Actions and leverage points
for ecosystem-based adaptation pathways
in the Alps

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Abstract

Ecosystems support the adaptation of societies to global changes through their contributions to people's quality of life. Ecosystem-based adaptation (EBA) implementation remains a challenge and will require changes of practices, structures and processes underpinning human and nature interactions, also considered as co-production of nature's contributions to adaptation (NCA). We analysed the levers required to implement EBA to reach a future desired by stakeholders of a mountain social-ecological system in the French Alps. Using a participatory backcasting scenario approach and a serious game, local stakeholders were invited to design a desired vision for their region in 2040 and reflect on strategies and levers for reaching it. We analysed co-production actions required to achieve adaptation objectives aligned with the vision. We then assessed how local communities can leverage these actions to navigate a desired adaptation pathway. EBA and landscape multifunctionality are critical to achieve stakeholders' vision. EBA require substantial adjustments, transformations, or new co-production actions, but natural capital was not a limiting factor for adaptation. Synergies among multiple co-production actions create windows of opportunity for local communities to achieve their vision through the combination of social levers. However, most powerful levers, like collaborative decision-making or common strategy design, appeared the most difficult to activate. EBA is mainly constrained here by social barriers reflecting the lack of collaboration and communication among stakeholders. Recognizing potential contributions of ecosystems to adaptation by maintaining and developing NCA supply can help communities to re-structure and re-think their local social-ecological system to achieve desired and sustainable pathways.

Highlights

- Nature's contributions to adaptation (NCA) are critical to achieve stakeholders' desired adaptation.
- Unlike the social system, ecosystem capacity for ecosystem-based adaptation implementation is not limiting.
- The local community will be most challenged for activating deep leverage points.
- Combinations of NCA co-production actions and leverage points open windows of opportunities for adaptation.

Keywords

Social-ecological systems; Nature's contributions to people; Leverage points; Adaptation pathways; Transdisciplinary; Mountains

1. Introduction

Given delays and prevailing resistance to climate change mitigation, it is now urgent for societies to adapt to maintain their quality of life and livelihoods (Steffen et al., 2018; IPCC, 2018). To tackle this challenge and avoid maladaptation, societies can reflect on adaptation pathways toward a desired future (Colloff et al., 2017a). Adaptation combines coping, incremental or transformative changes of values, knowledge, rules, and technology and behaviours in response to global changes (Fedele et al., 2019; O'Brien and Sygna, 2013). To ensure that these changes follow sustainable pathways, it is necessary to reframe social-ecological relationships, for example by reconnecting people to nature or recognizing the role of ecosystems for adaptation (Abson et al., 2017; Ives et al., 2018; Olsson et al., 2014).

People's livelihoods depend largely on the integrity of ecosystems and the benefits they provide, which are threatened by global change (Díaz et al., 2019). Sustainability science has acknowledged the role of ecosystems for sustainable adaptation to climate change under the umbrella of Nature-based Solutions, combining enhancement of livelihoods and natural systems (Cohen-Shacham et al., 2016; Seddon et al., 2020b). Among these, Ecosystem-Based Adaptation (EBA) focuses on the use of biodiversity and ecosystems to provide multiple social, economic and cultural co-benefits for local communities as part of broader adaptation strategies (CBD, 2009). By integrating nature conservation and socio-economic development, EBA can be central to adapting to change in complex adaptive social-ecological systems (SES) (Berkes and Folke, 1998; Fischer et al., 2015) using an adaptation pathways approach.

EBA approaches remain poorly considered compared with conventional options (e.g. engineered infrastructure). Current research on EBA focuses on demonstrating its relevance, effectiveness and outcomes for climate change mitigation (Donatti et al., 2020; Reid et al., 2019; Seddon et al., 2020a), and on knowledge gaps and barriers hampering its implementation (Kabisch et al., 2016; Nalau et al., 2018; Rizvi et al., 2015). However, there is still a lack of evidence on how EBA can be integrated into broader adaptation strategies (Reid et al., 2019) and on the governance arrangements necessary for implementation (Wamsler et al., 2016).

The EBA approach is deeply connected with the concept of Nature's Contributions to People (NCP) (Díaz et al., 2015). Nature's contribution to adaptation (NCA) is defined as the ecological processes providing benefits to increase people's ability to adapt to socio-economic and environmental changes (Colloff et al., 2020). To maintain their livelihoods, communities will need to modify their interactions with nature to sustain the supply of existing benefits where ecosystems will persist under climate change or realise new benefits from ecosystems that will be transformed (Lavorel et al., 2019).

Benefits from nature are jointly produced by interactions among social and ecological processes. These interactions are referred to as processes of NCP co-production (Lavorel et al., 2020; Palomo et al., 2016). NCP co-production involves human actions and inputs in a three-step process along a chain from ecosystems and their management to the flow of benefits (Bruley et al., 2021a; Lavorel et al., 2020). Ecosystem management actions (CP1) alter ecosystem structure and functions to obtain desired benefits (e.g. manuring of crops, planting trees or nature conservation). Physical mobilization via harvesting or access to nature (CP2) provides a flow of material or non-material benefits (e.g. from mowing, collecting plants or visiting a scenic place). Actions for the appropriation and appreciation of benefits (CP3) involve processes whereby people participate in distributing, using and valuing the benefits (e.g. transforming and marketing of local products, enjoying natural arts and crafts, feeling attached to a place).

Ecosystem-based adaptation pathways and the co-production of NCA are enabled or constrained by multiple social-ecological elements. The difficulty of implementing adaptation actions can be due to societal barriers such as values, knowledge, governance, economic factors and power structures within societies, as well as from physical and biological constraints (Eisenack et al., 2014; Nalau et al., 2018). To overcome these barriers, communities require new and different forms of agency that can be facilitated through the activation of leverage points for adaptation (Adger et al., 2009). There are two basic types of leverage points according to their ease of implementation and effectiveness to engage more radical changes in societies for adaptation (Meadows, 1999). Shallow leverage points are easier to implement but achieve limited overall system change. Conversely, deep leverage points might be more difficult to activate but bring about more transformational change. The challenge is to identify and activate these deep leverage points to enable transformational change in specific contexts (Abson et al., 2017; Fischer and Riechers, 2019). Hereafter, we use the term 'lever' as synonymous with 'leverage points'.

Adaptation strategies can be implemented at different temporal, spatial and governance scales according to salient adaptation issues. However, adaptation actions involving particular ecosystems and landscapes need to be implemented at the local scale by local communities (Balvanera et al., 2017; Rauken et al., 2015; Wamsler et al., 2014).

In opting for a place-based adaptation pathways approach to address climate change, local communities can empower themselves by engaging in processes of knowledge and governance co-production (hereafter referred as participatory knowledge production to avoid confusion with NCP co-production) (Norström et al., 2020; Wyborn et al., 2019). These processes facilitate learnings from shared experiential knowledge of past changes to the SES, predicting and anticipating future changes and developing iterative, reflexive approaches to adaptation (Fazey et al., 2015). Whereas exploratory scenarios focus on what could happen in the future, backcasting or a normative scenarios approach seeks solutions for a desired future and appear more relevant for engaging local stakeholders in reflecting on systems adaptation (Bizikova et al., 2015; Carlsson-Kanyama et al., 2008; Rosa et al., 2017). Backcasting allows stakeholders to define a desired vision for the future and reflect on strategies, actions and values to achieve it (Falardeau et al., 2019; Lavorel et al., 2019). The purpose of this approach is to explore what can be achieved in the long term through planning and discussion within the local community (Carlsson-Kanyama et al., 2013).

Ecosystems, biodiversity and ecosystem services of Mountain SES make important contributions to livelihoods and wellbeing of local inhabitants but also contribute to the quality of life of lowland populations (Martín-López et al., 2019). These systems provide important contextual settings to understand the role of ecosystems for adaptation to climate change, because mountains have been affected by some of the earliest and greatest impacts of climate change (Grêt-Regamey and Weibel, 2020; Palomo, 2017). In addition to harsh topographical and climatic conditions (Thornton et al., 2021), mountain societies are vulnerable to socio-economic changes due to their remoteness and high dependence on external drivers (Klein et al., 2019a).

