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Leverage points for scaling nature-based adaptation to climate change

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Abstract

1. Despite ambitious goals and policies, climate change adaptation efforts remain slow and insufficient compared to the pace and magnitude of climate change. Nature-based Solutions (NbS) offer a holistic approach, with assumed co-benefits that jointly address climate change adaptation and mitigation, biodiversity conservation and other societal challenges. NbS are increasingly implemented to enhance local adaptation to climate change; however, they remain mostly marginal and isolated considering the magnitude of the challenge. Therefore, pathways to rapidly scale NbS are urgently needed. We hypothesise that NbS implementors are limited in their scaling strategies by their decision context.
2. We propose an empirical framework for systemic analysis of decision contexts for scaling NbS, showcased for the Grenoble Region in the French Alps. We use mixed qualitative methods—policy and strategy document analysis, interviews and workshops with NbS experts, to explore a pathway to a conducive decision context. To characterize this context and the pathway to scaling, we identified the main leverage points, their underpinning levers and their interactions.
3. According to workshops participants, NbS scaling should be supported by a combination of several deep and some shallow leverage points working simultaneously, including knowledge production and sharing, values and perception, local governance, supportive policies, financial support and landscape planning culture.
4. Our results stress the need for more emphasis on how to support the integration of NbS principles into cultural roots and values; and on how to integrate deep leverage points into adaptation policies and strategies. However, this entails many challenges because of the diversity of actors with different objectives, values and power, and the multiple institutional scales and timeframes. We propose our integrative approach as a way to further support decision-makers in navigating complex decision contexts for scaling NbS and building on simultaneous progress within each leverage point.

KEYWORDS
climate change adaptation, decision context, leverage points, nature-based Solutions, transformative change

1 | INTRODUCTION

Societies worldwide are falling behind in addressing the increasing impacts of climate change on social-ecological systems (IPCC, 2022). Despite the formulation of ambitious objectives and public policies at global and national scales (Palomo et al., 2025; Seddon, Daniels, et al., 2020), adaptation efforts are still insufficient and fragmented in comparison with the rate of climate change (Berrang-Ford et al., 2021; UNEP, 2022a). There is too little progress in including adaptation in local policies (Biesbroek & Delaney, 2020; Omukuti, 2020) and even more in implementing existing adaptation policies (Runhaar et al., 2018). This stresses the need to accelerate the implementation of successful adaptation initiatives on the ground to achieve Sustainable Development Goals and to reduce people's vulnerability to climate change (Haasnoot et al., 2020; IPCC, 2022). Some argue that filling this implementation gap and accelerating successful adaptation can only be achieved through transformative change (Colloff et al., 2021), which is 'fundamental, system-wide shifts in views, structures and practices across technological, economic and social factors, including paradigms, goals and values' (IPBES, 2024).

Multiple projects have been initiated to address these challenges, as captured in databases of adaptation initiatives (e.g. ADAPTATION AT ALTITUDE, https://adaptationataltitude.org/adaptation-at-altitude; CLIMAT, https://climate-adapt.eea.europa.eu/; PANORAMA, https://panorama.solutions/en/explorer). Among the different types of initiatives (technological, institutional, behavioural/cultural), Nature-based Solutions (NbS) are gaining academic and political traction as an integrated approach to tackle climate change, preserve biodiversity and ensure human well-being (Berrang-Ford et al., 2021; Seddon, Daniels, et al., 2020). However, the effective delivery of these assumed co-benefits is highly context-dependent and strongly depends on appropriate implementation (Cohen-Shacham et al., 2019). NbS have been defined as 'actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature' (Cohen-Shacham et al., 2016). While acknowledging their multiple potential co-benefits, this study specifically focuses on NbS as crucial climate change adaptation initiatives. Indeed, NbS can support climate change adaptation by for example reducing urban heat islands, protecting coasts, mitigating drought and flood impacts (Chausson et al., 2020; Nalau et al., 2018). When poorly implemented, NbS can harm both biodiversity and people (Nesshöver et al., 2017, 2021; Seddon, Chausson, et al., 2020). However, NbS implementation processes can be transformative by considering multiple values of nature and benefits, including diverse stakeholders, types of knowledge and sources of funding and shifting towards sustainable practices (Maes & Jacobs, 2017; Palomo et al., 2021; Welden et al., 2021). This potential is crucial for achieving the systemic shifts advocated by IPBES (2024) to overcome underlying drivers of biodiversity loss such as human domination over nature and societal power imbalances. However, project monitoring and evaluation needs to ensure NbS are not co-opted by elite interests or lead to inequitable outcomes, thereby undermining rather than supporting transformative change (IPBES, 2024). While NbS are implemented increasingly at the local level (Chausson et al., 2020; Woroniecki et al., 2022), they remain mostly isolated. Instead, pathways to rapidly scale NbS implementation are critically needed (Carmen et al., 2024).

If implemented at scale, NbS, as adaptation initiatives, could bring new ways of thinking, organizing and doing and generate systemic transformations towards just and sustainable futures (Morais-Da-Silva et al., 2016; Pereira et al., 2018; Westley et al., 2014). The social innovation literature identifies five main forms of scaling (Moore et al., 2015; Sarkki et al., 2024). First, scaling out, or impacting greater numbers, is based on dissemination, replication and spreading in other locations, contexts or with new populations. Although scaling out is most studied, it is generally not sufficient to induce systemic change, as it does not address the institutional and cultural causes of problems, which require other strategies (Fastenrath et al., 2020; Omann et al., 2020). Secondly, scaling up involves changing higher-level institutions, policy, rules and legislation to create a supporting institutional context. Thirdly, scaling deep changes people's values, cultural practices and relationships. Additionally, scaling in involves internal organizational adjustments to embed new practices, structures or skills, and scaling down focuses on the necessary means and allocation of resources to implement policy changes on the ground (Sánchez Rodríguez et al., 2021).

However, scaling does not happen automatically, remains challenging, and requires a favourable context (Omann et al., 2020). Indeed, NbS implementation faces many barriers, including knowledge gaps on effectiveness, uncertainties, limited funding or political commitment, unsupportive and conflicting regulations and institutional fragmentation and silos (Bruley et al., 2021; Calliari et al., 2022; Kabisch et al., 2016; Lambin et al., 2020). In addition, scaling NbS is challenging, because of institutional and cultural resistance to change and the need for agents of change with multiple skills (Dubo et al., 2023; Lam et al., 2022; Westley et al., 2014). Although the need for scaling NbS to contribute to transformative changes is recognized (Colloff et al., 2020; Keesstra et al., 2023; Welden et al., 2021), little is known on how different forms of scaling are supported or hindered by decision contexts, that is, 'the settings of societal decision-making processes that determines how choices and decisions are made to address a specific problem' (adapted from Gorddard et al., 2016). Knowledge

gaps also include how to design pathways towards a more favourable context, in which scaling is facilitated by institutional, social, cultural, economic cognitive, knowledge and values factors (Bruley et al., 2021; Schröter et al., 2022).

