Chapter 7. Summary and synthesis of options, knowledge and technology gaps and capacity development[1]

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Note:

The Nexus Assessment chapters share a common thread of case studies highlighting Indigenous Peoples' and local communities' (IPLC) food systems. Chapters 1-4, 5.1-5.5 and 6 include one or more of these case studies. The case studies are presented in boxes and are distinguished by *box titles in italicized font*. Lessons learned from the common case studies are presented in Chapter 7, online Supplementary material 7.1.

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Executive summary

This concluding chapter of the nexus assessment maps out how to shift towards more sustainable pathways that build connections and synergies across biodiversity, water, food, health and climate change elements and actors, sectors, regions and scales and which can lead to potentially transformative futures that are just and sustainable (*established but incomplete*) {7.1, 7.2, 7.3}. Nexus approaches, particularly for selecting, negotiating and implementing response options identified in Chapters 4, 5 and 6, can help open and sustain future pathways and options by enabling key governance actors to tackle multiple systemic, compounding and cascading crises (*established but incomplete*) {7.2}. In order to do so, a series of suggested steps towards a "road map for nexus action" can help orientate understanding and action towards sustainable futures where positive nexus interactions are enhanced and failures to account for these interconnections leading to trade-offs and maladaptations are avoided. This road map can assist actors at all scales and across multiple sectors to work together to identify problems and drivers, test solutions and understand their synergies and trade-offs, develop processes to ensure equitable buy-in and participation, and facilitate implementation that is adaptive and iterative (*established but incomplete*) {7.3}.

There is a rapidly narrowing window of opportunity for action, given escalating environmental, social, cultural and economic crises and the costs of inaction (*well established*) {7.2.2, 7.2.3}. Many of the current and projected interactions across nexus elements have both negative social costs and rising risks across multiple systems such as increasing biodiversity loss, water and food insecurity, global pandemics and climate change, with particular concerns for amplifying, cascading and compounding effects through interlinkages among elements, actors, policies and responses (*established but incomplete*) {7.2.1, 7.2.2, 7.2.3}. Yet many nexus interlinkages fail to be addressed by policies, actions and options from a range of actors and institutions, due in part to the persistence of key nexus challenges around complexity, governance, values, scaling and finance as well as lack of capacities (*well established*) {7.3.7}. There are large costs of inaction in not resolving these crises, now and into the future, including both monetary and non-monetary damages from current and projected climate change; loss of human well-being and life from disasters and ecosystem degradation; loss of biodiversity and declines in other elements that are treated as externalities from resource extraction; and the risks of uncertain futures under conditions of climate change and biodiversity loss (*established but incomplete*) {7.2.3, 7.2.4}.

Acting now can result in cost savings as well as avoiding increasing damages over time (*established but incomplete*) {7.2.3, 7.2.4}. Evidence of the costs and benefits of undertaking key actions suggests that it is cheaper to invest in transformative actions, even in the short term (*established but incomplete*) {7.2.4}. For example, many response options are highly cost-effective themselves (e.g., ecosystem-based adaptation which has co-benefits for reducing the social and environmental costs associated with extreme weather events and biodiversity, while also providing livelihood and income opportunities), some pay for themselves in savings in other sectors (e.g., hidden costs associated with poor health or pollution) and for others their implementation would free up funding for use in implementing other response options (e.g., repurposing subsidies) {5.6, 7.3.5}. Response options implemented together in an integrated manner are often more cost-effective than acting on

each element independently. This implies that nexus governance approaches have the potential to deliver international objectives and meet global goals more inclusively and cost-effectively as well (*established but incomplete*) {7.2.4}.

Engaging actors and institutions through more inclusive processes is an essential component of nexus approaches, as this increases the possibility of co-developing and co-implementing response options and can assist in reconciling synergies, managing for trade-offs and encouraging co-benefits (*well established*) {7.3}. A road map as presented in the chapter can help spur discussion, improve negotiation of trade-offs and create more inclusive and collaborative action among a wide range of nexus actors and institutions beyond just policymakers, including the private sector and civil society alongside Indigenous Peoples and local communities and other marginalized actors and their interests (*established but incomplete*) {7.3.1, 7.3.2}. Actors confronting nexus challenges need a clear heuristic for framing, understanding, valuing and addressing these problems and for co-designing future pathways that reflect local sociopolitical realities and contexts {7.3}. A number of policy support tools and models are available to assist in developing these pathways: for example, using scenarios and futures thinking can inform the improved co-design of policies across sectors, determine key drivers shaping the nexus, identify trade-offs and co-benefits resulting from interactions in the nexus, and build understanding of the implications for the environment, people and economies at different scales (*well established*) {7.3.3}. Furthermore, nexus governance, with a focus on integrative, inclusive, equitable, collaborative and adaptive approaches, offers opportunities to for transformative change and associated shifts in structures, practices and values (*established but incomplete*){4.5, 5.6, 7.3}.

Attention to and negotiation of diverse visions and values of actors enables more pluralistic approaches, which can increase acceptance of response options and pathways, helping to ensure more equitable and potentially transformative outcomes for people and nature (*well established*) {7.3.4}. Participatory practices that uphold rights can help to build shared visions of alternative futures, with many processes and models available to envision sustainable transition pathways that engage with both complexity and uncertainty {7.3.4.2}. For example, policies and pathways that leverage Indigenous Peoples and local communities' own visions and knowledges show important attention to holism as well as successful outcomes for people and nature (*well established*) {7.3.4, appendix 7.2}. More transformative visions are those that provide alternatives to unsustainable and unjust values, knowledges and decision-making processes, societal structures and practices {7.3.4.1}. Attention to values can also shape consideration of specific safeguards at each step along the road map for nexus action to assist with 'course-correction' to enhance equity (*established but incomplete*) {7.3.7}.

Successful implementation and scaling of response options requires attention to necessary enablers which include policies and other sociopolitical options like financial and institutional enablers, among which dimensions of equity are particularly important (*well established*) {7.3.5, 7.3.6}. Drawing attention to enabling conditions, such as institutional capacities, financial and economic enablers, changes in behaviours and values, technological readiness and material endowments can help ensure better response option implementation (*well established*) {7.3.6}. Response option choices that pay attention to

participation, co-production and equitable distribution of benefits show stronger promise in delivering on positive outcomes for the nexus elements, and many tangible cases are already in practice of how this can be navigated and negotiated (*established but incomplete*) {7.3.5, appendix 7.2}. Yet not all response options chosen can be win-win, and understanding of the limitations, trade-offs and potential inequities involved are necessary, including consideration of previous policy failures (*established but incomplete*) {7.3.2, 7.3.3}. Attention to appropriate scaling of the most promising response options aids in accelerating their adoption, amplifying their impacts and normalizing them as mainstream solutions {7.3.7}. Systems thinking, participatory monitoring and continuous monitoring are also well aligned to nexus approaches and could be further extended (*well established*) {7.3.8.2}.