In this paper we analyse how ecosystems can be harnessed to achieve a vision desired by stakeholders of a mountain SES, as a key part of the process of developing and implementing an adaptation pathways approach. We posit that ecosystems support multiple adaptation options that are underexploited because of social barriers. We asked the following questions: (1) What vision do stakeholders hold for their future? (2) What is the role of ecosystems in this desired vision? (3) Which changes in ecosystems and actions by stakeholders are required to reach this vision? (4) How can the local community leverage these actions to steer the SES along a desired adaptation pathway? (5) How does EBA contribute to community and governance reorganization toward adaptation pathways? We developed a participatory backcasting approach to design a desired vision for the region in 2040 and identify levers and barriers to its achievement. Data from this two-year process was analysed with an analytical framework in which we assessed dependencies between potential levers (as perceived by participants), their influences on co-production actions required to benefit from NCA, and adaptation objectives required for achieving the vision (Fig. 1).

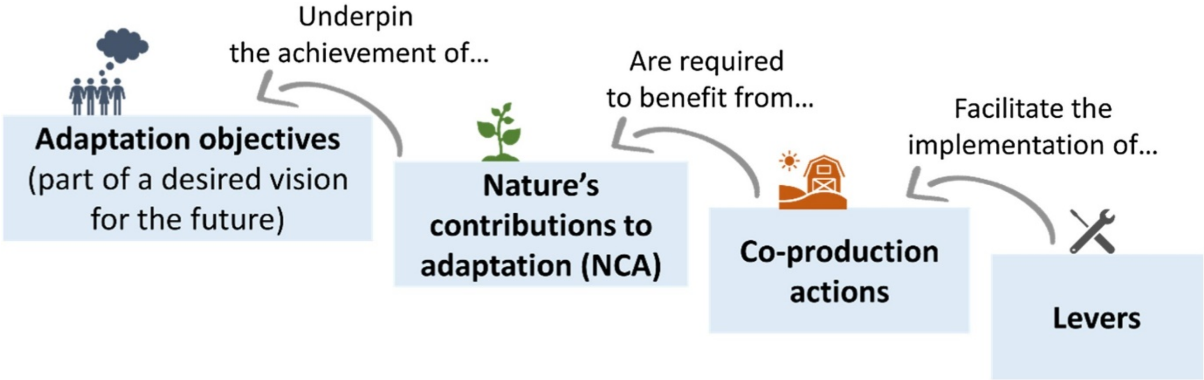

Fig. 1. Analytical framework showing dependencies between potential levers, their influences on co-production actions required to benefit from NCA on which adaptation objectives depend to achieve the vision of a desired future. Causality goes from right to left, whereas the order of the boxes from left to right corresponds to the successive steps of our analysis.

2. Study site

Located in the central French Alps at the edge of the Ecrins massif, Pays de la Meije comprises two municipalities, La Grave (484 inhabitants) and Villar d'Arène (322 inhabitants) covering 205 km² and ranging from 1135 to 3984 m in elevation (INSEE, 2016). Climate is alpine with Mediterranean influences and there has been an increase in mean annual surface temperature of 2 °C since 1950 (Hock et al., 2019). The landscape is dominated by grasslands and summer pasture on south-facing slopes, and by forest (below 2200 m), sparse vegetation, rocks and ice on north-facing slopes. The latter are included in the core area of Ecrins National Park and host a skiing area. As in other alpine regions, local communities historically adapted to mountain topographic and biophysical constraints while becoming increasingly vulnerable to climate change and socio-economic changes since the early 2000s (Bruley et al., 2021b). Tourism, a major economic sector centred around summer and winter mountain recreation, has already experienced the effects of climate change, as well as economic competition from other resorts. The tourism industry depends heavily on winter activities but also on mountaineering, threatened by decreasing snow cover at mid-altitude, melting glaciers and increased rockfall risks (Hock et al., 2019). Agriculture, which is mainly based on rearing of heifers and lambs, benefits from a longer growing season but is already experiencing increased climate variability (Ménégoz et al., 2020). In particular, droughts and heatwaves make fodder production uncertain (Grigulis and Lavorel, 2020; Nettier et al., 2017). Farmers strongly depend on European Common Agricultural Policy subsidies and the survival of small farms is threatened by a diminishing workforce and the limited availability of productive land. Local life is structured by the tourist seasons and employment is highly dependent on surrounding regions, making it vulnerable to external drivers such as tourist visitation. Beyond the specific living conditions imposed by topography, climate and geographical and administrative remoteness, accessibility is limiting. The region is characterized by low average income, difficulties for first home buyers due to a high density of holiday homes (around 60 % of all housing) and an unequal distribution of financial capital. There is an emigration deficit, with the departure of younger generations for education and job opportunities.

3. Methods

To understand how communities can harness benefits from ecosystems to adapt to climate change, we identified and analysed desired adaptation objectives, nature's contributions to these objectives, co-production actions to be implemented, and associated levers to be activated for adaptation. First, a backcasting scenario participatory process was used to identify the adaptation objectives for communities, enabling an initial analysis of barriers and levers through participants' perceptions. Secondly, we used a qualitative data analysis to identify NCA that contribute to the adaptation objectives and the capacity of ecosystems to supply them. We also explored how co-production actions contribute to NCA and how levers can influence the implementation of these actions (Table 1).

3.1. Participatory backcasting scenario approach

Following the backcasting approach, we co-designed a common vision for 2040 and explored adaptation pathways using a serious game. Some 68 stakeholders, from various socio-economic sectors (agriculture, tourism, culture, engineering, science, government, trade-workers, mobility, nature conservation, public services and students), age and gender, were involved in one or several steps of the participatory process (Table A.1). Participants were invited from a list of actors previously involved in the overall project (Bruley et al., 2021a, 2021b), complemented by snowball sampling and open invitations disseminated through municipalities and tourism offices. We chose the 2040 horizon because it allowed participants to project themselves into a future determined by the decisions and actions in coming years.

First, the visioning process helped in the co-design a vision of a desired future for Pays de la Meije in 2040 under climate change (P1 in Table 1). The information gathered during this process was consolidated into a final version of the common vision (Fig. A.2) and allowed us to identify adaptation objectives.

Secondly, we designed a serious game to engage participants into possible adaptation strategies (Salliou et al., 2021). Serious games are useful to engage diverse stakeholders around complex issues with high uncertainties such as climate adaptation but also to improve social learning and especially to increase trust between participants and researchers (den Haan and van der Voort, 2018; Flood et al., 2018). The game modelled local development between now and 2040 in the context of climate and socio-economic changes (Table 1, P2). The game was based on players' capacity to adjust their individual activities and develop collective projects to satisfy demands from incomers (tourists or new residents) and maintain local working and living conditions threatened by climate and socio-economic events. Individual or collective decisions made by players to adapt or anticipate these events affected the flow of incomers, landscape attractiveness and living conditions and were key to achieving the vision (for details on the game see Appendix A.3 and Salliou et al., 2021). Adaptation strategies during the game and levers and barriers to adaptation were immediately discussed in a debriefing and further queried in follow-up interviews. The list of adaptation objectives results from the compilation of all the objectives linked to ecosystems cited by the stakeholders during visioning process and game sessions. In the same way, the levers and barriers resulted from the compilation of those expressed by participants during debriefings and interviews.