Here, we present an empirical framework for systemic analysis of decision contexts and potential pathways for scaling NbS for adaptation (hereafter NbS will refer to NbS specifically for adaptation), showcased for an empirical place-based study in the metropolitan region of Grenoble in the French Alps. The framework comprises the identification of main leverage points within the decision context (i.e. places to intervene leading to transformative change in complex systems), their underpinning levers (i.e. the concrete means to realize these changes) and their interactions (Abson et al., 2017; Chan et al., 2020; Meadows, 1999). We addressed three research questions (RQ): (1) Which changes in the decision context are required to support NbS scaling? (2) What are the leverage points and associated levers to achieve changes in the decision context? (3) Which pathway could transition towards an enabling decision context? Following the Three Horizon Framework (Sharpe et al., 2016), we elicited expert knowledge, first, by assessing the characteristics of the current (Horizon 1) and desired enabling (Horizon 3) decision context for NbS scaling in the study region directly informed changes required (RQ1). Then, by exploring the transition between these contexts (Horizon 2), we identified leverage points and the associated levers (RQ2) and developed the pathway (RQ3).

2 | DATA COLLECTION AND ANALYSIS

This study follows a qualitative and deductive approach (Soiferman, 2010) comprising four main steps (Figure 1, Top row): scientific and grey literature scoping; exploratory interviews; planning and strategic document analysis; experts and local stakeholders workshops. Our data collection and analysis approach was structured following the Three Horizon Framework (Sharpe et al., 2016) and targets decision context as the primary system for change, viewing its transformation as essential for enabling the scaling of NbS for adaptation (Figure 1, bottom diagram). The first horizon (H1) represents the current decision context losing prevalence with time while keeping essential elements giving way over time to the enabling context as the emerging third horizon (H3); this can be achieved by a transition pathway and associated leverage points as the second horizon (H2) building on emergent practices (seeds of changes) and new practices (new levers).

Mountain regions are particularly sensitive to the impacts of climate change such as droughts or floods, which affect ecosystems, human health and safety and livelihoods (Gobiet & Kotlarski, 2020; Klein et al., 2019). The Grenoble Region is composed of 273 municipalities with almost 740,000 inhabitants. Land uses include dense urban, peri-urban and rural areas in the plains, and rural and two protected areas in the hills and mountains. We chose this case study for its proactive approach to climate change adaptation including a pilot study carried out in 2021–2022 by the

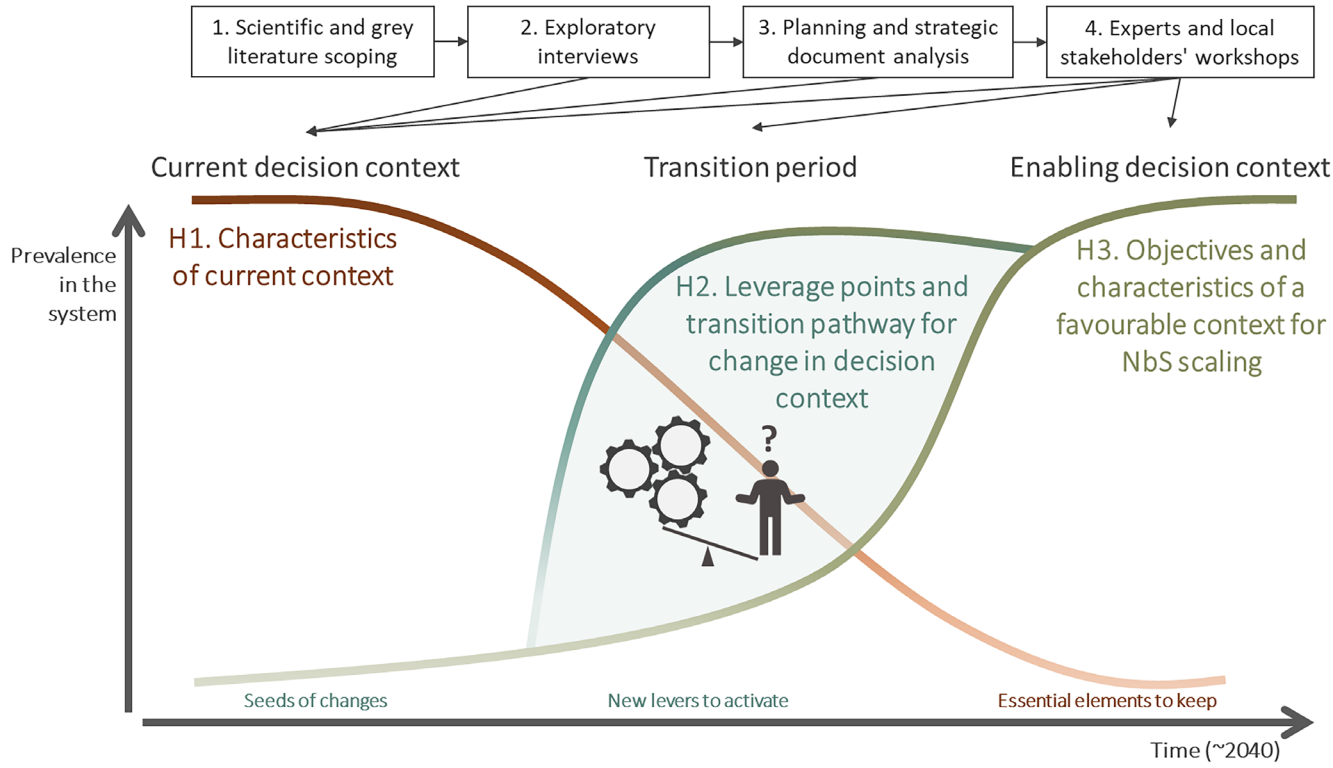

FIGURE 1 Methodological steps and research framework. Top row indicates the four methodological steps and their contributions to the analysis. The bottom diagram shows the framework of analysis, which structured the expert workshops. (H1 = first horizon; H2 = second horizon; and H3 = third horizon) (adapted from Sharpe et al., 2016).

regional administration to develop an adaptation strategy. We had the opportunity to follow the development of this strategy and to collaborate with land planning and already engaged management actors (Vannier et al., 2019).

First, to identify key factors characterizing decision contexts for NbS scaling, we conducted a scoping literature review (ARTISAN, 2022; Hussain et al., 2022; Tozer et al., 2022; UNEP, 2022b). We identified seven social, economic or political factors (ARTISAN, 2022; Hussain et al., 2022; Tozer et al., 2022; UNEP, 2022b): public policies and regulation; financial mechanisms; stakeholder involvement; knowledge production; knowledge sharing; habits and practices; and values and mindset. Those will be used to frame and analyse decision contexts during expert workshops.

Secondly, to obtain an initial understanding of the current decision context on adaptation and NbS in the region, we conducted 10 exploratory interviews with national, regional and local experts (see Table S1). These interviews covered the history of adaptation in national, regional and local public policies and institutions and the inclusion of NbS in adaptation. They were also an opportunity to identify potential participants for the workshops.

Thirdly, to gain a better understanding of existing levers to NbS scaling, we analysed five sub regional planning documents produced between 2015 and 2022 and that included adaptation in their action plans (see Table S2). These include two territorial climate–air–energy plans (PCAET), two regional natural park charters and one report of the regional adaptation strategy pilot study. From each document we recorded the adaptation objectives (often qualitative such as 'increasing the level of protected forest'), targeted climatic risks, social-ecological systems (forests, agricultural systems, aquatic systems, urban areas, protected areas) and implementation levers. We scored whether the levers were associated with concrete implementation measures (0: no lever was identified, 1: lever identified but without concrete measure, 2: concrete measure associated with the lever, 3: measure already in place).