Addressing nexus challenges with use of the road map for nexus action can be assisted by the mobilization and strengthening of existing capacities that support the analytical, bridging, negotiation, social networking and motivational work of diverse actors involved in nexus governance. Amplifying and scaling action can be facilitated through strengthening additional capacities that can enhance transformative change (*well established*) {7.3.7}. In addition to the capacities identified in Chapter 4 necessary for facilitating nexus governance, several capacities have been identified that can amplify the transformative potential of response options. Supporting stewarding capacities can assist with understanding nexus elements and interactions by drawing on multiple world views, visions, evidence and knowledge sources, and by strengthening self-organization and collaborative action while facilitating continuous monitoring and learning assisted by knowledge brokering and intermediary organizations (*well established*) {4.2, 4.5, 7.3.7, 7.4.1}. Fostering 'unlocking' capacities can support actors to characterize indirect and direct drivers and their impacts revealing maladaptations, vested interests and incentive structures that create resistance to change, and can include the use of decision-support tools that support the sharing, assembling, implementing, assessing and evaluating of different knowledges (*established but incomplete*) {4.5, 4.6, Table 4.13}. Transformative 'innovation' capacities can uncover novel response options and enabling conditions, while anchoring and embedding them in context to assist with the transition away from business-as-usual approaches (*well established*){4.5, 5.6}. These capacities in turn can strengthen 'orchestrating' capacities which can facilitate strategic alignment of nexus response options (*well established)* {5.6}, foster collective nexus action across arenas of engagement operating across scales and sectors (*well established*) {4.6, 7.3.2} and co-create opportunity contexts for emerging novel response options (*established but incomplete*) {7.3.2}. Furthermore, continuous and iterative learning, monitoring and evaluation can help actors incorporate rapidly changing social, environmental and technological drivers {7.3.8, 7.4.3}.

Knowledge and technology gaps remain but should not prevent acting now (*established but incomplete*) {7.4}. Knowledge gaps particularly remain on nexus interlinkages (e.g., 3, 4 and 5-way interactions among elements of the nexus for understanding past trends, current status and future trends); data availability (e.g., on some nexus indicators); assessment methods, tools, scenarios and models (e.g., for supporting implementation of response options); engagement of Indigenous and local knowledge and Indigenous Peoples and local communities (e.g., scenarios that are informed by Indigenous and local knowledge); nexus response options (e.g., successful examples of scaling out); nexus governance (e.g., dimensions and dynamics of governance across scales and regions); and nexus financing

(e.g., integrating nexus benefits in financial decision-making and asset pricing) (*established but incomplete*) {7.4.2}. Mechanisms for addressing nexus challenges are also absent in most existing global frameworks and monitoring approaches (*established but incomplete*) {7.3.8.2}. There are also capacity gaps (e.g., on strengthening partnerships and capacity transfer) {7.4.1} and technology gaps (e.g., effectiveness of emerging technologies in delivering outcomes across the nexus) {7.4.3}. However, on-going research is filling these gaps, and in many cases, better understanding of these gaps can be accomplished through active co-production of knowledge while simultaneously taking action (e.g., through iterative experimentation) (*established but incomplete*) {7.3.8}.

7.1 Introduction

The preceding chapters have established the basis for understanding key interactions among the nexus elements of biodiversity, water, food, health and climate change and addressing the policy-relevant questions that emerge from them across biophysical, social, cultural, economic and governance systems. Current challenges of inequitable finance flows, short-term, fragmented and siloed actions, and a privileging of economic growth over human and ecosystem health have created indirect and driver drivers of negative change across the nexus. In turn, these interlinkages, feedbacks and emergent risks and outcomes are complex and dynamic. Nexus approaches and nexus governance can help navigate these interactions and feedback loops across actors, sectors, regions and elements (Estoque, 2023). **Chapters 4**, **5** and **6** have focused on assessing specific response options and other policy choices that enhance positive outcomes and synergies across nexus elements by focusing on practical questions of what to act on and by whom. While the preceding chapters have provided evidence for the necessity and urgency of tackling nexus challenges and finding pathways forward for just and sustainable futures, this chapter offers practicalities on how and what kind of transformation is possible.

This concluding chapter maps out how to identify, move towards and reinforce pathways that build connections and synergies across the nexus and can lead to transformative futures that are sustainable and just (Schipper et al., 2022). Past approaches that centre on one or two elements of the nexus and a narrow range of actors have not been sufficient because they do not account for the many interconnections between elements, across scales and among actors. Many policy and sociopolitical options exist to help decision makers navigate the complexity of the nexus by identifying current interconnections, opportunities and trade-offs, as well as facilitating understanding and anticipatory stances towards future risks and thresholds. This concluding chapter is designed to facilitate action not just among policymakers, but to spur vital deliberation and action among all governance actors. Gaps in current governance approaches, particularly siloed sectors and failures to anticipate trade-offs, suggest the need for a new approach, identified in this assessment as nexus governance. With a focus on integrative, inclusive, collaborative, equitable and adaptive decision-making, this approach can amplify synergies and reduce entrenched social-ecological inequities to increase transformative potential to tackle key nexus challenges (Ghodsvali et al., 2022; C. Stein & Jaspersen, 2019).

Key to understanding these processes are tangible real-world examples of where nexus approaches have catalyzed action in positive ways. For example, the cross-chapter case studies on Indigenous food systems that were found in each chapter of this assessment have provided grounded examples of holistic approaches to managing across nexus elements (see appendix 7.A.1 for a summary of lessons learned). These food systems are integrated and indivisible systems that combine high agrodiversity, self-determination and control over land and diets that meet guidelines for health and climate change, all guided by ILK and values reflected in cosmovisions (e.g., the philosophies, perceptions and world views held by IPLC regarding physical and spiritual connections with the environment). Many of these food systems have strong transformative change potential, which could also inform transformative change for broader food systems governance, including the incorporation of multiple views, the foregrounding of equity and benefit-sharing, the recognition of human health and well-

being as inseparable from environmental health,, and the possibility of transforming current control and consolidation of production and supply chains (Kuhnlein & Chotiboriboon, 2022).

Based on cases and examples, the chapter builds a "road map for nexus action" that can assist with synthesizing nexus approaches, nexus governance for decision-making, response options and visions for future pathways. A focus on the practicalities of 'how' can enable actors to determine what range of visions for the future of the nexus exist, what societies need to do to reflect these visions and values, and how to get there. The chapter outlines how actors and institutions can identify and assess steps for action and chart future pathways through an integrated road map (e.g., heuristic framework) to address nexus interlinkages and challenges. Furthermore, while this assessment has focused on the nexus of biodiversity, water, food, health and climate change, the insights gained have the potential to be applied in other nexus contexts as well, including in other sectors (e.g., energy, see Section 7.2.1) or on new issues emerging in international environmental policymaking (e.g., ongoing plastic pollution treaty negotiations). The chapter additionally provides a synergistic linkage with the IPBES Thematic Assessment of the Underlying Causes of Biodiversity Loss, Determinants of Transformative Change and Options for Achieving the 2050 Vision for Biodiversity (Transformative Change Assessment) by highlighting how nexus governance and response options can be crucial elements to help enable pathways towards transformative change.

7.2. Necessity and urgency for action

7.2.1 Importance of other nexus interactions

There are many other sectors or drivers that interact with the five nexus elements that are the focus of this assessment, and which contribute to the potential urgency of action. Consideration of other sectors or drivers affects the nature of interactions within the nexus and the response options for addressing them. Although not the focus of this report, other key sectors and drivers have been considered throughout the report and findings are consolidated and summarized in this section, as they may be of particular interest for actors engaging in the road map steps.