Table 1. Description of the data collection and analysis steps

Step (P for Participatory, D for desk analysis)	Details of data source and collection methods	Details of data analysis	Analysis outputs
P1 - Visioning (39 participants - April to June 2018)	Two workshops (20 participants in 4 groups): Groups designed their vision based on values and the desired quality of life and activities for 2040 in a context of global change. Visions were then shared and discussed by all participants. Two focus group (11 participants): (1) Agriculture: Discuss feasibility of the vision for agriculture (5 farmers). (2) Habitability: Discuss living conditions in the vision (6 women). Ten semi-structured interviews (10 key actors not represented in the workshops): Discuss, validate and enrich the common vision with new points of view.	Aggregating the four visions after the two workshops because they were similar. Consolidating all information into a final common vision Identifying and classifying EBA objectives in the vision.	Common vision in 2040. Lists of EBA objectives. Values associated with the vision - qualitative information.
P2 - Gaming (46 participants – May to September 2019)	Ten game sessions (36 participants - between 2 and 6 participants per game). Game sessions structured by: • 2h game - players make individual and collective decisions to maintain local quality of life in response to climate and socio-economic events in 2020-2040 (full description of the game in appendix A.3). • 1h debriefing of first impressions, game strategies, levers and barriers to adaptation. Nine semi-structured interviews (actors with in-depth knowledge of the region): Based on game sessions outputs, identify concrete adaptation actions, barriers and levers.	Refining adaptation objectives based on adaptation strategies discussed during the game linked to the vision. Classifying levers and barriers perceived by participants into potential levers for adaptation.	Refined information on adaptation objectives. List of potential levers for adaptation. Influences of levers on actions - - qualitative information. How ecosystems are considered for adaptation by participants - qualitative information.
D1 - Matrix analysis	Four elements: • Adaptation objectives: data collected from visioning and gaming • Nature's contribution to adaptation (NCA): Identification and classification of NCA based on IPBES NCP classification • Co-production actions: Identification of human actions required to benefit from NCA • Potential levers for adaptation: Based on debriefings and interviews of gaming process.	Coding qualitative data to build dependence matrices (0= no link, 1= facilitating and 2= necessary): • How adaptation objectives depend on NCA • How NCA depend on co-production actions • How co-production actions depend on leverage activation. • Linking the three matrixes using a network representation. Grouping adaptation objectives and NCA, and NCA and co-production actions using a network community detection algorithm.	Representation of the dependences between levers, co-production actions, NCA and adaptation objectives.
D2 - Lever analysis	Using dependence matrices between co-production actions and potential levers. Using participants perception on each lever as current barrier and potential lever for adaptation.	Assessing the actionability of potential levers based on participants perception. Assessing the effects of levers on co-production actions using the matrix from step D1.	Analysis of levers.
D3 - Background material: NCA future supply modelling	Land cover map, climate change scenario, and existing ecosystem models to assess future NCA supply.	Modelling the potential supply of 12 NCA under climate change.	Percentage of change in modelled NCA supply in 2040. Qualitative appreciation of NCA demand in 2040.

3.2. Data analysis

To support a systemic analysis, the data obtained and classified from the participatory process (adaptation objectives and potential levers) was coded into three matrices representing: (1) how adaptation objectives depended on NCA; (2) how NCA depended on the implementation of co-production actions, and (3) how co-production actions depended on potential levers (D1 & D2 in Table 1). NCA were identified based on the IPBES NCP classification (Diaz et al. 2018). To better fit our data, we grouped or split several IPBES categories: water quality and quantity were grouped as water regulation; cultivated materials and medicinal products were grouped as cultivated products; wild food, materials and medicinal products were grouped as wild products; soil protection was split into soil fertility and erosion control and psychological and psychosocial experiences were separated.

Co-production actions were identified across the three steps of the co-production chain. Identified actions encompassed actions of ecosystem management (CP1), ecosystem mobilization and access (CP2) and benefits appropriation and appreciation (CP3) (Bruley et al., 2021a; Lavorel et al., 2020). A common coding was applied to characterize the dependence among matrix elements: 0 for no dependence, 1 for facilitating and 2 for necessary. We represented the interactions between the four elements of the analytical framework (Fig. 1) as a network, with one column for each element. The nodes in each column were connected to the nodes of the previous or subsequent column based on the interactions coded in the three matrices. Lastly, we clustered adaptation objectives that depended on similar NCA using a community detection algorithm on the network data (fast-greedy; Csardi, 2018). Finally, we clustered co-production actions that influenced similar NCA and levers that influenced co-production actions.

To assess ecosystem capacity to sustain the future demand for NCA, we modelled the potential supply by 2040 of 12 NCA using existing models for projecting impacts of climate and land cover changes resulting from the game (Appendix A.4).

4. Results

The results are organized in four subsections along our analytical framework (Fig. 1) highlighting the dependency between overarching adaptation objectives, NCA bundles, sets of co-production actions and groups of levers (Fig. 2).

4.1. Adaptation objectives related to ecosystems

From the visioning and gaming process, we identified 11 ecosystem-based adaptation objectives to maintain local quality of life. The objectives were related to different interests and activities (e.g. tourism, agriculture, daily life, and natural or cultural heritage) and involved multiple stakeholders (e.g. farmers, tourist professionals, craftspeople, scientists, teachers, or newcomers involved in developing new activities) (Table 2, fifth column). Some adaptation objectives, like those about governance, mobility and daily life, were excluded from this analysis because they were not directly related to ecosystems. Participants presented these adaptation objectives in response to climate change, in particular to decreasing snow cover and longer summer seasons, but also to changing socio-economic drivers, like new consumption patterns and the risk of homogenization of mountain valley identities. They also saw adaptation objectives as a way to cope with economic difficulties by increasing high value-added products and services (Table 2, fourth column).

4.2. Dependence of adaptation objectives on NCA

We identified four overarching adaptation objectives according to their dependence to NCA (Fig. 2, column 1&2, and details in Fig. 3): (1) “Natural and cultural assets are valued” including objectives linked to sharing and preserving natural and cultural assets (Scientific tourism, Preserve nature, Education, and Arts and crafts); (2) “Agriculture is diversified” including objectives solely linked to farming (with Agro-tourism, Diversify agriculture, and Maintain livestock); (3) “New resources are exploited” including Green energy and Irrigation system; and (4) “Mountain sports are diversified” (with Winter sports and Diversify leisure).

NCA were key to achieving all adaptation objectives, and synergies existed between NCA that simultaneously benefited multiple objectives, forming bundles of NCA. Tourism-related objectives were spread across three overarching objectives, which highlights that tourism depends on multiple NCA bundles. The first two overarching objectives were linked to multiple NCA, and had many in common, whereas the last two were linked to distinct NCA. Some NCA like habitat and biodiversity, water regulation and psychological experiences played a central role, with links to at least three overarching objectives (Fig. 2, pie charts). However, more specific NCA were linked to one or few objectives, like energy or physical experiences. Non-material NCA (supporting identities, psychological experiences, learning) and material NCA (food, cultivated products) underpinned the overarching objectives of “Natural and cultural assets are valued” and “Agriculture is diversified”. In contrast, regulating NCA were common across overarching objectives and acted as intermediate NCA for all of them. Only water and hazard regulation NCA were critical for the objectives “New resources are exploited” and “Mountain sports are diversified”.

Modelling potential supply and demand of NCA by 2040 revealed that under land-use changes associated with the vision and climate change scenarios, most ecosystems would be able to support future demand associated with the adaptation objectives (Table A.6). While future demand increased or was stable for almost all NCA, potential supply varied across NCA. Supply of crops and some regulating NCA (like soil fertility) increased. Supply was stable for some non-material NCA (opportunities for recreational activities, scientific tourism and landscape aesthetic). Supply decreased for grassland NCA (water regulation, fodder production and erosion control). Thus, supply capacity of NCA appeared not to limit adaptation objectives except for maintenance of livestock, which is highly dependent on grassland NCA.

