land tenure for marginalized communities	35.7	70	25	44	14
U14	9	Expansion of invasive species decreases the value of land	33.3	10	75	22	50
U15	10	Increased wildfire frequency, extent, and intensity	26.2	20	0	44	29
U16	11	Limited representation and cooperation of diverse stakeholders in decision making	23.8	30	0	0	29
U17	11	Alternative land uses compete with food production and local crop varieties	23.8	50	25	22	14

U18	11	Uneven distribution of technological, infrastructural, and communication change	23.8	40	50	11	14
U19	11	Deforestation due to failed integrated forest management	23.8	50	0	56	0
U20	12	Industrialization and mining cause chemical pollution of water, soil and air	21.4	30	25	11	14
U21	12	Deepened regional disparities in per capita income due to increased education or abandonment of agricultural livelihoods	21.4	30	25	33	7
U22	12	Discrepancies in power/resource access and external private investments lead to conflict	21.4	40	0	22	14
U23	13	High carbon energy production dominates, with centralization and government subsidization	19.1	10	0	0	43
U24	14	High infant mortality, poor respiratory health, malnutrition, and infectious diseases	14.3	0	50	33	0
U25	15	Lack of trans-boundary management and coordination of water supply and demand	11.9	10	25	0	7
U26	16	Glacial melt leads to changes in water availability, ecosystem structure and function, and tourism industry	9.5	0	0	0	21
U27	17	Timber industry declines as production becomes more capital and technology intensive	7.1	10	50	0	0

Appendix G. Summary statistics of factors for each cluster (mean ± standard error). Clusters are indicated by the colours used to depict them in Fig. 1-3. Chi-square and p-values for Kruskal-Wallis rank sum tests indicate differences among clusters (df = 3 for all tests). The Gini coefficient is a measure of the degree of inequality in the distribution of household income in a country, where if income were distributed with perfect equality the index would be zero, or 100 if distributed with perfect inequality. The Human Footprint index indicates the level of human impact at a local level on a scale from 1-100, from low to high impact. Net migration is estimated for the 5 arc-minute pixel in which the study site was located (de Sherbinin et al., 2012). The Standardized Precipitation Evapotranspiration Index (SPEI) is an index of drought conditions, where lower numbers indicate more drought. See definitions in Appendix B. Land cover is not reported here because categorical data were used, including tourism/logging, crops/non-timber forest products, pastoral, agro pastoral, and tourism/residential (Klein et al., 2019*a*).

No	**Site characteristics**	**1: Gold**	**2: Green**	**3: Blue**	**4: Purple**	χ^2	**p**
1	**Site GDP** per capita (USD)	19,811± (4,622)	14,783± (10,247)	28,406± (6,391)	40,789± (2,768)	11.85	0.008
2	**National Gini coefficient**	33.1 ± (1.2)	43.8 ± (6.6)	37.4 ± (1.6)	33.7 ± (1.0)	9.79	0.02
3	**Site Human Footprint index**	36.4 ± (7.6)	20.1 ± (2.6)	22.1 ± (4.5)	33.2 ± (4.6)	3.36	0.34
4	**National tourism** (international, inbound, overnight visitors, in millions)	19.75 ± (9.75)	19.83 ± (16.23)	39.08 ± (11.09)	38.54 ± (7.48)	7.83	0.05
5	**National extreme events** (% of population exposed to droughts, floods, extreme temperatures, 1990-2009)	1.13 ± (0.39)	1.38 ± (0.23)	1.43 ± (0.87)	0.84 ± (0.59)	4.87	0.18
6	**Site migration** (net total number of migrants 1990-2000)	675± (4,754)	-18,678± (12,954)	-2,229± (2,420)	334± (1,054)	4.49	0.21
7	**Site elevation minimum** (m.a.s.l.)	692 ± (250)	777 ± (450)	725 ± (248)	753 ± (133)	0.91	0.82
8	**Site elevation maximum** (m.a.s.l.)	2,984 ± (840)	3,458 ± (914)	2,005 ± (325)	2,579 ± (333)	2.44	0.49
9	**Site SPEI**	-0.32± (0.11)	-0.42 ± (0.0075)	-0.11 ± (0.10)	-0.14 ± (0.061)	5.73	0.13
10	**Site mean annual temperature** (°C)	8.6 ± (2.6)	17.2 ± (2.9)	9.9 ± (2.8)	6.4 ± (0.6)	6.46	0.09
11	**Site mean annual precipitation** (mm)	75.9 ± (10.1)	70.4 ± (5.8)	81.4 ± (13.9)	87.3 ± (10.2)	1.38	0.71