Energy use (driver): Energy provision, access and use are important factors of human well-being and sustainable development, with energy production being one of the main drivers of climate change and air pollution (IPCC, 2022b; Naik et al., 2021). Energy is considered as an element in many nexus studies, where it is often analysed in combination with food and water (Albrecht et al., 2018; Weitz et al., 2017). These three elements are highly interconnected because they compete for resources (e.g., water for irrigation vs. hydropower, or land for crop production vs. renewable energy, or biodiversity conservation vs. renewable energy) and are under increasing pressure from alternative needs driven by population growth and industrialization (Zhang et al., 2018). The provision of energy is among the main drivers of biodiversity loss and emissions of pollutants to the environment (Steffen et al., 2015), and thus transitioning to cleaner and renewable energy systems is key to mitigating climate change and improving human health (**Section 5.5.3.8**). The main renewable energy options and energy-related measures (e.g., carbon capture and storage, energy efficiency) are discussed in **Chapter 5.5**, where each response option is evaluated across a range of

environmental and socioeconomic indicators, e.g., offshore wind energy (**Section 5.5.3.5**) and solar photovoltaics on land (**Section 5.5.3.6**).

Mining (driver): Mining provides a critical source of raw materials for the manufacturing, transportation, construction and energy sectors, and is one of the most energy-intensive industries worldwide (Igogo et al., 2021). Mining consumes about 38% of global industrial energy use, 15% of global electricity use and 11% of global energy use (Igogo et al., 2021). Mining activities, which include prospecting, exploration, operation, abandonment and reuse of a mine, can lead to several direct and indirect impacts on environmental systems (Haddaway et al., 2019), and consequently on the nexus elements. Deforestation, soil erosion and contamination, contamination of water streams and wetlands, waste management, acid mine drainage (see **Chapter 2**, **Box 2.12**), metal deposition, sedimentation and increases in dust and pollutant emissions are some of the direct and more prominent negative impacts (Haddaway et al., 2019; Sonter et al., 2014), directly impacting biodiversity, water, food and climate systems. Other impacts are also observed, such as health problems due to exposure to contaminated water and food resources (Roach et al., 2013), food insecurity due to biodiversity loss and water contamination, and increased risk of emerging infectious diseases, such as malaria (see **Chapter 2**, **Box 2.12**). Health impacts often arise near mining areas and involve anemia and stunting in children (Von Der Goltz & Barnwal, 2019).

The global extraction of minerals has grown at an unprecedented rate in recent decades, now covering a total area of 57,277 km (Maus et al., 2020). The increased demand for some metals and minerals, such as lithium (used in powering electric or hybrid vehicles), is associated with unsustainable mining practices, especially affecting hydrological systems (Flexer et al., 2018) and presenting a trade-off for sustainable development. However, mining areas are unevenly concentrated with 51% of total area occurring in just five countries: China, Australia, the United States, Russia and Chile (Maus et al., 2020). The increasingly important role of deep sea mining has the potential to negatively impact on ocean biodiversity, calling for an urgent need to address existing knowledge gaps (Miller et al., 2018). Promising options for the integration of renewable generation into mining operations can contribute to the decarbonization of operations and reduce the risks associated with the volatility of fossil fuels (Igogo et al., 2021), mitigating some of the negative impacts of mining.

Pollution (driver and impact): Pollution, the introduction of harmful substances that range from chemicals and particulate matter to noise and light, is an important factor affecting the nexus elements across various environmental mediums, including the atmosphere (air), hydrosphere (water), lithosphere (soil) (**Section 2.5.2.4**) and all living organisms (Landrigan et al., 2018; Naidu et al., 2021). These impacts can be local as well as transboundary (Caswell et al., 2018; Groh et al., 2022; Naidu et al., 2021; Prist et al., 2023; Sigmund et al., 2023). Pollution is sometimes considered as a third planetary crisis behind biodiversity loss and climate change (Baste & Watson, 2022) and the IPBES Global Assessment Report on Biodiversity and Ecosystem Services (Global Assessment) rated pollution as the fourth most important driver of biodiversity loss (third-most important for freshwater) (IPBES, 2019b).

There are several forms of pollutants that interfere with human health and biodiversity (2.5.2.4), e.g., air pollution, where particulate matter (PM) and ozone, originating from the

burning of fossil fuels and wildfires, contribute substantially to the global carbon budget and lead to increased acute and chronic cardiovascular and respiratory diseases (Apte et al., 2015; Butt et al., 2020; Johnston et al., 2012; Koplitz et al., 2016), as well as negative economic impacts: for each one hectare of Amazon burned a cost of $2 million is generated in health services (Prist et al., 2023). Agriculture and the use of agricultural inputs can pollute water and soils, with heavy metals, plastic and microplastics, chemicals, antibiotics and nutrient excess, leading to biodiversity loss. Soil contamination reduces fertility, alters physical and chemical proprieties and leaches into water bodies. Moreover, biological or synthetic pesticides applied to crops are not only a threat to biodiversity but also directly and indirectly affect human health (Beckmann et al., 2019; Landrigan et al., 2018; Pham et al., 2011; Richter et al., 2015). Plastic pollution is increasing as one of the most serious environmental challenges, posing threats to animal and human health (Barboza et al., 2018; Li et al., 2023).

Pollution remains responsible for approximately 9 million deaths per year, corresponding to one in six deaths worldwide (Fuller et al., 2022; Landrigan et al., 2018). While reductions have occurred in the number of deaths attributable to the types of pollution associated with extreme poverty (i.e., household air pollution and water pollution), there are increased deaths attributable to ambient air pollution and toxic chemical pollution (i.e., lead). Deaths from these modern pollution risk factors, which are the unintended consequence of industrialization and urbanization, have risen by 7% since 2015 and by over 66% since 2000 (Landrigan et al., 2018). A number of response options in **Chapter 5** focus on reducing pollution, including nutrient (**Section 5.3.3.7**), pesticide (**Section 5.3.3.8**) and plastic and microplastic pollution (**Section 5.3.3.9**), water pollution (**Section 5.2.3.12**), short-lived climate pollutants (**Section 5.5.3.8**) and pollution prevention for health (**Section 5.4.3.7**).

Land, land degradation and soil (drivers and elements): Land is an essential component for all nexus elements (IPCC, 2019). Human consumption of food and other resources affects land use and its change, which in turn are key drivers of climate change, biodiversity loss, distribution of emerging diseases, food security and disruption of nutrient and water cycles (Fuller et al., 2022). Land degradation can disrupt important ecological processes such as nutrient cycling, seed dispersal and pollination, directly impacting habitats, causing species loss, disrupting ecological processes and facilitating the invasion of invasive alien species and the emergence of zoonotic infectious diseases, while deforestation and soil erosion can impair the ability of forests to capture and store carbon dioxide (IPBES, 2018, 2023b). Climate change-induced land degradation also negatively affects many aspects of health, including clean water, food and shelter (Brevik et al., 2019; Talukder et al., 2021). Estimates suggest that land degradation has contributed to the loss of ecosystem services valued at $6.3 trillion/yr as a result of impaired ecosystem functions (Sutton et al., 2016).

Improved land use is a critical outcome of the implementation of many response options, with a large proportion of the solutions proposed in **Chapters 5.1 to 5.5** having positive outcomes for land use (Nabuurs et al., 2022). Co-benefits of improved land management include improved biodiversity conservation, water availability and quality, ecosystem health, enhanced resilience and climate change adaptation, reduced risks and vulnerability to emerging diseases, and fostering the maintenance of cultural practices and values for many communities (**Sections 5.2.3.2**, **5.2.3.4**, **5.4.3.8**, **5.4.3.10**). Soil has also frequently been considered as a nexus issue (e.g., (Hatfield et al., 2017) and soils have been shown to

contribute positively to all nature's contributions to people and all of the Sustainable Development Goals (SDGs) (Keesstra et al, 2016; Smith et al., 2021). The ecosystem functions provided by soils underpin all elements of the nexus considered in this report. While soil was not considered as a separate nexus element in this assessment, soils frequently emerge throughout the report, featuring as important response options in both the food (e.g., **Section 5.3.3.2**) and climate change (e.g., **Section 5.5.3.1**) subchapters, with soil health emerging as an important shared solution (**Chapter 5.6**).