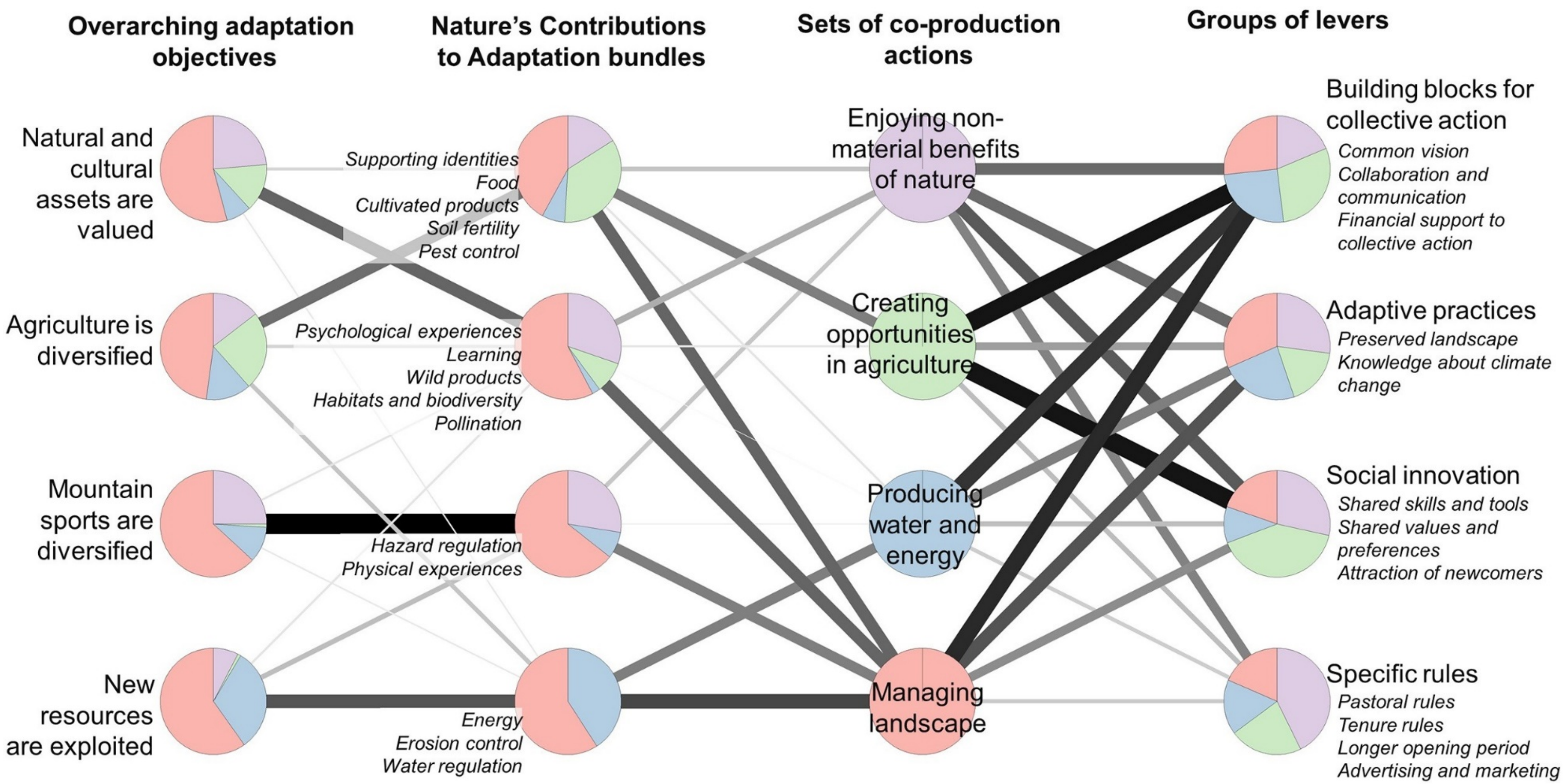

Fig. 2. Representation of the dependency links between the overarching adaptation objectives, NCA bundles, sets of co-production actions and groups of levers. Overarching adaptation objectives and corresponding bundles of NCA (column 1 and 2) are based on clustering of adaptation objectives according to their dependence on NCA (details in Fig. 3). Sets of co-production actions (column 3) are based on clustering of co-production actions according to their contribution to NCA (details in Fig. 4). Groups of levers (column 4) are based their nature and their leverage effect on co-production actions sets (details in Fig. 5). Colours in the pie charts represent the four sets of co-production actions and how they contribute to bundles of NCA and to overarching adaptation objectives, and on which groups of levers they depend. The pie charts show the contribution of each set of co-production actions. The thickness of the lines is proportional to the strength of the link between two clusters. (Details of the whole network in Fig. A.5).

Table 2. Description of adaptation objectives derived from visioning and gaming.

Adaptation objectives	Description	Adaptation to what?	Who is involved?
Diversify leisure	Diversify and adapt recreational practices to climate change and year-round soft-tourism, develop activities requiring little infrastructure	Climate change (weather variability, increasing risks, increasing temperature); tourist demand; competition from other mountain areas	Tourism professionals (guides, huts, shops…), mountain practitioners
Scientific tourism	Develop scientific tourism especially about climate change in the mountains ("open-air laboratory"). Rely on the local scientific centre and environment richness	Climate change (weather variability, increasing risks, increasing temperature) as an opportunity; tourist demand	Tourism professionals (guides, national park staff...), mountain practitioners, visitors, scientists, teachers
Winter sports	Diversify winter activities with emerging activities outside resort (ski touring, kite-surfing, Nordic skiing) and maintain winter identity ("free ride")	Climate change (decreasing snow cover, increasing risks & temperature); tourist demand; competition from other mountain areas.	Tourism professionals (all), winter mountain practitioners, new visitors
Diversify agriculture	Grow products with high added value on terraces and offer local products for inhabitants and visitors through local distribution channels. Create a local brand. Gain independence from agricultural subsidies	Low incomes from agriculture; change in consumption pattern; competition from other mountain areas; climate change as an opportunity (longer growing season); homogenization of mountain regions identity	Farmers, local retailers, Inhabitants, visitors, agricultural institutions
Agro-tourism	Introduce visitors to mountain agriculture, promote know-how and local products. Allow farmers to benefit directly from tourism	Tourist demand; competition from other mountain areas	Famers, artisans, tourism professionals (link to agriculture)
Irrigation system	Create water retentions for irrigation to meet the demand for land under cultivation and increase drought resistance for fodder production	Climate change; increasing downstream demand for water	Farmers, municipalities
Maintain livestock	Maintain livestock farming and pastoral activities to maintain open landscape identity. Diversify of livestock production to obtain direct incomes	Low incomes from agriculture; homogenization of mountain regions identity	Livestock farmers, agricultural institution, distribution channel, retailers
Education	Develop activities to educate and raise awareness of visitors to the local values, natural and cultural specificities (habits, risk management, daily life, use of nature...). Develop spaces for exchange between locals and visitors	Biodiversity loss; competition from other mountain areas; tourist demand; climate change (weather change, increasing risks, increasing temperature); homogenization of mountain regions identity	Tourism professionals (all), mountain practitioners, visitors, local inhabitants
Preserve nature	Preserve the landscape which makes the identity of this region. Limit urbanization, infrastructure and preserve the richness of ecosystems	Homogenization of mountain regions identity	Municipalities, inhabitants, National Park
Green energy	Produce green energy to achieve "energy autonomy" through solar, hydroelectric and wood fuel. Improve buildings energy efficiency	Rising energy costs; competition for energy resources	Municipalities, inhabitants
Arts & Crafts	Develop arts and crafts by allowing settlement of artisans. Attract new skills to strengthen the creative and cultural aspect.	Tourist and inhabitants demand; competition from other mountain areas; change in consumption pattern	Local communities, newcomers, visitors