Fourthly, we facilitated three workshops with experts to collectively identify the required changes in the decision context to support NbS scaling. Two 1-day workshops were organized in January 2023, with 12 and 9 participants (see Table S1) from local and regional public institutions and academia. To focus discussions, we analysed adaptation to drought and heatwaves, two major climate risks in the region. We divided participants into four subgroups according to their expertise: freshwater systems ($n=6$), forest and agroforestry ($n=6$) and urban areas ($n=5$ and 4). Using the Three Horizon Framework as a backcasting approach, participants envisioned a desired future and analysed how to reach it (Falardeau et al., 2019). Steps included the following: (i) defining a coherent set of future objectives for scaling NbS, (ii) describing an ideal future decision context to reach the objectives, (iii) characterizing the current decision context, (iv) reflecting on the transition phase, the changes required in the decision context (elements to be abandoned, or maintained or new levers to be developed), the interactions among these changes and which actors should be in charge of these changes. Discussions in Steps (ii) to (iv) were organized according to the seven decision context factors (see Figure S1 for an illustration of workshop output). This normative choice was made to constrain participants to consider all the drivers and to not overlook those that usually are, as values or habits. A third workshop, considered as a fifth subgroup, convened 30 local actors from the tourism sector, agriculture, forestry and infrastructure, in collaboration with Espace Belledonne, an association intending to initiate discussions on adaptation in the Belledonne range. We adapted the method to a 2-h format and to the expertise of the participants, who reported their experiences with adaptation, identified the barriers encountered, analysed changes needed to scale adaptation and finally prioritized actions.

We then analysed and synthetized data from the workshops. We first considered all suggestions for changes in the decision context mentioned by participants during discussions on the transition phase (H2). While workshop discussions involved a range of perspectives on potential changes, only suggestions cited at least twice by participants across the five sub-groups were included as levers (i.e. the concrete means for intervention) in the analysis. Each selected lever was then characterized according to the perceived actors in charge, its likely scale of action (local, regional, national), and its potential leverage effect as defined by Abson et al. (2017), that is parameters, feedback, design or intent. Individual levers with similar underlying mechanisms and leverage effects were then grouped. These clusters, representing key places to intervene to change the decision context supporting NbS scaling, were then defined as leverage points, drawing on Meadows (1999). Lastly, we analysed participants' discussions on the interactions and dependencies among these levers and leverage points to draw a potential transition pathway and map interconnections between levers forming action blocks.

This research involved the participation of human subjects but does not require ethical approval as no personal data was collected during the process. All the participants signed a consent form concerning the audio recording of the interviews and workshops and the use of the anonymised information provided for publication purposes.

3 | RESULTS

This section presents the findings from our mixed-methods approach, addressing our research questions by first outlining the current state of adaptation and NbS planning objectives, then detailing the characteristics of the current and desired enabling decision contexts, the combined levers forming leverage points and finally a potential transition pathway for decision context transformation supporting NbS scaling.

3.1 | Adaptation and NbS scaling objectives

To contextualize the need for scaling NbS for adaptation, we examined the current integration of adaptation and NbS objectives within key regional and local planning documents. Despite the

TABLE 1 Proportion (and number of actions) based on nature targeting adaptation and mitigation in key documents (GREG: Grenoble Region, PCAET: Territorial Climate–Air–Energy Plan, PNR: Regional Natural Park).

	GREG adaptation strategy (not adopted)	PCAET Grenoble Metropole (2020–30)	PCAET Pays Voironnais (2019–25)	Vercors PNR charter (2023–38)	Chartreuse PNR charter (2022–37)	All
Actions that are based on nature	59% (13)	17% (5)	13% (3)	56% (10)	22% (5)	31% (36)
Actions that aim at adaptation	82% (18)	24% (7)	21% (5)	33% (6)	9% (2)	31% (36)
Actions that aim at mitigation	27% (6)	41% (12)	75% (18)	22% (4)	22% (5)	39% (45)
Total	22	29	24	18	23	116

existence of adaptation policies at European, national and regional levels, the integration of adaptation and NbS-related actions into local planning documents across the study area appears limited, unevenly prioritized and often lacks clear and quantified objectives (Table 1). For instance, while the Grenoble Region's non-binding adaptation strategy logically dedicates a high proportion of its actions to adaptation (82%) and NbS (59%), other reviewed documents showed a much lower and variable proportion of actions related to adaptation (9%–33%) and NbS (13%–22%). One notable exception was the Vercors regional park charter with 56% NbS-related actions. Objectives remained generic and not quantified, for example in forestry: 'Sustainably manage public and private forests (sylvo-genetic balance, natural regeneration, adapted species)' (GREG adaptation strategy) or 'Adapt forests and agriculture to climate change impacts' (PCAET Pays Voironnais); in agriculture: 'Changes in agricultural practices (no tillage, soil cover in winter, storage of agricultural effluents)' (GREG adaptation strategy); in cities: 'Greening cities and villages, create islands and cool paths' (PCAET Grenoble Metropole); and in water management: 'Limit water heating: re-plant hedges, riparian forests, restore river morphology' (GREG adaptation strategy).

3.2 | Current and enabling decision context

To evaluate the depth of change required, we characterized current decision context (H1) and then envisioned a desired enabling future (H3) to scale NbS, based on workshops participants' descriptions (Table 2). When describing decision contexts, participants were prolific on issues related to knowledge, policies and regulation, and stakeholder involvement but much less on values and habits, which they found more difficult to identify. Across the seven decision context factors analysed, a clear gap emerged. Participants perceived the current context as containing some supportive elements ('seeds of change') but remaining largely reactive and constrained by policy and funding limitations, siloed knowledge and prevailing habits and values that favour short-term gains and individual interests. In contrast, participants desired an enabling context characterized by supportive and locally tailored policies, agile and collaborative governance, accessible and co-produced knowledge, and a societal mindset prioritizing collective interest, long-term sustainability, as well as a positive valuation of nature and learning-by-doing.

The analysed strategic and planning documents mentioned many NbS levers shaping the current decision context, but often without concrete implementation measures (Table 3). Levers related to knowledge production, knowledge sharing and stakeholder involvement were frequent, but not associated with concrete measures. Conversely, the levers linked to public policies were those with most measures (e.g. existing public policies). Financial mechanism levers were among the least cited despite their critical role, with only one existing measure identified (i.e. private funds for sustainable forest management). Finally, few levers on habits and practices, and even fewer on mindsets and values were mentioned, for example, public commitments of municipalities supporting NbS (e.g. 'choice of local food or wood by public institutions').

3.3 | Six places to intervene supporting NbS scaling

During the workshop transition phase (H2), participants suggested numerous levers to bridge the gap between the current and enabling decision contexts, forming six main leverage points and implying multiple changes to foster an enabling context for NbS scaling (Figure 2). Below, we describe each leverage point and its associated levers, as conceived by participants as priority means of intervention.

Sharing a common understanding on NbS was the most cited leverage point. It refers to information sharing among academics, training organizations, associations, mediators and the media, along with all information users (e.g. citizens, students, professionals, elected representatives). Three levers were cited in the five workshop groups: education and training at all ages and in all sectors to increase skills (e.g. 'Need to include NbS issues in formal and lifelong educational and training systems, as for training of elected representatives'), awareness raising activities (e.g. 'Propose neighbourhood and market meetings, conferences or field trips') and local resource hubs as a

TABLE 2 Current and future enabling decision context for the Great Grenoble Region.