7.2.2 Rising future risks

As noted in **Chapters 2** and **3**, the continuation of current trends will continue to increase risks across most of the nexus elements, highlighting the dangers of continuing inaction. The impacts of these trends also constrain future decision-making to achieve policy goals such as the SDGs, the Kunming-Montreal Global Biodiversity Framework and Paris Agreement, potentially putting the goals out of reach (**Section 3.7.2**). Scenarios based on current trends (e.g., particularly the scenario archetypes of *nature overexploitation* and *food first* from **Section 3.7.1**) not only place biodiversity at risk but have negative or neutral implications for all other nexus elements (**Sections 3.2 to 3.7**). Scenarios based on continuing trends include a steady increase in food demand of between 51-98 per cent between 2005 and 2050 (Alexandratos et al., 2012; Valin et al., 2014; Van Dijk et al., 2021), with an increasing share of livestock products (Alexandratos et al., 2012; Valin et al., 2014) and increasing food loss and waste (Bijl et al., 2017; Lopez Barrera & Hertel, 2021). Globally, the environmental impacts of food systems in terms of greenhouse (GHG) emissions, land use change, water use and nitrogen and phosphorus cycling are projected to increase by 50-90 per cent between 2010 and 2050 under current trend scenarios (Springmann, Clark, et al., 2018). Where increases in food demand are not met by supply, these scenarios result in negative impacts on all nexus elements, including worsening food insecurity and nutritional health due to inadequate nutrient supply linked to chronic diseases and premature mortality (**Section 3.6**).

Climate change is projected to have continuing impacts on all nexus elements, with the risk of exposure to climate change projected to double across multiple sectors between the 1.5°C to 2°C temperature increases that are the goals of the Paris Agreement, and double again between a 2°C and 3°C warmer world (Byers et al., 2018), with the latter being representative of current trajectories. Impacts of climate change on biodiversity in these scenarios are generally negative and include shifts in the distribution of species and ecosystems, changes in species abundance and increased risk of extinctions (Kok et al., 2018; Leadley et al., 2014; Pörtner et al., 2021; Tallis et al., 2018). Scenarios of climate change impacts also include increasing stresses on water resources and food production systems, greater flood risks, higher risk to sanitation and hygiene, worsening of heat-related human mortality and morbidity, food-borne, water-borne and vector-borne diseases and mental health challenges (IPCC, 2019, 2021, 2022a). These have in turn been linked to increased pressures on social actors and rising risks of social conflicts (Bowles et al., 2015; Koubi, 2019; Schilling et al., 2020; Unfried et al., 2022), which can exacerbate other political conflicts, economic stressors and social unrest across the globe (Ben Hassen & El Bilali, 2022; Le Billon & Lujala, 2020; Scheidel et al., 2020).

These current and future trends foretell escalating environmental, social and economic damages, presenting a narrowing window of opportunity for action (Chapman et al., 2022; Lenton et al., 2019; Milkoreit et al., 2018; Richardson et al., 2023). These risks are compounded by the emergence and after-effects of the COVID-19 pandemic and the interconnected health, social and economic impacts of this global disruption (Lambert et al., 2020; P. McElwee et al., 2020). There are particular concerns around the risks of biodiversity loss and climate change producing compounding and cascading effects through their interlinkages with other nexus elements, actors and policies, which can result in the escalation of one crisis triggering or exacerbating other crises (Falk et al., 2023; Lawrence et al., 2020; Pescaroli & Alexander, 2018; Simpson et al., 2021). Focusing solely on single crises may therefore lead to unforeseen risks and missed opportunities (Bach & Wegrich, 2019; De Waal et al., 2019). These overlapping and interconnected crises have been labelled a "polycrisis".

Polycrisis situations present particular governance challenges in solving for, or having to adapt to, multiple stressors and compounding and amplifying effects, for which there are often no historical analogues at the global scale (Keys et al., 2019; Simpson et al., 2023). New and emergent tipping points (e.g., a point at which a system reorganizes, often abruptly and/or irreversibly) may be more rapid and non-linear than previously understood, particularly in ecological systems in response to climate change (Armstrong McKay et al., 2022; Barnosky et al., 2012; IPCC, 2022a; Meyer et al., 2022; Pigot et al., 2023). Recent studies have emphasized that many risks and deep uncertainties cannot be quantified or modelled and thus are under-considered in decision-making around climate change in particular (Kemp et al., 2022; Rising et al., 2022). These uncertainties around amplifying, cascading and compounding effects between and across elements provide even more justification for action to avoid tipping points, thresholds and potential systemic risks (Pascual et al., 2022).

In particular, the multiple and interconnected nature of these crises point towards needing to shift from managing single risks (e.g., typically one-by-one, lacking in context and connections, and ignoring patterns) to thinking of systemic risks (e.g., avoiding assuming that the future will be like the past of largely stable or predictable climate, being aware of the differences between what is known about risk and what is unknown) (IPCC, 2022a; Sikula et al., 2015). This will also require more attention to 'unknown unknowns', such as the low probability but high-risk events known as tail risks (Weitzman, 2011). For example, exceeding the 1.5°C temperature target entails many adverse impacts, some irreversible, and additional risks for human and natural systems (IPCC, 2023). The damages that could be caused by tail risks, particularly given an increasingly chaotic climate, include exceeding biophysical tipping points with high irreversibility such as extreme melting of polar ice or dieback of the Amazon forest (C. A. Boulton et al., 2022; Brovkin et al., 2021); these impact are so enormous and globally impactful that it is not possible to assess all the potential economic and non-economic damages of such events (Dietz et al., 2021).

Shifting from managing risk to building resilience (e.g., increasing the capacity of systems to absorb shocks or resist disturbance without crossing a threshold) is receiving increased attention within nexus literature (Hogeboom et al., 2021; Stringer et al., 2018). This is particularly the case with regard to the important role of biodiversity in helping to strengthen

resilient ecosystems, particularly to the impacts of climate change (Oliveira et al., 2022). Similarly, the water system is fundamental in ensuring resilience for terrestrial ecosystems, but is at risk from increasingly frequent tipping points in aquatic systems (e.g., harmful algal blooms, river depletion) (Boltz et al., 2019; Falkenmark et al., 2019). These important processes are reflected in use of terms like the ‘insurance value' of ecosystems and biodiversity to help humans avoid and adapt to shocks that might cause economic losses (Hahn et al., 2023).

Accordingly, ecosystem management actions and policies are increasingly aimed at protecting or reinforcing resilience to potential disturbances, such as through ecological forecasting to provide early warning of regime shifts and tipping points; increasing connectivity and protecting intact ecosystems; maintaining biodiversity and diversity across ecosystem types; and managing feedbacks (Chambers et al., 2019; P. D. McElwee et al., 2023; Pace et al., 2015). Resilience can also be built through socially-focused policies such as monitoring livestock stocking densities and harvest intensities or promoting cultural practices that increase resilience, like controlled fires or sacred forests (Caillon et al., 2017; Folke et al., 2016). Nexus approaches have been important to these efforts, as they have improved understanding of how resilience in one ecosystem (e.g., upstream forests) can help ensure resilience in another (e.g., off-shore coral reefs) (Delevaux et al., 2018). In addition, they have helped identify where negative impacts and loss of resilience in one system (e.g., soils after wildfires) can feedback to reduce resilience in another (e.g., pollution of water quality from elevated concentrations of heavy metals and trace elements) (Belongia et al., 2023).