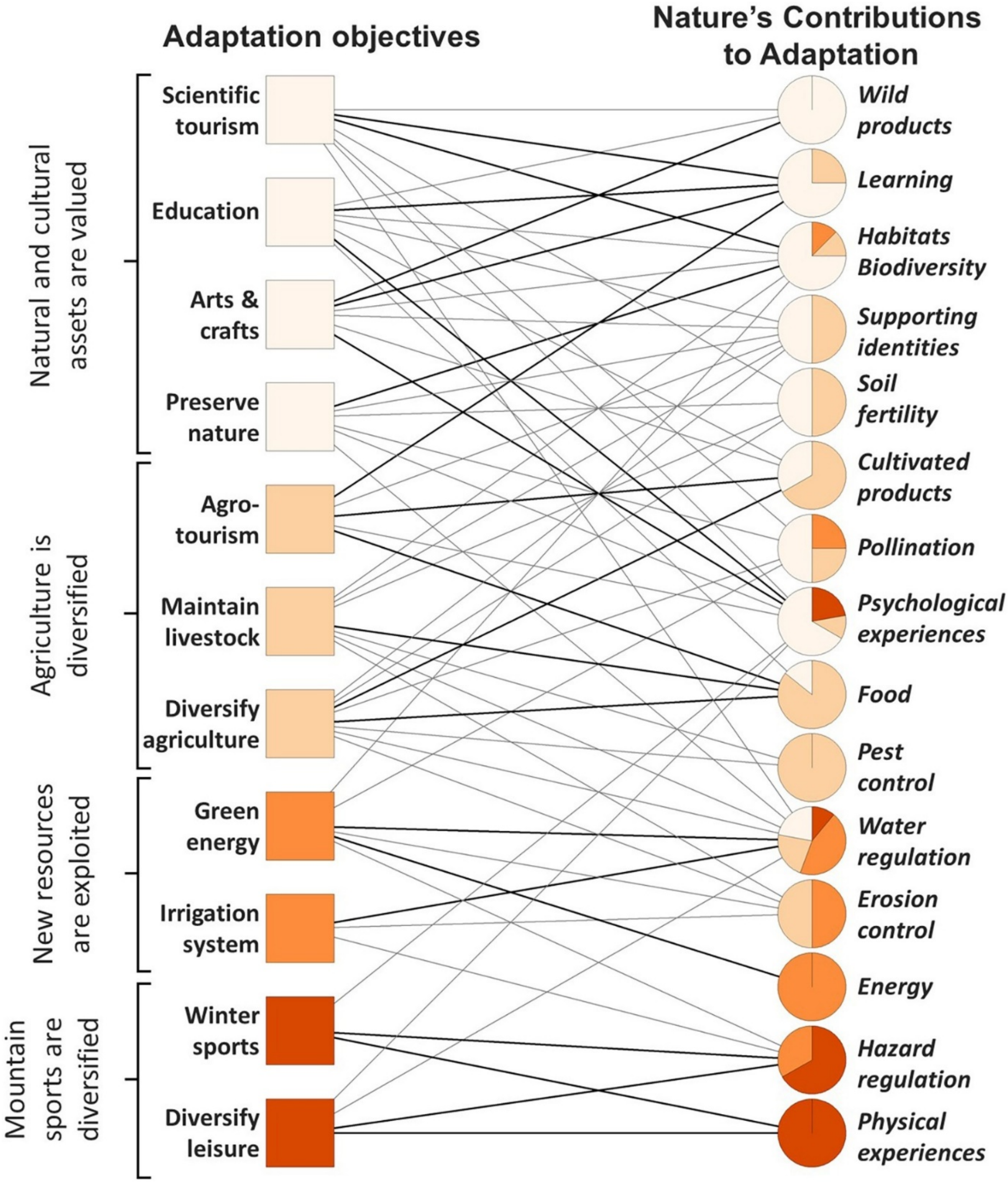

Fig. 3. Network representation of the dependences between adaptation objectives (column 1) and Nature's contributions to adaptation (NCA) (column 2). Colours represent 4 overarching adaptation objectives depending on NCA that are necessary (thick lines) or facilitating (thin lines) for their achievement. The pie charts show the contributions of NCA to each overarching adaptation objectives.

4.3. Co-production actions for adaptation

We identified 16 co-production actions required to implement desired adaptation (Table A.7), forming four sets of actions according to their contribution to different NCA (Fig. 4): "Managing landscape", "Producing water and energy", "Creating opportunities in agriculture" and "Enjoying non-material benefits of nature".

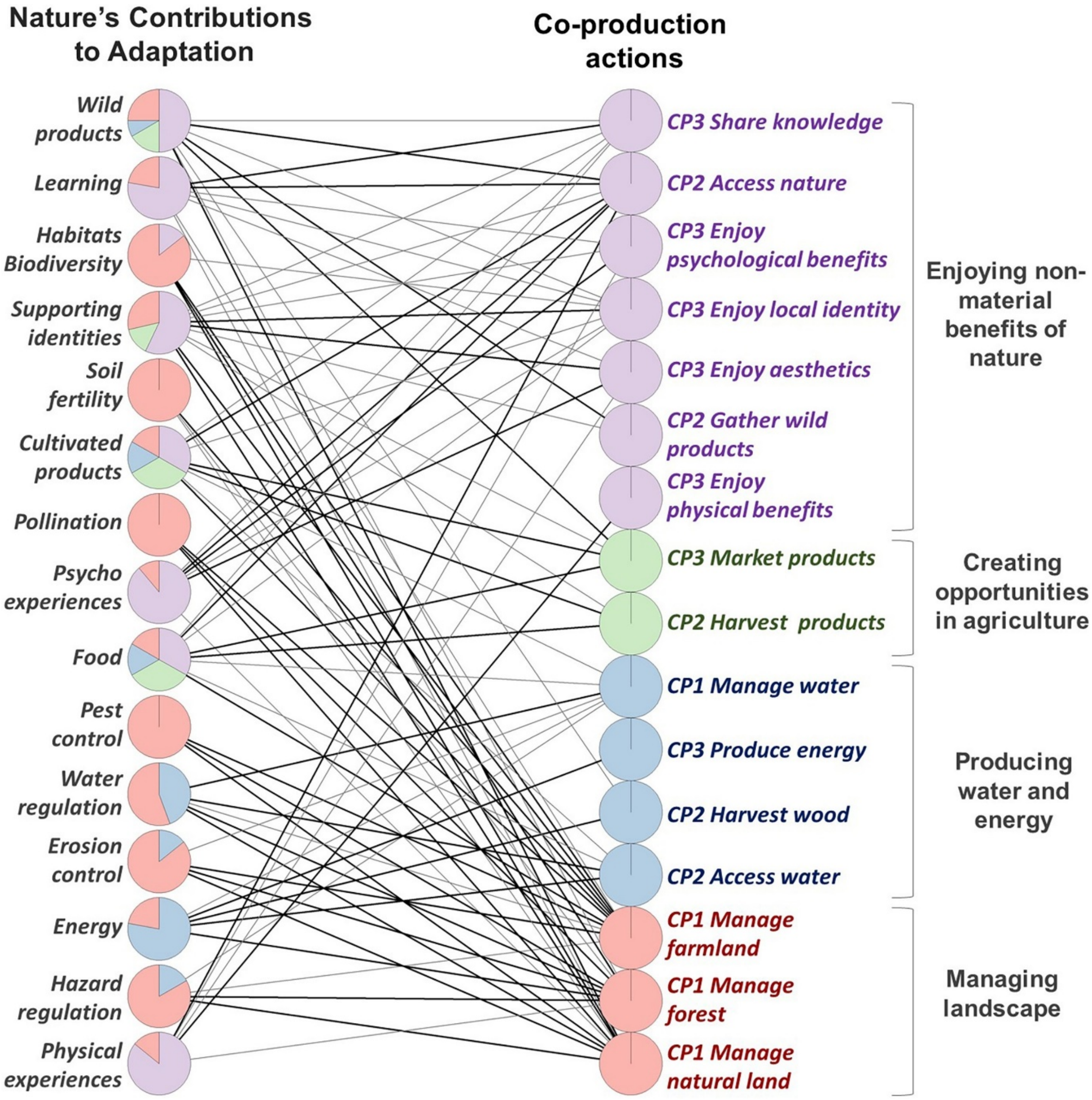

Fig. 4. Network representation of co-production actions (column 2) required to benefit from Nature's contributions to adaptation (NCA) (column 1). Colours represent four sets of co-production actions according to their contribution to NCA that are necessary (thick lines) or facilitating (thin lines) to realize benefits. The size of the portions in the pie charts is proportional to the contribution to each NCA of the sets of co-production actions.