Decision context factors	Current decision context	Enabling decision context
Public policies and regulations	Existing public policies and regulations include NbS (e.g. French National Plan for Climate Change Adaptation 1 and 2, Common Agricultural Policy on hedges, Zero Net land Artificialisation). However, they remain poorly implementable and implemented, siloed, incoherent, short-sighted, inertia and complex. Among them, private property and its underpinning rules represent a major obstacle, especially concerning forestry, agricultural and urban management	Adaptation and biodiversity preservation are major priorities at the core of all public policies, as economy and employment are prioritized currently. They are coordinated by an agile local governance to guarantee the coherence of actions. NBS are standardized by the legislation, and their application would be based on stronger regulations, notably through real control
Financial mechanisms	Public funds are available (e.g. Green Fund, Recovery Plan, Common Agricultural Policy, Water Agency) but misdirected, fragile, fragmented and politicized, targeted for mitigation rather than adaptation solutions	The implementation of adaptation projects by NbS is ensured by adapted, simplified, accessible and stable funding. The sources of funding are diversified (e.g. public/private partnership, taxes/penalties, incentives, participatory budgets, foundations) and emanate from the redirection of funding for harmful practices to the environment and health
Stakeholder involvement	There are institutional and actors' networks (e.g. around the management of natural risks in the mountains) and a new working group on NbS (ARTISAN/ADEME). However, local governance is siloed, disconnected from the ground, with little support and skills for NbS initiatives. Mobilizing elected representatives, citizens and practitioners around NbS remains difficult	Building on the existing willingness among actors to collaborate, all steps in the implementation of NbS initiatives are carried out in a transversal, inclusive and collaborative process, within the institutions' departments and with all concerned actors in the region
Knowledge production	Scientific community and practitioners are interested but produce knowledge that remains poorly operational, disconnected from the field, with strong gaps (real costs and benefits, efficiency, methods), in comparison with knowledge produced on grey solutions for which detailed implementation, cost evaluation and monitoring methods are available	Research and on-the-ground actors work together to produce operational and locally applicable knowledge (e.g. to deal with mountain specificities). Experiments contribute to the development of knowledge on the design, implementation, monitoring and evaluation of NBS projects
Knowledge sharing	Training/awareness networks exist at different scales (e.g. CRACC on a national scale, GRECs or *Adaptaville* on a regional scale) but knowledge is not easily accessible, training is siloed, outdated, not aligned with needs (e.g. agricultural high school with well-separated courses on agriculture, forestry and ecology). There is also a lack of structure to showcase NbS. Persistent confusion on what are NbS and overlaps with other practices (i.e. green infrastructure, ecological restoration, ecological engineering)	Knowledge is aggregated, accessible and shared with all in local resource hubs and practices networks. Adaptation and biodiversity issues are included in all formal and lifelong education. Different actors' groups are trained and informed through a variety of methods and media (e.g. learning feedback, simulation, serious games, meetings in the field, conferences)
Habits and practices	Adaptation is perceived as a renunciation compared to mitigation. There is a strong resistance to system transformation to maintain the current system in place. Supported by silos logic, individual interest, the prioritization of productivity (e.g. in agricultural and forestry sector) and a lack of collective commitment that often rely on local champions	Actors show commitment and courage to prioritize adaptation over economic and individual interests. Good practices (i.e. long-term, transversal, systemic, sustainable, nature-based solutions) are valued and considered as the norm
Values and mindset	Awareness is growing but there is a dominance of individualism, disconnection from nature, misperception of nature and change, preference for spectacular over relevant actions, generalized wait-and-see attitude.	The dominant values are turned over relational, collective and solidarity values. Nature's place (e.g. presence of nature in the city), experimentation and risk-taking are positively perceived in action and daily life by all.

single point of contact, to gather, homogenize and share knowledge and ensure availability for all (e.g. 'Giving an open access to scientific papers', 'Updates global/national data to local specificities'). A fourth lever cited in four groups involves the co-production of operational knowledge for all NbS implementation steps between academics, practitioners, decision-makers and citizens and a better integration of different knowledge systems (e.g. 'Develop co-production of local research needs and ambitious experimental project to build indicators').

Changing nature and people perception refers to changes in values, perception and representation of nature, people and, people–nature interactions. A frequently cited lever was cultural changes in nature perception (e.g. 'See nature as a common heritage and go beyond restricted perceptions such as river=flooding,

TABLE 3 Levers mentioned in analysed documents for the implementation of NbS in the forests, agriculture, freshwater, urban and natural areas (details per sector in Table S3).

	Public policies and regulations	Financial mechanism	Knowledge production	Knowledge sharing	Stakeholder involvement	Habits and practices	Mindset and values
Lever with measure already in place	2	1	0	0	0	4	0
Lever with concrete measure	10	6	2	2	3	2	0
Lever without a concrete measure	6	8	21	20	14	9	11
Actions with no lever identified	12	15	7	8	13	15	19

wetlands=mosquitos or free evolution=decline') and people–nature interactions (e.g. 'Increase the place of nature in urban areas and planning'). A second one was about facilitating experimentation, accepting failure and dealing with uncertainty in action (e.g. 'Value the right to experiment and fail, accept that solutions take time'). Another lever cited in four groups was changing the dominant set of values by valuing solidarity, commons, justice, collective action, social relations and relational values, instead of utilitarianism and individualism. All this, triggered by a lever cited in three groups, related to an increasing recognition of climate change by people experiencing impacts.

Restructuring local governance was seen by participants as a central leverage point, with the involvement of decentralized institutions and actors in NbS. Among the four corresponding levers, the most frequently cited lever was developing an agile governance system that could ensure the coherence of local actions according to local specificities (e.g. 'Adapt policies to mountain context or develop a common vision'). The second lever referred to mainstreaming collaborative and inclusive work at all implementation steps (e.g. 'Implement multi-stakeholder groups on hedges' or 'Systematize the use of collective intelligence methods'). A third lever was breaking silos and developing transversal practices within institutions and sectors. The last two levers related to the functioning of the governance system and the multifunctional nature of NbS, which call for these cross-sectoral practices. The last lever involved supporting local actions by integrating NbS into cross-cutting local strategic and planning documents (e.g. 'Include NbS in air-energy-climate or local urban plans').

Building supportive policy framework involves policymakers and decentralized institutions collaborating to ensure that national policies are flexible in their local implementation. It encompasses four main levers. The most frequent lever, cited in all groups, is the local tailoring of national policies to ensure their local relevance and applicability (e.g. 'Adapt policies to coastal or mountain specificities' or 'Build experimental and territorialized legislation'). The second lever is about prioritizing adaptation and including NbS within adaptation solutions (e.g. 'Adaptation and biodiversity are becoming of national interest' or 'Renaturation in urban areas become a priority for planning'). Thirdly, constraining regulation and control could enforce the use of NbS in certain cases (e.g. 'Identify priority adaptation zone in urban areas with restrictive regulations on soil permeability, rainwater management, open ground surface'). The last lever is the integration of adaptation into sectoral public policies at different scales (e.g. 'Orient CAP subsidies towards adaptive practices or in road infrastructure policies').