Safeguarding and building resilience is reflected in many of the **Chapter 5** response options, particularly those in the categories of conserving, restoring and managing ecosystems: examples include groundwater governance (W09), working with biodiversity in agroecosystems (B03, C11), restoring soil health (F02) and carbon storage capacity (C01), expanding restoration practices to increase tree cover (B05, C13), and designating marine and terrestrial protected areas (B01). By mimicking natural processes, many nature-based solutions enhance the resiliency of both people and built and natural infrastructure (B02, W11, C14), as do examples of integrated landscape and seascape approaches (B09) and integrated watershed-health interventions (H12). Other sociopolitical options and financial response options to enhance resilience include microfinance (**Section 6.2.6.2**), which can help reduce vulnerabilities and provide a financial buffer for shocks (Gatto & Sadik-Zada, 2022) or rights-based approaches (B10) that can help ensure livelihood security during crises, such as the COVID-19 pandemic (Dey & Amerasinghe, 2022). Efforts to enhance resilience goals and reflect them in policy often entail attention to adaptiveness and reflexivity (Arnold et al., 2017; Davidson et al., 2019; Folke et al., 2016), also identified as key components of successful nexus governance (**Section 4.5**).

7.2.3 Costs of inaction

There are large costs of inaction for continuing under current trends. These include current and future projected damages to natural systems; costs of loss of human well-being and life from unhealthy and unsustainable diets, disasters and ecosystem degradation; efficiency losses from duplicative policies; and equity costs of rising inequality and intergenerational injustices and violence (Agarwala et al., 2022; Damania, Polasky, et al., 2023; Dasgupta,

2021; Kedward et al., 2023; Oda et al., 2023). Nonetheless, there are also real political and business risks to both action and inaction, which is one reason why delay has often occurred (Schipper et al., 2022). However, these costs of inaction grow over time: the more delay occurs, the higher the price tag of eventually addressing these impacts, as the sections below explain.

While many of the figures noted below focus on the measurable and monetary values of costs and risks, it should be noted that there are many more that are not as easily valued, particularly for the risks associated with biodiversity loss, land degradation and water insecurity, which remain often unpriced (Dasgupta, 2021). As noted in **Chapter 6**, over half of global GDP is estimated to be moderately or highly dependent upon the state of nature (WEF, 2020), yet damage to nature is treated as an unpriced externality (**Sections 6.1** and **6.2**) (UNEP, 2015). Ensuring the inclusion of these values has been a driving force behind the adoption of natural capital accounting (B13, see **Section 5.1.3.13**).

In addition to natural capital accounting, true cost accounting approaches have been used to estimate the environmental and health consequences of current pathways, and of food systems in particular (De Adelhart Toorop et al., 2021; Rockefeller Foundation, 2021). The recent FAO (2023) State of Food and Agriculture confirmed these hidden costs ($12.7 trillion, in 2020 dollars), based on data from 154 countries. These include damage from climate change, nitrogen losses and pollution in air and water, and habitat loss as well as burdens of disease from dietary patterns, nearly 40 per cent of which were generated in upper middle income countries (FAO, 2023b). Additional recent analysis has suggested that the costs of these externalities can be equal to or larger than the economic value of food production: hidden costs from environmental (38%) and health impacts (62%) have been estimated to be as high as $19.8 trillion, more than double the value of the total food consumed globally ($9 trillion) (Hendriks et al., 2021).

Similarly, externalities associated with fossil fuel and chemicals overuse have created a global air pollution crisis, resulting in 6.67 million deaths, with water pollution leading to an additional 1.36 million deaths. Welfare losses as a result of these premature pollution-related deaths were estimated at $5 trillion in 2013 (UNEP, 2019). Three million disability-adjusted life years (DALYs) and $12 billion in yearly economic losses are estimated a result of pollution, a cost disproportionately borne by the poorest countries (Fuller et al., 2022).

Estimating the costs of anthropogenic GHG emissions across the biosphere beyond air pollution have also revealed substantial costs and damages. This includes work to estimate the social cost of carbon using various integrated assessment models with different climate impact functions, assumptions on climate sensitivity, the inclusion of extreme events, and if endogenous adaptation to climate change is included, all of which contribute to substantially different estimates on the cost of emitting an additional ton of CO_2 (e.g., from as low as $1/ton to $185 or more) (Ackerman & Stanton, 2012; Auffhammer, 2018; Kikstra et al., 2021; Moore et al., 2017; Weitzman, 2010). However, many of these models do not sufficiently represent damages across the nexus elements, e.g., many do not capture the value of biodiversity and natural capital (Druckenmiller, 2022). If these damages were included, the optimal cost of a ton of carbon would rise substantially as most current estimates remain well below actual damages (Bastien-Olvera & Moore, 2020; Tol, 2023)

Other bottom-up approaches to estimating sectoral impacts from climate change have also been undertaken to simulate specific pathways of impact, such as depreciating capital stocks that slow growth (Moore & Diaz, 2015), representing reductions in individual's utility functions (Weitzman, 2009, 2010), direct impacts of heat on human health and productivity (Newth & Gunasekera, 2018; L. A. Parsons et al., 2022) and temperature and other climate impacts on food systems resulting in changing food supply, dietary quality, malnutrition and health outcomes (Beach et al., 2019; Hasegawa et al., 2018; Myers et al., 2017; Nelson et al., 2018; Springmann et al., 2016). One study found the long-term benefits of climate change mitigation to health alone to be in the order of $50–380 per ton of CO_2 mitigated (West et al., 2013), which would raise the social cost of carbon significantly higher than at present.

Unsurprisingly given this variety of approaches there are a wide range of estimates of the cost of climate inaction, as well as the cost of mitigating future carbon emissions to achieve emissions levels consistent with 1.5 or 2°C futures (Gambhir et al., 2022; Kotz et al., 2024). Nevertheless, many of these estimates suggest the cost of climate inaction are substantial, contributing to trillions of dollars of losses by end of the century (Rennert et al., 2022). Oda et al. (2023) estimated both market and non-market costs of climate change and suggested the cost of climate inaction could range from 2-4 per cent of global GDP by end of the century, with biodiversity losses contributing a third to half of these costs (Oda et al., 2023). In analyses of the impacts of climate change on the United States economy, the Office of Management and Budget has estimated that the United States gross domestic product could be reduced by 3 to 10 per cent by end of the century, leading to annual Federal revenue loss of 7.1 per cent by the same time period, leading to challenges in funding basic government functions (OMB, 2022). Other analyses have focused on specific damage estimates that have already occurred; one recent study estimates nearly $150 billion per year are directly attributable to anthropogenic emissions, leading to around $2.8 trillion in damages over the past 20 years of inaction, with more damage in recent years (Newman & Noy, 2023).

There are also substantial financial and governance risks, both for the private sector and for governments, from delays and inaction (Ai & Gao, 2023; Greenstone et al., 2023; Kedward et al., 2023; OECD, 2023; Ranger et al., 2022). Sovereign credit ratings are likely to be impacted by climate and nature risks, leading to higher borrowing for countries in the future and associated loss of budgetary revenue for other government functions (see **Section 6.2**) (Agarwala et al., 2022). For example, one model predicted that climate change could increase the annual interest payments on sovereign debt by $45–$67 billion/yr under even lower emissions scenarios (RCP 2.6), rising to over $200 billion/yr under high emissions scenarios (Klusak et al., 2023). Similarly, concerns about financial risks of banks and private companies exposed to nature and climate dependencies have risen in recent years, associated with potentially billions in exposure (Battiston et al., 2017; Calice et al., 2021; Crona et al., 2021) (see also **Section 6.1**), as well as legal and political risks for companies and sectors (ClientEarth, 2023). Estimates of climate risk on assets indicate that housing stock and pension funds both face risks of asset devaluation under longer-term climate trends (Gambhir et al., 2022). Stranded assets and other forms of financial value at risk could exceed more than $1 trillion in the oil and gas sector alone, with most of the risk for private investors in OECD countries, who would have exposure through pension funds and financial markets (Fuller et al., 2022).