"Managing landscape" actions were required for all NCA. Other actions had a more targeted effect on specific NCA, like "creating opportunities for agriculture" actions on food, cultivated products or supporting identities, or "producing water and energy" actions on food, cultivated products, energy and water regulation. Actions of "enjoying non-material benefits of nature" were mostly required for non-material and material NCA. While some NCA depended mainly on one set of actions, such as regulating NCA for "managing landscape" actions, other mostly material NCA depended on actions from all action sets (like wild and cultivated products, food and supporting identities).

Most sets of co-production actions contributed to all adaptation objectives (Fig. 2, columns 1–3), like "managing landscape" actions which were critical to achieve all objectives. This was also the case for "enjoying non-material benefit of nature" actions, which played a more important role for objectives linked to tourism. "Creating opportunities for agriculture" had a more targeted role on objectives linked to local production. These results highlight that the majority of NCA and adaptation objectives were more-or-less dependent on all sets of co-production actions, reflecting the importance of landscape multifunctionality and synergies between sets of actions. Thus, while landscape management is an indispensable basis for realization of benefits from all NCA, mobilization and appreciation actions are also necessary to benefit from material and non-material NCA.

Many co-production actions are already in place and expanding, according to the stakeholders who participated in our analysis. However, to achieve adaptation objectives, many other transformative and novel actions need to be developed. For example, natural area management, traditional livestock and pastoral activities and existing tourism would need to be maintained or adjusted. Other co-production actions would need to be transformed in response to climate change impacts, e.g. mountain guides and ski resorts activities. In addition, novel practices would need to be implemented, such as new activities linked to agro-tourism, scientific tourism or new farming practices and development of new markets for locally-produced food, art and crafts.

4.4. Levers to implement co-production actions

The information collected during the game revealed 12 levers that can facilitate co-production actions for adaptation (Fig. 5, Table A.8). The levers formed four groups according to their nature and influence on co-production actions and their cascading effects on adaptation objectives: "Building blocks for collective action, adaptive practices, social innovation and specific rules" (Fig. 2, column 4). Below, for each lever group, we first summarise their leverage effect on co-production sets based on their aggregated influence on each action (Fig. 5, rows 1–5, Fig. A.5). Then, we assess how easily the local community could activate them according to participants perceptions (Fig. 5, rows 6–8). Finally, we detail the interrelationships between levers that facilitated or inhibited the activation of other levers.

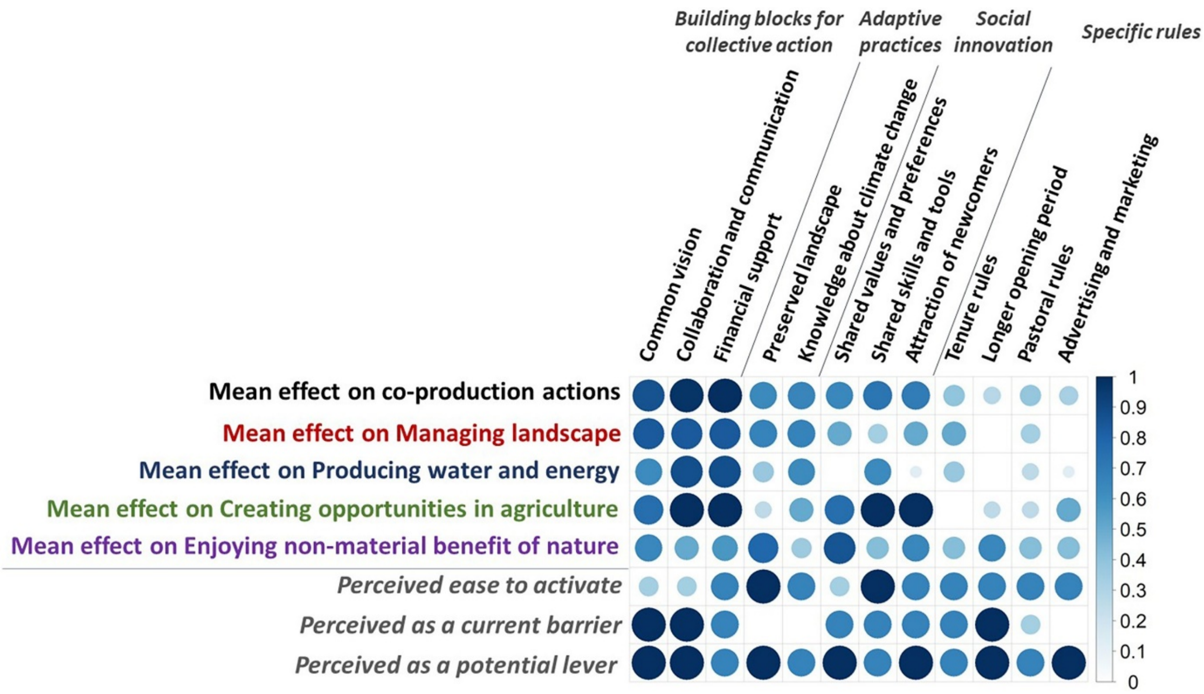

Fig. 5. Ease of activation of potential levers for adaptation identified by participants and leverage effects on co-production sets. Ease of activation reflects to what extent this lever can be activated by the local community and was assessed based on how participants perceived each lever as a current barrier or Fig. A.5). The size and shade of the dots indicate the strength of each lever in the corresponding category (large and dark = strong, small and pale = weak).

The three levers grouped under "building blocks for collective action" were key to achieve the vision because they influenced all co-production actions and activated many other levers. Two levers, increase collaboration and communication and building a common vision, had a strong aggregate leverage effect on all sets of co-production actions. For example, they were required to implement collective strategies on "managing landscape" and "creating opportunities in agriculture" for land allocation for new agricultural practices or for marketing of local products. A third lever, Financial support from public or private investors, was also essential for most co-production actions, such as the development of irrigation or establishing new activities. However, these levers were perceived as difficult to activate due to internal or external barriers. To increase collaboration and for building a common vision, people needed to get involved in collective decisions and actions, overcome resistance to change and improve their capacity for collaboration. The local community was aware of its limited control over external budgets and investors to obtain more financial support, in addition to the low potential for local investment. These three levers also interacted with other levers. For example, the lever increase collaboration and communication was essential for building a common vision, which involves bringing all actors to the table. By doing so, they would facilitate the activation of levers requiring co-ordination between actors from different sectors, such as skills and tools, knowledge on climate change sharing practices. Financial support could also be facilitated by collective decision making and by attracting new investors through newcomers.

Preserved landscape and knowledge about climate change formed a second group of levers: "adaptive practices". These levers support the implementation of adaptive co-production actions in agriculture, tourism, water and energy management and particularly important to support "enjoying non-material benefits of nature" actions. Participants perceived preserved landscape as already activated, given the generally good condition of ecosystems. The fact that some knowledge about climate change was already used for adaptation of mountaineering and agricultural practices led participants to identify it as easy. To be activated these levers require the activation of “building blocks for collective action”, i.e. levers to develop a collective strategy to maintain landscape preservation and collaboration across actors from all sectors, including scientists. They also depend on economic and policy incentives (e.g. regulation of pastoral rules).

A third group included three levers that could lead to “social innovation”. Attraction of newcomers could bring workforce and new skills, which are necessary to implement new NCA co-production. Shared values and preferences, based on place attachment, could support the choice to act locally, such as for production of local food, arts and crafts and nature conservation actions. Shared skills and tools, including infrastructure, facilitated all agricultural co-production actions from crop management to products marketing. “Social innovation” appeared particularly important for “creating opportunities for agriculture” and “enjoying non-material benefits of nature” by supporting new nature-based livelihoods. Shared values and preferences depend on individual values, dispositions and choices that are difficult to influence and act on in a collective way. For example, the local community may create the conditions to attract newcomers, but their settlement and activity choice depends on individual preferences. The activation of these levers could be facilitated by the increase collaboration and communication lever to develop processes and habits of deliberation to help reconcile and negotiate conflicts between individual values.