Securing, reorienting and diversifying funds for NbS involves governments, policymakers but also civil society such as companies, insurance or citizens. This leverage point included four levers. Two levers were identified in four groups: increasing funding from the private sector (e.g. '20% of insurance companies' profits could fund NbS as avoided costs', or 'Develop municipal crowdfunding for local NbS projects') and establishing incentives and disincentives (e.g. 'Impose tax benefits for companies that finance wetland and river restoration' or 'Provide bonus for private good practices to improve soil permeability in urban areas'). A third lever is re-allocating funds from harmful policies to NbS implementation, which could increase coherence between sectoral policies by (e.g. 'Reallocate road infrastructure budgets to include NbS'). Finally, a less cited lever was funding for project management, that is, human and technical resources from design to evaluation, in order to guarantee coherence between NbS objectives and their implementation (e.g. 'Develop the provision by companies of skilled professionals rather than funds').

Changing landscape planning culture refers to the modification of norms and behaviours and applies to actors at all levels, from policymakers to local practitioners. A widely cited lever was the mainstreaming of NbS in territorial planning, so that NbS would no longer be the exception (e.g. 'Create standards for planning including adaptation and NbS' or 'NbS are integrated in public markets with strong criteria'). Two levers were cited by three groups: one relies on the commitment from both elected representatives and citizens to push for and engage in adaptation processes to steer changes (e.g. 'Normalized civil disobedience and political courage to counteract top-down policies not aligned with adaptation'). The second lever was mainstreaming inclusive and transversal approaches within the governance system. A last lever concerned a shift towards lifestyles with reduced environmental impact.

Leverage points for NbS scaling	Levers associated to leverage points	Identified in workshops groups (n=5)	Actors in charge	Leverage effect	Action scale
Sharing a common understanding	Education and training at all level		Formal and lifelong educational system	Design	National to individuals
	Raising awareness activities		Everybody	Design	National to individuals
	Homogenised and accessible knowledge in Local resource hub		Scientists, practitioners, mediators and citizens	Design	Regional to local
	Operational knowledge (Scientific and practical)		Scientists, practitioners and citizens	Design	Regional to local
Changing nature and people perception	Nature's place and perception		Everybody	Intent	Individuals
	Accept to experiment and fail and uncertainties/ long term		Everybody	Intent	Collective and Individuals
	Change in dominant values		Everybody	Intent	Individuals
	Experiential recognition of climate change		Everybody	Intent	Individuals
Restructuring local governance	Locally coherent and agile governance system		Decentralized institution to be determined	Design	Regional/local
	Increase collaboration/ inclusiveness/co-construction		Institutions, practitioners, citizens, companies	Design	Regional to local
	Breaking silos		Institutions, companies	Design	National to local
	Integration of NbS in planning documents		Decentralized institutions	Design	National
Building supportive policy framework	Policies tailored to local specificities/coherence		Policy makers and decentralized institutions	Design	National to local
	Adaptation as a priority		Policy makers	Intent	National/global
	Constrained regulation and control		Policy makers	Design	National
	Integration of adaptation and NBS in sectoral policies		Policy makers	Design	National
Securing, reorienting and diversifying funds	Private sector funding		Companies, insurance, citizens	Parameters	National to local
	Incentives/disincentives		Policy makers	Parameters	National
	Reallocation of harmful funding		Policy makers	Design	National
	Funding for NbS project investment and functioning		Policy makers	Parameters	National to local
Changing landscape planning culture	NBS/ adaptation normalization		Everybody	Design	Collective and Individuals
	Political and citizen commitment		Policy makers, elected representatives, citizens	Intent	Collective and Individuals
	Systemic and transversal approaches		Practitioners, policy makers, companies...	Intent	Collective and Individuals
	Frugality		Everybody	Intent	Collective and Individuals

FIGURE 2 Leverage points and associated levers identified by participants during workshops.

3.4 | Leverage points interconnections

To understand the systemic nature of the required changes, we also analysed the interconnections between these six leverage points (Figure 3). In particular, *Restructuring local governance* involves three interconnections with other leverage points. First, two leverage points at the national and global levels influence the restructuring of local governance through a top-down connection: *Building supportive policy framework* for the prioritization of adaptation strategies and *Securing, reorienting and diversifying funds* towards NbS implementation. These two leverage points can offer the necessary space for local governance to implement NbS that are coherent with national biodiversity and climate policies. Second, one bottom-up connection involves two deep leverage points, *Changing landscape planning culture and Changing nature and people perception* at the individual and collective level. These leverage points are necessary to change working habits and develop the transversal, collaborative and inclusive practices required for effective local governance of NbS implementation. Finally, the third connection regards *Sharing a common understanding*. This leverage point supports the restructuring of local governance as it allows the involvement of many actors and ensures the best use of knowledge.

3.5 | One potential transition pathway

Finally, we synthesized participants' insights on the interplay of levers into a potential transition pathway. Workshop participants struggled to organize the proposed levers along a timeline and a sequence of decisions, and to formalize a temporal pathway, but they provided convergent information on how to group levers into action blocks on which to progress simultaneously rather than in a sequence (Figure 4). Participants also provided information on bidirectional connections among levers (dependencies and feedback), which we report only graphically (Figure 4) as they were not explored thoroughly in the workshops.

The first block of actions regards the development of a *common understanding and priorities around adaptation*, seen as a priority by all groups, through a long-term process that will become more prominent in the future. We note this finding may be biased by the participation of researchers and actors close to the research world in the workshops. Growing climate change awareness might help in this regard. This would contribute to the prioritization of adaptation within public policies and strategies on a national scale. Moreover, it could initiate a process of change in value systems and landscape planning culture, based particularly on education, training and awareness-raising at all levels from the common foundation of understanding.

The second block would establish *new rules and ways of doing*, including formal (e.g. policies, regulations) and informal rules (e.g. ways of doing, working habits) that facilitate NbS implementation and long-term regional adaptation. The prioritization of adaptation within national policies could foster its inclusion within sectoral policies (agriculture, tourism, industry...) but also its tailoring to local specificities and its integration into planning and development tools. This could also have a significant impact on funding, notably through the creation of dedicated funds, financed by a variety of mechanisms: a reallocation of environmentally harmful financing, the implementation of more