Importantly, inaction gaps are expected to grow over time and at a high cost. Delays in delivering global biodiversity goals have been estimated to double the cost of action, with wider costs across the nexus through reduced agricultural productivity and higher food prices (NHM & Vivid Economics, 2021). Delays in addressing climate change mitigation have been estimated at an additional $0.5-5 trillion per year depending on reaching goals of 1.5°C or 2°C targets (with the higher end of costs of mitigation associated with reaching 1.5°C) (Sanderson & O'Neill, 2020). For lower income countries, estimated median costs of adaptation for the short-term (2030) are around $127 billion per year, rising to $295 billion/yr by 2050. Specifically for Africa, estimates of needs for adaptation include $50 billion/yr to cope with 1.5ºC warming by 2050, but would increase to between $100-300 billion a year by the end of the century should temperatures rise to 4°C (IPCC, 2022a).

Delays in action also increase the likelihood of discussions around the need for consideration of other options, such as for carbon dioxide removal (CDR). Failing to act on GHG mitigation now leads to a potentially increased need for land- and ocean-based measures for carbon removal later (see **Section 3.6.3**). Modelled pathways by the IPCC Working Group III report shows that CDR is required to limiting warming to 1.5 - 2°C, with the scale of CDR depending on the degree of GHG emission reductions in the near term (IPCC, 2022b). However, many of these carbon dioxide removal approaches and technologies can have serious negative feedbacks across nexus elements (Boysen et al., 2017; Cao, 2021). For example, ocean-based measures for carbon removal may have negative impacts on biodiversity as well as raising important social and ethical concerns, but these have not been strongly discussed in the literature (Cooley et al., 2023; Loomis et al., 2022), indicating clear knowledge gaps. Land-based measures such as bioenergy with carbon capture and storge (BECCS) or widespread afforestation without safeguards also likely entail significant potential for trade-offs with livelihoods, food security and well-being (Bluwstein & Cavanagh, 2023; P. McElwee, 2023), as well as negative impacts for other nexus elements like biodiversity and water (Creutzig et al., 2021; Günther & Ekardt, 2022). In addition to ecosystem-based methods, technological carbon removal methods, e.g., direct air carbon capture and storge (DACCS), are increasingly considered, but these are highly energy-consuming technologies which may have far reaching but as of now currently unknown consequences for nexus elements (Adun et al., 2024). While some studies have shown that relying on a diverse range of CDR approaches can reduce impacts and economic costs of their employment across the nexus (Fuhrman et al., 2023), many gaps remain in our understanding of potential feedbacks and other interactions.

7.2.4 Costs of action

Directly comparing the costs of acting now to prevent the large-scale potential damages noted above faces significant challenges. For example, biodiversity and nature's contributions to people protect many built and physical assets but often their value is not considered in benefit-cost analysis due to their non-market value (Dasgupta, 2021); in other cases, costs of action are relative and context-dependent, making them difficult to compare (Karolyi & Tobin-de La Puente, 2023; Rodríguez-Labajos, 2013). Despite these problems, increasing numbers of studies show that pre-emptive action is often significantly cheaper than dealing with the cost of climate and biodiversity losses after the fact. For example, estimated damages from climate change likely already outweigh by a factor of six the mitigation costs

that would be necessary to limit global warming to 2°C according to one recent study (Kotz et al., 2024). Other models have confirmed that when the full scale of potential damages are added into integrated assessment models, the benefits of reduced temperatures leading to lower damages to natural and social systems compensate for the extra mitigation costs of more ambitious policies, even in the shorter term before 2050 (Drouet et al., 2022).

Other studies have looked at counterfactuals of empirical damages from extreme events. For example, the total economic impact of Hurricane Katrina in the United States, estimated at $150 billion, would have been significantly reduced if coastal wetlands in the region had been preserved (UNDP & UNEP FI, 2021). In comparison, during Hurricane Sandy in 2012, also in the United States, wetlands are estimated to have reduced the costs of flood damage from that event by more than $625 million (Narayan et al., 2017). Protecting coastal wetlands has been estimated to have the potential to save the insurance industry $52 billion a year through reduced losses from storm and flood damage (Barbier et al., 2018).

The direct costs of zoonotic disease outbreaks between 2000-2010 have been estimated to surpass $20 billion, including public and animal health service costs, compensation for lost animals and production and revenue losses to the livestock sector (World Bank, 2010), while costs of pandemics linked to emergent zoonoses has been estimated to exceed $1 trillion per year, based on a range of diseases over the past century (IPBES, 2020). Preventing this disease emergence through biodiversity conservation and One Health measures has been estimated to cost an order of magnitude less than dealing with these health impacts later (e.g., potentially costing between $22-31.2 billion per year for integrated global strategies which would be as low as 2 per cent of the costs of dealing with pandemics) (Dobson et al., 2020).

The substantial gap in adaptation finance (estimated to be at least $194-366 billion per year (UNEP, 2023)) leaves many in lower income countries particularly exposed to these increasing human, economic and ecological costs. Estimates of the costs of adaptation for crops and livestock sectors alone by 2045 are around $145 billion annually (Weindl et al., 2015), while another recent estimate suggests costs of $205 billion per year for adapting the entire food sector to climate change (Petykowski et al., 2024). On the local scale, a recent estimate noted that around 439 million smallholder producers globally are estimated to already invest approximately $368 billion annually in climate change adaptation actions for nexus-related activities, e.g., food production and nature conservation on their lands, with each household spending an estimated $838 per year (Hou-Jones & Sorsby, 2023).

Widespread application of response options such as renewable energy, rehabilitating degraded landscapes and supporting sustainable food systems and circular economies can involve significant costs at the start (see **Chapter 5.6**). For example, a recent study aggregated the needs and costs of ecological restoration to be on the order of $1 trillion (Mirzabaev & Wuepper, 2023). However, the value of the benefits and synergies of such investments often surpasses the costs over time if all the direct and indirect, non-monetary and monetary returns are considered, particularly for future generations (Opal & Nathwani, 2023). As several studies have pointed out, the cumulative value of benefits of choosing environmental sustainability pathways is high given multiple co-benefits, while the risks of doing nothing are often underestimated in models (Ekins & Zenghelis, 2021). For example, the cost savings of aligning climate and health goals have been quantified in terms of

replacing fossil fuels with renewables, estimated to cut €250 ($269) billion from the global costs of controlling health-threatening air pollution (Rafaj et al., 2013). In the case of restoration costs mentioned above, while upfront costs can be daunting, restoration usually pays for itself within ten years, and sometime sooner, providing economic returns from $1.1-4.4 per every dollar spent (Mirzabaev et al., 2021).