The fourth group, “specific formal and informal rules”, had a more targeted effect on specific co-production actions. Tenure rules can act on land allocation for agriculture, wood and water production and property access for newcomers. Through their effect on grassland access and aesthetics, pastoral rules and their impact on farming practices mostly influenced actions for “managing landscape” but also for “enjoying non-material benefits of nature”. Longer opening periods regulation and advertising and marketing affected mainly co-production actions related to the development of year-round tourism, local products and everyday life. Participants perceived these levers as hard to activate because formal rules were beyond local decision-makers’ powers. Changes to informal rules, such as opening periods for the tourist season, which could be decided locally, were met with strong resistance. Tenure rules could be a prerequisite to activate the newcomer’s attraction lever and pastoral regulation could facilitate the activation of the preserved landscape lever.

These findings highlight the different roles of levers to implement co-production actions in ways that correspond to the values and objectives in the vision. Some were essential because they influenced many actions, while others were more specific but necessary to achieve some objectives. This analysis also highlights that levers with a broader leverage effect on co-production actions were not necessarily easier to activate by the local community, even if some of them had already been activated. Moreover, to implement the co-production actions needed to achieve the vision's objectives, the community would need to activate mostly social, human and financial levers. Finally, we observed that some levers were necessary to activate others, which informed where to intervene in pathways towards the vision.

5. Discussion

Through a place-based participatory and expert process, we analysed how EBA could contribute to implementing the vision for the future identified by participants as part of the early phases of an adaptation pathway approach. We found that adaptation objectives are based on multiple NCA, which require adjustment, transformation or development of new co-production actions to reach the vision and maintain the SES on a desired pathway. To implement these co-production actions and create 'windows of agency for change' (Lavorel et al., 2019), the local community will have to overcome important societal barriers, resulting in the re-organization of structures and processes for community governance and participation.

5.1. Recognizing the role of ecosystems for adaptation

Within the vision developed by participants, we demonstrate how ecosystems, and specifically NCA co-production, are essential components for adaptation to global change in this SES. In the different steps of NCA co-production, EBA involves far more than ecosystem management and involves all actions that enable the community to benefit from ecosystems for adaptation, including non-material benefits. These interrelationships form a complex interaction network between bundles of NCA, co-production actions and related social, economic and political levers, with numerous synergies, co-benefits and feedbacks. These interrelationships involve a wide variety of actors, economic sectors and interests through multiple NCA co-production actions.

Research on EBA has focused mainly on ecosystem management for specific purposes, with an emphasis on EBA effectiveness (Chausson et al., 2020; Seddon et al., 2020b) but without attention to the side-effects of NCP co-production. In addition, projects on the ground often focus on solutions targeting only one or a few NCP, typically regulating NCP (risks, climate mitigation), especially in mountain regions (e.g. Moos et al., 2018) and urban systems (e.g. Zölch et al., 2018). For example, (Palomo et al., 2021) found that only a few EBA projects in mountain regions considered non-material NCP, whereas we have highlighted the critical role of these NCP for adaptation in a mountain SES. Moreover, most EBA involve different types of values, knowledge, stakeholders' commitment and practices as a means for transformation of SES (Palomo et al., 2021). As many adaptation projects or strategies do not incorporate benefits from ecosystems, i.e. NCA, this suggests that EBA will need to be integrated with other socio-economic and political processes to support future sustainable adaptation. A first step towards this integration will be for local actors to recognize the important role of ecosystems for adaptation (Lavorel et al., 2019, 2020).

Although ecosystems are central to the objectives of the vision, they are often overlooked when participants analysed their current quality of life (Bruley et al., 2021a) or throughout the participatory adaptation process, even when explicitly questioned about it. There are two possible reasons for this lack of recognition of the role of ecosystems in adaptation. First, people tend to take nature's benefits for granted until they fall short. This is particularly true in our study area where ecosystems are in good condition. Greater awareness of nature's benefits may apply in places undergoing environmental decline and where climate change is having detrimental effects on NCP, for example in degrading coastal ecosystems (Jackson et al., 2001) or under increasing disaster risk in mountain regions (Klein et al., 2019b). Secondly, participants may be tacitly aware of the ecological limits of the SES they live in, because participants did not mention any objectives that were beyond the current capacity of ecosystems and they rejected such objectives and limits as an unwanted future.

Studies such as ours can benefit local adaptation by building awareness and knowledge of NCA, i.e. the benefits of ecosystems as a prerequisite for implementing adaptation (Wamsler et al., 2016; Zölch et al., 2018). The backcasting approach can help, but needs to go further than what we achieved in order to make explicit the role of ecosystems for local adaptation pathways. Such an approach could promote ecosystem conservation and help reconnect people with nature (Ives et al., 2018).

5.2. Navigating adaptation pathways

Adaptation pathways are sequences of decisions and actions that steer a social-ecological system towards a vision in response to biophysical and socio-economic drivers of change (Colloff et al., 2017b; Wise et al., 2014). We did not construct with stakeholders a detailed adaptation pathway in the form that has been proposed elsewhere (Butler et al., 2016; Cradock-Henry et al., 2020; Haasnoot et al., 2013). However, we consider the co-design of a desired vision and the deliberative reflection on strategies and levers to achieve associated adaptation objectives form an important starting point for adaptation pathway development and implementation.

Our analysis of co-production actions and associated levers reveals nexuses of co-production that can form and inform intervention points, or windows of agency, along a desired adaptation pathway (Colloff et al., 2021; Lavorel et al., 2019; Prober et al., 2017). First, we identify that the set of actions for managing landscapes towards multiple NCA is central to fulfilling all adaptation objectives (Fig. 2). Moreover, it is a prerequisite for actions of the other two steps of co-production. These actions can therefore be considered as a necessary condition for adaptation pathway development and thus the first window of agency towards the desired vision. This perspective is consistent with multifunctionality as a critical mechanism in EBA (Lavorel et al., 2020; Minang et al., 2015). Decisions and actions at this level can lead the system to unwanted trajectories, such as the abandonment of agriculture, which is common in mountains (Hinojosa et al., 2016).

To ensure landscape multifunctionality, future choices regarding the protection of natural areas and the use of agricultural land appear particularly critical (Huber et al., 2020). Levers of collective actions have pervasive impacts on all co-production actions and throughout the development and implementation of adaptation pathways, starting with landscape management actions. Early implementation of adaptation actions for landscape management will have the flow-on effect of keeping adaptation options open and creating further windows of agency. As such, these levers for managing landscapes by acting on collective goals and system organization represent deep leverage points with strong impacts on structure and function of the SES (Abson et al., 2017; Meadows, 1999). However, it is not guaranteed that collaborative management of ecosystems will be effectively addressed to achieve the desired vision (Bodin, 2017). There is a need to combine ecosystem management with particular levers, especially those in the groups of adaptive practices and social innovation.

Actions for enjoying benefits of nature underpin a large part of adaptation objectives through the network of co-production actions and resulting NCA and, importantly, depend on all levers. Accordingly, the adaptation action of establishing nature tourism can be regarded as a second crucial window of opportunity to achieve the vision. This action depends heavily on ecosystem management but involves a different set of actors from those engaged primarily in management. It would allow the maintenance, development and reconfiguration of the main source of income and employment in the region. The combination of social innovation (via skills, knowledge and values sharing), collective action and rules within the community (e.g. on the tourist season opening dates) can be a deep leverage point for adaptation of tourism practices and activities. Achieving the vision requires co-operation among tourism stakeholders to combine their resources and act collectively in the service of common interests and objectives (Wyss, 2013).