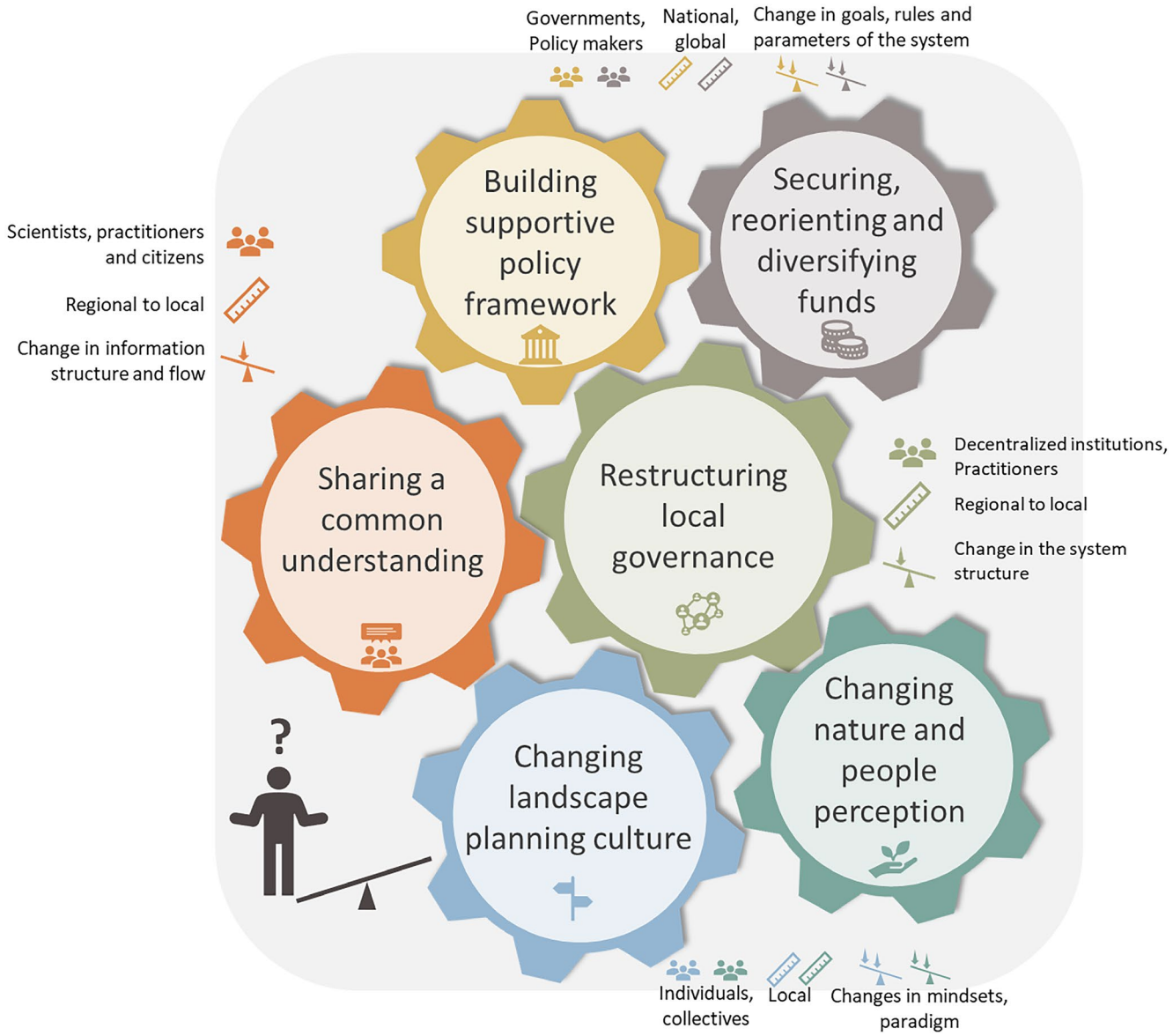

FIGURE 3 Leverage points identified by participants during workshops to move from the current decision context towards a context enabling NbS scaling. Icons indicate involved actors, scales and places to intervene (following classification of Meadows, 1999) in a system for each leverage point.

restrictive regulations in favour of adaptation and associated incentives for good practices through a financial bonus/malus system, and lastly, various forms of contribution from the private sector (insurance, companies, individuals). The latter is also related to changes in informal rules and actors' involvement. Indeed, public policies more adapted to the local context and changes in values and behaviour could support the implementation of new ways of working (breaking silos, cross-cutting, collaborative and inclusive approaches) and the commitment of various actors to adaptation.

The third block, *Securing coherent adaptation locally* fed by change in the two other action blocks and influencing them in return, would aim to institutionalize a local governance system guaranteeing coherent and flexible local action for adaptation, in particular through the implementation of NbS at scale.

4 | DISCUSSION

Guided by the Three Horizons framework, we co-explored the transition to an enabling future decision context and identified a comprehensive set of interconnected levers and leverage points supporting scaling directions. Emerging from place-based research on a specific metropolitan area of the French Alps, our findings offer valuable empirical grounding and critical insights with broader relevance into systemic challenges and opportunities for NbS scaling. The systemic barriers to effective NbS implementation identified, such as inadequate funding and regulation, institutional fragmentation or specific knowledge needs, are common across diverse contexts (Deely et al., 2020; Grace et al., 2021; He et al., 2022; Sarabi et al., 2019). Similarly, the leverage points we highlight, including fostering shared understanding, integrating diverse values, changing habits and

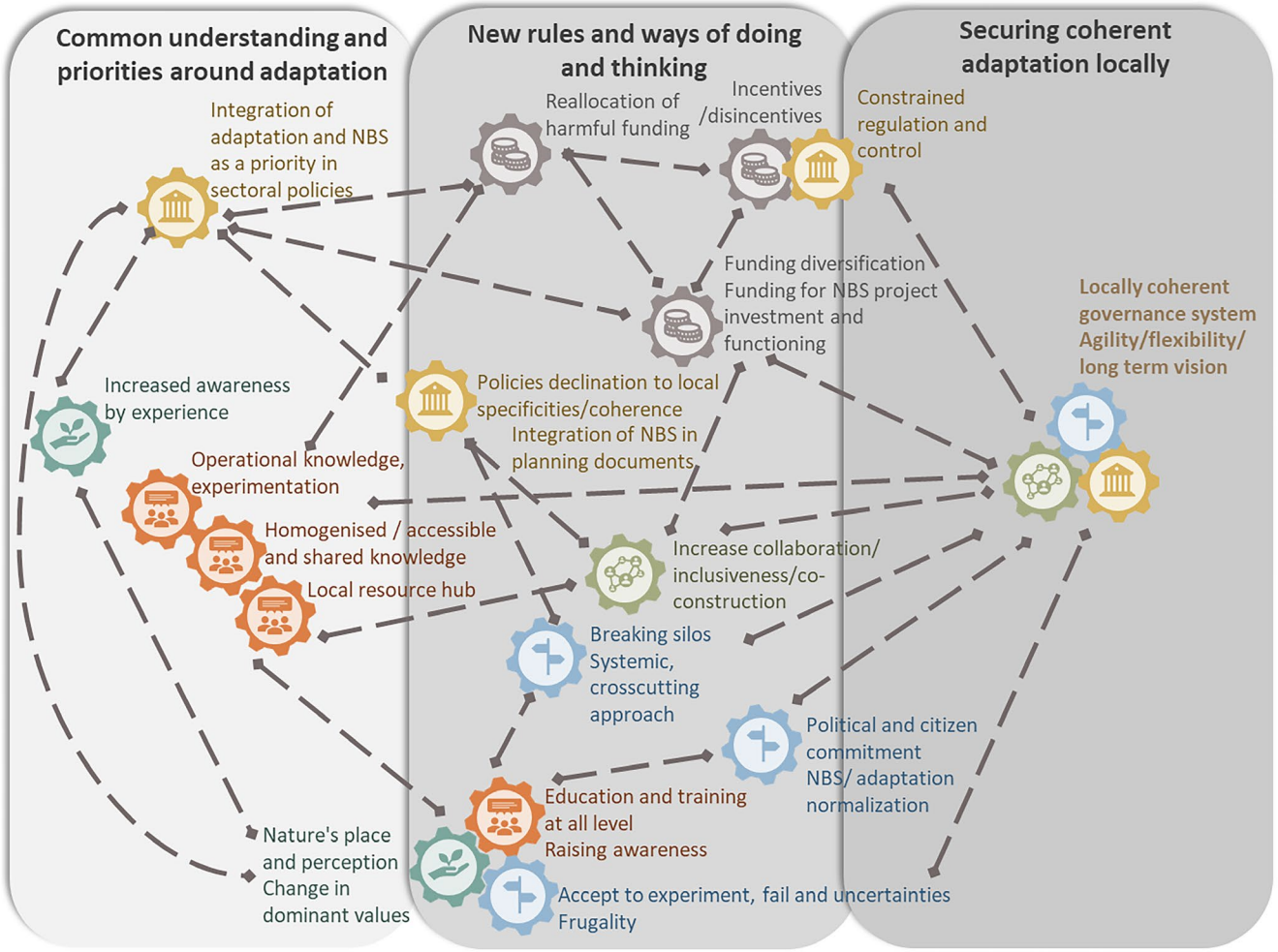

FIGURE 4 Synthesis of a potential transition pathway to bridge the gap between current and enabling context for NbS scaling showing interactions among different levers identified by participants during expert workshops. Bidirectional connections among levers are those highlighted during the workshops; others may exist but are not reported here. The three grey blocks do not follow a chronological way but happen simultaneously.