Finally, there are also huge costs to siloed policies that waste resources and human efforts, which could be applied to harmonized nexus approaches. Although policy coherence through integration intuitively saves resources by combining efforts to achieve multiple goals, the question of how much it saves in actual practice has rarely been directly addressed. One study found that clustering SDG targets in Cote d'Ivoire, Mali and Senegal led to considerable cost savings as compared to implementing the targets individually (Pedercini et al., 2019). A recent analysis of Rwanda's implementation of the Rio Conventions found that integrating across these policies (e.g., not having separate plans to meet goals of each of the conventions) could reduce the transaction costs of land restoration by more than half. Well-coordinated implementation (e.g., applying a nexus approach) was estimated to save more than $45 million per year as compared to siloed individual policies that were not coordinated (Mirzabaev et al., 2023). Current inefficiencies in policies, particularly around land and water management, are estimated to be forgoing $329 billion in annual income from agriculture, grazing and forestry (Damania, Polasky, et al., 2023). These and other studies point to the potential of nexus approaches to reduce the costs of achieving multiple goals.

7.3 Road map to applying a nexus approach

Nexus approaches can deepen understanding of the interlocked challenges across biodiversity, water, food, health and climate change and provide a way to better operationalize solutions that are more than the sum of individual parts. Nexus approaches recognize that interactions across nexus elements are complex and dynamic systems, where change results from the interplay of multiple interacting elements, relations and actors and the reinforcement of positive relations and feedback loops in the system (Estoque, 2023). Nexus approaches seek to optimize synergies by working across nexus elements and their interrelations to deliver multiple co-benefits simultaneously. However, difficult decisions and trade-offs may still be required, and a nexus approach considers important interlinkages alongside the actors, institutions, power and finance that can enable or constrain positive change in a system. While such complexity means linear cause-and-effect may be difficult to determine, understanding patterns of interactions and feedbacks between nexus elements can move us towards or away from sustainable and just futures.

Actors confronting these ecological, economic and social challenges need a clear heuristic for framing, understanding, valuing and addressing these problems. Such a heuristic can support actors in charting future pathways that make sense in their own particular circumstances. Accordingly, the concepts of "principles for action" and "road maps for action" are increasingly popular ways of presenting tangible steps for tackling nexus challenges (Cremades et al., 2019; Gondhalekar & Erlbeck, 2021). For example, (Cremades et al., 2019) suggest a series of principles for integrating actions across the water, energy and land nexus with climate services that include understand stakeholders' needs; define nexus resources and system boundaries; engage in co-selection of climate variables; explore socioeconomic and

climate scenarios; ensure extended time periods for analysis; understand the nexus as a complex system; improve nexus governance; explore nexus economic analysis; identify low probability/high impact events; and have clarity on synergies, co-benefits and trade-offs. Alternatively, (Wahl et al., 2021) suggest a set of principles for operationalizing food-water-energy research in urban areas that recommend that: (1) knowledge development be linked to implementation; (2) engagement of stakeholders should align with government actors for implementation; (3) analysis should extend beyond material flows to include behaviours, habits and social patterns; (4) nexus thinking should be embedded in participatory approaches; and (5) policymakers in urban settings should actively integrate nexus research into their planning processes.

Other heuristics have included the concept of 'development cycles'. For example, (Gondhalekar & Erlbeck, 2021) suggest a development cycle for dealing with urban nexus issues that includes: identifying key assets; innovating on synergistic opportunities; designing and delivering options; capacitating and communicating solutions; and mainstreaming and scaling up. As another example, (Grafton et al., 2016) suggest a road map for risks and options assessment for decision-making that includes "(i) determining the decision space, objectives and stakeholders, or *scope*; (ii) *identifying* the triggers to be assessed; (iii) *assessing* causal risks; (iv) analyzing decision *options* involving controls and mitigants, including a summary and justification for the decisions; and (v) *implementing* decisions and reviewing outcomes".

Building on this previous work, authors of this assessment across multiple chapters worked together to discuss and create a useful road map for nexus action that outlines how key steps that align with nexus approaches can be taken by diverse actors engaging in different arenas of engagement and institutional settings. The road map can be visualized as a series of flexible stepping stones, not necessarily needing to be taken in a linear order, but which collectively form a pathway for action (**Table 7.1, Figure 7.1**). The road map is not only relevant to policymakers but is intended to enable all actors to work together to chart a course of action that enables more positive nexus outcomes. For an example, see appendix 7.2, case study 1 for how the steps of the road map can be used to help guide transboundary river management for the Amazon River Basin.

Table 7.1. Suggested steps of the road map for nexus action.

Step	Cluster	Section of chapter
Characterizing indirect and direct drivers of change	Explore nexus context	7.3.1
Identifying and convening governance actors	Explore nexus context	7.3.2
Understanding nexus elements and interactions	Explore nexus context	7.3.3
Co-creating visions and aligning values among actors	Coordination and strategic action	7.3.4
Identifying response options and assessing their synergies and trade-offs	Coordination and strategic action	7.3.5
Assessing enabling conditions and overcoming barriers	Implementation and scaling	7.3.6

Negotiating implementation and scaling and strengthening transformative capacity	Implementation and scaling	7.3.7
Ensuring ongoing monitoring, evaluation and learning	Implementation and scaling	7.3.8