Creating opportunities in agriculture is the third most impactful set of actions for supporting adaptation objectives through NCA, while also most strongly dependent on all levers being activated (Fig. 5). Co-production actions for adjusting, transforming or developing novel NCA from a diversified agricultural system is thus the next critical window of agency along the pathway to achieving the vision. These actions create economic value from agroecosystem management and are also based on consumption of local products by tourists. Farm diversification strategies can positively affect income (Bassi et al., 2020) and are critical to achieve the desired vision. Moreover, agricultural diversification is often seen as a key adaptation to climate change as an alternative to livestock and fodder production (Flury et al., 2013). Creating opportunities in agriculture depends on social innovation and collective actions, illustrating the interconnectedness between different levers and groups of levers. Implementation is based on sharing of skills and infrastructure but also on the innovative capacity of newcomers, particularly young people (Bassi et al., 2020). However, the economic success of local agricultural products is dependent on the creation and maintenance of markets and demand, whether local or global (Flury et al., 2013). Social innovation and collective action are required to set up markets for local produce. Adaptation of agricultural outcomes often follows rather than precedes changes in markets, as we described in the history of this SES (Bruley et al., 2021b). Agriculture and its NCP is a cornerstone for vulnerability and resilience in many mountain social-ecological systems globally (Klein et al., 2019a).

Actions for producing water and energy represent a fourth window of agency. These depend on developing specific adaptive practices and have the potential to condition the success of actions linked to agricultural adaptation to climate change as well as the tourism actions. In particular, they have the potential to determine a choice that would lead to the highest level of innovation for exploitation of new resources. This window of agency could allow the local community to surpass the objectives of their vision in terms of sustainable production and consumption of water and energy.

To follow up on the identification of these windows of agency, it maybe necessary to study the synergies and trade-offs between the implementation of the different actions and objectives. We have highlighted some complementarities between actions allowing the co-production of multiple NCA, especially regarding natural capital. However, there could be competition for some capitals, especially financial capital, which could be granted to some actions at the expense of others, as seen during the recovery from a natural disaster (Bally et al., 2020). Therefore, stakeholders will need to prioritize adaptation actions along pathways for responding to short-, medium- and long-term issues. Prioritization belongs to decision-makers and the local community and can be based on maintaining the livelihood of those most vulnerable to climate and societal changes or on adapting practices that compromise the integrity of ecosystems and reduce options for future adaptation.

5.3. Nature-based adaptation for transformative climate change adaptation?

Our analysis of the influence of levers on co-production actions highlights key leverage points. Evolving modes of governance, innovation, enhancing and sharing knowledge, adapting rules and practices to future challenges are mentioned, among others, as key points for moving forward on sustainable pathways (Chan et al., 2020; Clark and Harley, 2020), but also as social co-benefits of climate adaptation initiatives (Owen, 2020). However, to be activated, these levers require many changes by the community and their governance system to create the conditions for the implementation of EBA to keep the system on a pathway towards the desired vision.

The rather un-innovative vision the stakeholders produced, which attempts to solve the problems currently experienced by the local community (Butler et al., 2016; Palomo et al., 2021), reveals the elements on which actors can or cannot act, as trivial as they may appear. Behind most of the levers identified are significant barriers to adaptation, linked to governance and institutions, world views, social relations, economy and finance. Indeed, the barriers identified by participants are mostly socio-economic: nature is not perceived as a barrier or limiting factor and is not central to participants' concerns. Similarly, climate change, with the exception of melting glaciers and uncertainty about precipitation (snowfall and drought), is not the most critical perceived issue. However, whereas we analysed only barriers identified by participants, other barriers acting at a larger scale should be considered for their significant impact on the local SES, for example in relation to national policies or global markets (Biesbroek et al., 2013; Burch, 2010; Carlsson-Kanyama et al., 2013; Nalau et al., 2018).

To overcome these barriers, changes will be necessary in the decision context for adaptation, including values, rules and knowledge interactions (Gorddard et al., 2016). For example, a key impediment to collective action and social innovation results from a combination of values and rules. The strong resistance to change in sections of the community, combined with the deep governance path-dependency of the French traditional democratic system, leaves limited scope for collaboration and participation in decision making and action. Changing the values and rules system to replace individualism with collaboration, sharing and participative actions will be challenging. All the values related to nature will also need to be considered to leverage adaptation actions (Pascual et al., 2017; Topp et al., 2021). In particular, the imbalance in power relations, with powerful decision-makers carrying values of resistance to change and embedded in the current form of governance, highlights the need for empowerment of other actors. Changes in informal rules that engage local actors with knowledge (e.g. learning about the role of ecosystems for adaptation and exploring options that will benefit ecosystems and people) could help empower local actors through shifts in power relations, especially those actors who are more vulnerable to the negative effects of global change (Woroniecki et al., 2019). Thus, we observe that transformative adaptation not only plays out in the 'visible' sphere, i.e. ecosystems and co-production actions, but also in the 'invisible' sphere: the creation of the necessary conditions for the implementation of those actions, with agency for change among individuals via the collective. Most of the co-production actions identified did not require significant transformation of actors' practices or ecosystems. But, conversely, to turn barriers into leverage points, the local community will need to transform the way they think, decide and act (Gretter et al., 2018).

These findings lead to the important question of who is involved in adaptation? While the majority of studies on adaptation pathways focus on policy changes in support of local authorities (Werners et al., 2021), results from our transformation oriented approach reveal that adaptation through NCA co-production actions is in the hands of individuals with competing values, knowledge, interests and power (Bosomworth and Gaillard, 2019; Cradock-Henry and Frame, 2021). Authorities have an undeniable role to play in activating levers to guide, facilitate and support adaptation actions, but the adaptation process that stakeholders have envisioned is largely based on the decisions and actions of individuals and the community. This point highlights the need to include all stakeholders in reflecting on the future adaptation of a region.

Although our approach was not intended to develop an action plan, the windows of agency and leverage points we highlight can form the basis for a next step of participatory research on the development and implementation of adaptation pathways (Cradock-Henry et al., 2020). In particular, the use of a participatory approach to backcasting scenarios and the engagement in the serious game helped stakeholders share world views and values, and structure a common understanding of the SES, in addition to building trust and respect. An agreed perspective on adaptation aligned with a desired vision is a first step towards leveraging NCA co-production actions for adaptation. It is also an important step towards participatory knowledge production and learning required to initiate transformative and sustainable change (Norström et al., 2020; Swart et al., 2014; Wyborn et al., 2019). Indeed, these approaches address sustainability challenges by providing new options while dealing with uncertainty (Bosomworth and Gaillard, 2019; Colloff et al., 2021), developing capacity and networks (Wyborn et al., 2019), generating empowerment and agency (Barnes et al., 2020; Woroniecki et al., 2019), re-framing human-nature relationships (Colloff et al., 2021, 2020), and encompassing different values and preferences.

6. Conclusion

We have shown that ecosystem-based adaptation (EBA) is central to the adaptation pathways of a mountain social-ecological system in the French Alps. EBA requires adjustment, transformation or development of new human-nature interactions (i.e. co-production actions). Co-production analysis reveals social-ecological mechanisms underpinning adaptation and the interactions between community agency and the implementation of EBA. To implement these actions, the local community will need to make significant changes in its social system in order to shift the SES along a desired pathway. This would be a precursor step to engaging in the development and implementation of co-designed adaptation pathways and in the associated learning process.

Further work is needed to consider EBA in broad adaptation strategies. In order to progress towards sustainable futures and the required transformations towards them, it is necessary to embed EBA within adaptation strategies in a systemic way and not only as marginal adaptation or sector-centric adaptation as often done in tourism, agriculture, fisheries or risk management. Moreover, our study stresses the need to make stakeholders aware of the role of ecosystems for adaptation and to link it to their main socio-economic concerns by demonstrating they are intimately linked. Recognizing the role of ecosystems in adaptation by maintaining and developing NCA supply in future adaptation pathways can help reconnect people to nature, re-structure and re-think the local social system to achieve adaptation objectives.

Author contributions

E.B. designed the research, produced data for the case study and wrote the paper; S.L. designed the research, participated in concept development and wrote the paper; B.L. participated in concept development, production of figures and wrote the paper; M.J.C. participated in concept development, reviewed and edited the paper; N.S. participated in game design, produced data for the case study and edited the paper and T.M. produced data for the case study.

Declaration of Competing Interest

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

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