prioritizing NbS in climate policies, resonate with the findings of in other research settings (Dubo et al., 2023; Fastenrath et al., 2020; Sarkki et al., 2024; Tozer et al., 2022; UNEP, 2022b).

Although the specific solutions must be locally tailored, our findings contribute to the growing understanding of how to scale NbS by highlighting systemic, transferable dynamics that enable their implementation in varied socio-ecological settings facing climate adaptation challenges (Locatelli et al., 2025). This knowledge is essential to scale good practice towards nature-based transformation (Colloff et al., 2020) and avoid the pitfalls that could instead foster maladaptation through ecologically and socially harmful practices (Seddon, Chausson, et al., 2020).

4.1 | Building resources, practice and leadership for replicating NbS

Scaling-out NbS entails several strategies such as growing, replicating, transferring or spreading principles (Lam et al., 2022). Scaling-out requires producing and sharing best evidence from scientific and practical knowledge (Calliari et al., 2022). Despite numerous initiatives to support global and local knowledge production, important gaps remain, for example, on NbS effectiveness, efficiency, co-benefits and adverse impacts (Chausson et al., 2020; Grace et al., 2021; Kabisch et al., 2016). Filling these knowledge gaps requires long-term experiments, monitoring, modelling and spatial analyses combining scientific, technical and practical knowledge to select the best NbS for specific socio-ecological contexts (Thomas et al., 2018; Vermeulen et al., 2018). Cross-sectoral and cross-scale approaches build necessary social capital to share common goals, knowledge and experience to develop and spread successful NbS (Fastenrath et al., 2020; Omann et al., 2020). Secure funding is also key to growing or replicating NbS. Considering alternative funding models (e.g. crowdfunding, sponsorship foundation), engaging the private sector in financing NbS, harmonized assessment of incentives and disincentives, accountability to foster good practices and devaluating bad practices are common solutions (Droste et al., 2017; Lambin et al., 2020). Finally, some levers identified by participants

but poorly addressed in other cases could support scaling out. Of note is the suggestion of NbS implementors experimenting, learning by doing and failure being valued by society.

The social innovation scaling literature (Gorissen et al., 2018; Lam et al., 2022; Moore et al., 2015) suggests that the number of levers identified could also support NbS implementers in engaging in scaling strategies. First, implementors would need to modify the purpose of their initiatives towards greater impacts, which could be enabled by a supportive social, cultural and political context (Lam et al., 2020). They will also need to develop leadership, management, political, partnership and learning capabilities (Moore et al., 2015; Westley et al., 2014). The levers associated with training and capacity-building could facilitate such processes but will need to target such skills rather than only technical practice, as requested by workshop participants. NbS implementors thus will play a central role in building an enabling context as they contribute to producing and sharing practical knowledge, shaping policy debates, showcasing principles underpinning their initiatives and raising awareness about NbS. Further research is needed to investigate two-way interactions between decision context and NbS implementors' agency.

4.2 | Reshaping institutions and policies

Scaling up requires changes at higher institutions and government levels to influence rules, legislation and policies, and improving policy coherence locally (Moore et al., 2015). Levers supporting these two strategies identified by workshop participants were consistent with the literature. Achieving transformative changes in favour of NbS implementation requires breaking structural barriers such as conflicting policy frameworks or limited financial capacity (Portugal Del Pino & Marquez, 2023). Thus, aligning climate and biodiversity priorities in national to local policies, including sectoral, could facilitate NbS up-scaling (Calliari et al., 2022). Furthermore, adequate and just allocation of funds, consistent investments, especially by the private sector, and binding climate and biodiversity policies could mainstream NbS implementation (Calliari et al., 2022; Gerritsen et al., 2021; Toxopeus & Polzin, 2021). Up-scaling strategies also rely on increased capacity and support from policymakers, elected representatives and the private sector. Widely sharing knowledge, including integrating NbS into professional training and formal education, could be effective (Davies & Lafortezza, 2019; Thomas et al., 2018).

Two other forms of scaling identified recently can help to unpack up-scaling and are consistent with the levers linked to restructuring governance and to the changing landscape planning culture (Sarkki et al., 2024). First, scaling down, that is, guaranteeing the means to implement policies at local level. Participants requested top-down dynamics to tailor national policies to local contexts, as highlighted in other local ecosystem-based adaptation cases (Bruley et al., 2021; Dubo et al., 2023). They also highlighted the need for funding resources (manpower, infrastructure, training…) for NbS implementation from design to maintenance (Dorst et al., 2022).

Then, scaling-in, that is, adjusting the structure, functions or capabilities within an organisation to implement the expected practices, 'recognizing that change "outside" requires change "inside" institutions too' (Sánchez Rodríguez et al., 2021). Although critical barriers linked to institutional functioning and capacities have been reported repeatedly (e.g. limited collaborative governance and insufficient public resources), levers for the required restructuring are rarely documented (Dorst et al., 2022). Accordingly, participants pinpointed this issue without suggesting any effective levers. Polycentric governance involving collaborative, cross-sectoral and inclusive arrangements is proposed as effective for NbS implementation (Kabisch et al., 2016; Martin et al., 2021), but a strong public actor at the core of this system is still necessary (Wamsler et al., 2017; Zingraff-Hamed et al., 2021). The inter-municipal level is suggested as most relevant for integrating NbS and adaptation in landscape planning (Fastenrath et al., 2020).

4.3 | Deep levers for transforming practice and institutions

Deep-scaling and the levers identified to support it through societal changes in beliefs, practices and values remain poorly addressed in the NbS and scaling literature. Two types of levers are however frequently identified. The first is changing the conceptualisation of nature–people relationships and reconnecting people with nature (Chausson et al., 2023; Welden et al., 2021). The second is increasing climate risk perception as a trigger in behavioural change and implementation of adaptation measures (Braunschweiger & Ingold, 2023; Dubo et al., 2023). Cognitive and cultural factors identified by workshop participants such as learning by doing, dealing with uncertainties, long-term vision and failure or commitment are often reported as important levers but lack concrete means for their activation (Colloff et al., 2021, 2025). Deep-scaling NbS could also be supported by increasing awareness, building like-minded communities and integrating multiple types of knowledge (Lam et al., 2022). This could be fostered at local resource hubs to share, learn, engage in relationships and networks through a variety of activities and with multiple audiences.

Ultimately, scaling initiatives require leveraging all directions simultaneously (up, in, down, out and deep), as efforts to leverage only one direction may be ineffective (Sánchez Rodríguez et al., 2021). However, existing literature and international reports on NbS focus predominantly on the replication of initiatives and their integration into standards and policies, omitting essential deep-scaling strategies to support them (Cohen-Shacham et al., 2019; Cortinovis et al., 2022; Fastenrath et al., 2020; Xie et al., 2022). In fact, among scientific inputs, a review of 20 scaling frameworks used in innovation research only identified four main scaling directions, and deep scaling was insufficiently represented (Sánchez Rodríguez et al., 2021). Greater attention should be dedicated to how to integrate NbS in cultural roots, people's worldviews and practices (Omann et al., 2020). Further studies of interrelationships among scaling directions appear essential.

4.4 | Addressing deep leverage points in policies

There is a mismatch between these levers required to scale NbS, and those we identified in policies and planning documents. Although the French national adaptation strategy calls for NbS, we show that adaptation is barely considered in the emerging Grenoble Region's policy. Despite NbS inclusion in these documents and some major recent projects (e.g. Grenoble metropolitan Canopy Plan), a significant lack of operational levers persists, and the concept remains vague for actors, poorly mobilized and connected with adaptation (Salmon & Chuna, 2021). These findings suggest that these local adaptation strategies do not address and provide the means to activate deep leverage points.

Abson et al. (2017) pointed out that sustainability research and policy interventions failed to address issues of system design and intent (i.e. deep leverage points). A statement reiterated more recently pointed out that scientific attention tends to focus on shallow levers as they are more straightforward and easier to assess (Dorninger et al., 2020). As observed in the local policy documents studied, which are the strategic tools for scaling adaptation at the local level during the next 10 years, levers relying on existing or concrete measures to be implemented are those related to policy instruments (e.g. protection area), financial mechanisms (e.g. subsidies) and habits and practices (e.g. prioritizing of local food production). Such interventions are important, but by themselves, they will not lead to the changes required in the decision context unless deep leverage points are included. Furthermore, levers identified by the stakeholders almost all involve changes to the design and intent of the system (i.e. deep leverage point). It seems necessary to include within public policies the means to intervene and to question the current decision context, particularly regarding the production, flow and use of knowledge, the means of human and nature reconnection (Ives et al., 2018), but also the choices of what is valued or the role and functioning of institutions, their objectives and way of working.

4.5 | Unlocking synergies for effective NbS scaling

As our study highlights, NbS scaling can be triggered via a broad range of possible levers, at various places in the system. Indeed, the action blocks identified by workshop participants for the transition phase underscore the need for simultaneous progress across multiple leverage points rather than a linear sequence. Supporting NbS stakeholders in their decisions and actions for prioritizing interventions requires a clearer understanding of interactions, causality links and feedback loops among leverage points (Dorninger et al., 2020). However, while individual leverage points and associated levers are well known, they are often addressed separately and rarely considered in an interconnected and systemic way (Bennett & Reyers, 2024).

By using an approach integrating the Three Horizons Framework and different dimensions of the *decision context for* NbS scaling (Gorddard et al., 2016), our study highlighted several key interactions between leverage points (Abson et al., 2017; Riechers et al., 2022). For example, participants mentioned that supportive policies and regulations can provide and orient financial incentives, subsidies or taxes for implementing NbS. This, in turn, can make such solutions more economically viable and attractive to investors, thus amplifying their adoption and scaling (Calliari et al., 2022; Chausson et al., 2023). Participants also highlighted the importance of bottom-up influences: while institutions have an essential role in shaping society and organization behaviour and action, strong public support and awareness can also lead to increased demand for NbS. This social pressure is required to push policymakers to create and implement policies that encourage NbS adoption (Dacin et al., 2002). Sustained efforts are also necessary to enhance civil society's understanding and concerns about climate change and adaptation challenges. This can be facilitated through education and awareness raising campaigns that highlight the value of these solutions in addressing local impacts and thus gain local support and acceptance. Changes in values, perceptions and habits also depend on knowledge exchange and will be fundamental in encouraging the involvement and commitment of multiple actors in NbS co-production processes (Dubo et al., 2023).

Participants identified that restructuring local governance will require internal and external structural changes (Kauark-Fontes et al., 2023). First, this requires policies that encourage broad institutional collaboration and partnership, secured funds and integrating NbS in local planning policies (Frantzeskaki et al., 2020). Secondly, it involves changing local institutions' practices and habits towards more inclusive and collaborative approaches (Wamsler et al., 2020). Finally, knowledge availability and sharing, needed to implement NbS, were identified by our participants as foundational, supporting and being supported by all leverage points. This in turn depends heavily on research funding and the inclusion of diverse types of knowledge and stakeholders. Networks and partnerships are also particularly important for the co-production and sharing of this knowledge (Wamsler et al., 2014; Sarabi et al., 2019).

Addressing these levers together remains particularly challenging as it involves many actors with different objectives, values and power (i.e. national policymakers, civil society, local institutions, researchers, NbS practitioners, private companies and sectoral practitioners), institutional levels (from municipalities to states), spatial scales (from very local to national level) but also time frames (from immediate decision to long term policies or deep change in values). Our study did not analyse interconnections and synergies in depth (Dorst et al., 2022). However, the analysis and schematisation of the leverage points and pathway brought a relevant perspective to participants of the complexity and multi-scale interconnections within the decision context. The structured nature of the Three Horizon framework proved beneficial, enabling participants to collaboratively reflect on current realities, to envision future possibilities and facilitated the systematic exploration of transformative changes essential for NbS scaling (Schaal et al., 2023). Nevertheless, structured dynamic pathway approaches would appear useful to further support implementers and policymakers in their actions (Adams

et al., 2024; Richardson et al., 2020). While our approach helped to identify key leverage points and their broad interactions, further research is needed within this framework to explicitly co-design transformative pathways for the scaling decision context (Osei-Amponsah & Abdulai, 2025; Werners et al., 2021). This approach should be refined and replicated in different contexts for identifying common patterns of causality and ultimately supporting more effective actions to scale sustainability and adaptation initiatives (Carmen et al., 2024; Di Fant et al., 2025).

AUTHOR CONTRIBUTIONS

Enora Bruley designed the research, implemented the participatory approach, contributed to data acquisition and analysis and wrote the paper; Ignacio Palomo, Sandra Lavorel, Bruno Locatelli and Titouan Dubo participated in research process design and data acquisition and analysis; all authors reviewed and edited the paper.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Most of the qualitative data are presented in the results or as supplementary information. Furthermore, the raw data are not suitable for formatting for dissemination.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. List and characteristics of interviewed actors (EX INT) and expert workshops (ESW) participants in each subgroups: Forest and Agroforestry (F&A), Freshwater systems (FS) and Urban systems (URB 1 & 2) (Details of actors who participated in the local workshop were not recorded, so they do not Fig. in this list).

Table S2. Analysed strategic and planning documents description.

Table S3. Number and characteristics of levers identified in planning documents' action plans for the implementation of adaptation objectives based on NbS in the sectors of forest, agriculture, freshwater, urban and natural areas. 0: no lever was identified, 1: lever identified but without concrete measure, 2: concrete measure associated with the lever, 3: measure already in place.

Figure S1. Illustration of workshops output.

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