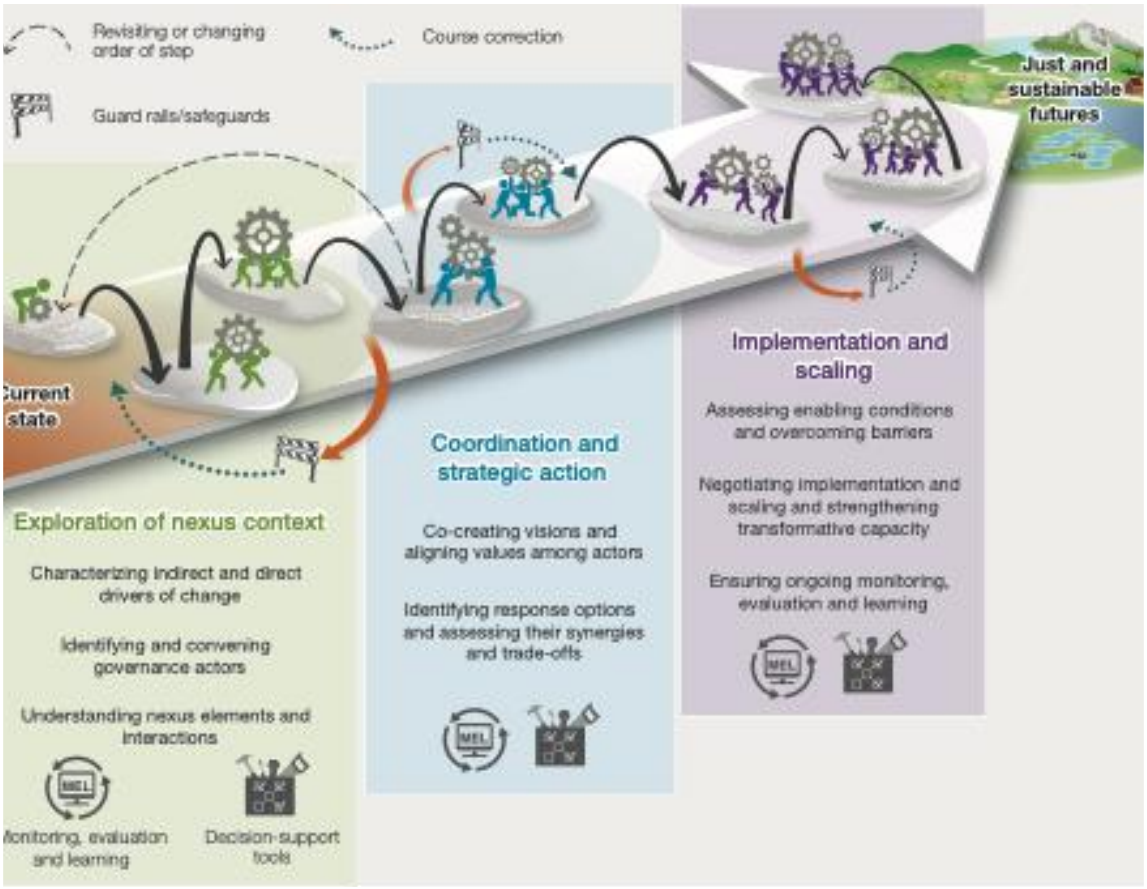

Figure 7.1. Schematic of different steps of the road map for nexus action. Addressing nexus challenges will require a number of interlinked, flexible steps to ensure that the right interactions are being addressed across the nexus elements, the right actors are involved in the process and the right decisions are being negotiated that are consistent with values and visions of stakeholders. Actors working together across each of the suggested eight steps can move towards context-relevant and appropriate outcomes, including just and sustainable futures, particularly if enacted through negotiated and collaborative problem-solving in an iterative manner. Clusters of steps cover exploration of the contexts of nexus problems, coordination and strategic action to address problems using a nexus approach, and implementation and scaling of solutions, with decision-support tools available along the way. The clusters of steps also highlight the importance of iterative monitoring and evaluation. Each step along the road map is important but not necessarily sequential, as demonstrated by the black arrows showing steps that move decision-making processes forward and the grey dashed arrows showing where steps may need to be revisited or implemented in a different order, thus entailing experimentation. Some steps need to be taken multiple times in an iterative manner (e.g., monitoring of change to re-negotiate and update planning and implementation over time as needed, with moves back to step 1 and ongoing social learning and adaptation). Green dotted lines indicate course correction, which can be supported by

consideration of specific safeguards (see 7.3.7) to ensure recalibration back to sustainable pathways.

The steps in the road map for nexus action aim to directly address the nexus challenges introduced in **Chapter 1** (e.g., high complexity, siloed governance, multiple values, inadequate scaling and lack of financing) in order to surface tensions, trade-offs and synergies and improve governance and decision-making that is deliberative, reflexive and timely. The steps include building a shared understanding about nexus elements and their interactions along with a shared vision and aligned values; identification of potential response options and associated synergies and trade-offs; critical analysis of the barriers and enablers that will shape success; identification of ways to enable ongoing and enduring implementation, including identification of signals for when a shift to other response options is necessary; and how the process and outcomes will be monitored, evaluated and revised over time. Several steps specifically aim to improve coordination and strategic action, including expanded attention to values and visions alongside actors and the arenas of engagement in which they interact, which can broaden spaces for dialogue, shift power dynamics, increase trust and social license and create greater support and legitimacy for response options. Such a process can help clarify key interactions and manage trade-offs in decision-making.

Subsequent sections explain each step in more depth (Sections 7.3.1 to 7.3.8), and each section outlines a series of questions for governance actors to consider as they explore ways to mobilize activities aligned with the road map in their particular context. This question-based approach is not prescriptive but helps readers work through the suggested steps in a practical way to identify tailor-made implementation pathways that advance positive change across nexus elements in a synergistic fashion. Additionally, the specific case studies in appendix 7.2 provide practical examples of how the different steps of this road map have been implemented in varied settings, including in New Zealand, India, Switzerland and China.

The role of various actors in the road map is context-dependent and hence which actors need to be involved, at what scale, how and when will vary. There are opportunities for actors at all levels, including multilateral action through the governing bodies of agreements related to the nexus elements, policymakers and legislators as appropriate and in accordance with their respective mandates, private sector actors, civil society, academic and research institutions, IPLC, youth, women and other actors related to any systems within the nexus (see **Chapters 5.1.2**, **5.2.2**, **5.3.2**, **5.4.2**, **5.5.2** for more information on actors for each nexus element). These actors, whether farmers, cooperatives, IPLC or policymakers, are already often highly interconnected through economic and social networks, and interact in various formal and informal arenas of engagement, from local farms or ecosystems to marketplaces, community organizations, national parliaments and international bodies (see **Section 4.5.1**and **Section 6.4.1**) (Schipper et al., 2022). Different actors will play different roles along the steps of the road map and should not be seen as 'fixed' in particular places: the respective roles of different actor groups/institutions may change over time, or across steps. Who is responsible for convening the implementation of these processes, their monitoring and evaluation, and building trust and ensuring transparency within these processes will also vary. While in many cases this will be national or subnational governments or policymakers, they need not always

be the driving force, nor be the appropriate actor to take all steps. While many governance steps are initiated by policymakers or civil society movements, there are also examples of individual actors that transcend different arenas of engagement to instigate change. For example, Ojha et al. (2021) describe how academics mobilize academic legitimacy to engage in policy processes or political advocacy around environmental issues, contributing to transforming national forest policies or climate governance. Who maintains or sustains these efforts over time also varies.

Nonetheless, specific capacities will likely be needed for the different actors as they consider different steps (see **Section 4.5.5**, **Table 4.12, Figure 4.19**). **Table 7.2** illustrates the various actors who have been involved in cases related to a specific response option drawn from **Chapter 5.1** on integrated land and seascape approaches in Xinshe, Taiwan, China (**Section 5.1.3.9**) as an exemplar, noting that other problems or response option discussions and choices will likely look different. Different actors may be more or less important for different steps.

Table 7.2. Steps for actors along the road map.

Road map steps	**Key actors influencing implementation outcomes**	**Key capacities needed (4.5.5)**	**Example: Biodiversity response option Integrated Land and Seascape Approaches (ILSA) in Xinshe, Taiwan, China (see Section 5.1.3.9)**
Characterizing indirect and direct drivers of change	Knowledge and educational communities Governments Global and regional institutions Civil society IPLC (including traditional and Indigenous governance leaders and mechanisms) Private sector and business organizations	Analytical Bridging	Science institutions using decision-support tools (e.g., participatory GIS) can identify the spatial scales of drivers. The identification of drivers can also surface power dynamics.
Identifying and convening governance actors	Knowledge and educational communities National and sub-national governments (depending on the boundary of the system) Civil society organizations (CSO), community-based organizations (CBO) and IPLC (including trade unions, faith-based organizations)	Bridging Motivational Social networking	Governments and private sector actors (e.g., certification organizations and businesses) often work in partnership with IPLC and academia (e.g., in multistakeholder platforms)

	Private sector and business organizations (including professional associations)		
Understanding nexus elements and interactions	Knowledge and educational communities Science-policy interfaces CSO, CBO and IPLC Global institutions	Analytical Bridging	Problem identification by global and regional institutions like the Satoyama Initiative, UNESCO Man and Biosphere Reserves, FAO Globally Important Agriculture Heritage Systems, and validated with local actors through knowledge coproduction
Co-creating visions and aligning values among actors	Knowledge and educational communities Science-policy interfaces CSO, CBO and IPLC Private sector and business organizations	Bridging Negotiation	Food production and nature conservation are often key goals, and ILSA is often implemented in formal partnerships to balance across these demands though collaborative work programmes
Identifying response options and assessing their synergies and trade-offs	Knowledge and educational communities CSO, CBO and IPLC Financing institutions	Negotiation Analytical Bridging	Examples include biodiversity-focused spatial planning, zoning regulations, habitat restoration subsidies, payments for ecosystem services, product certification and support for sustainable farming practices, all involving multiple stakeholders
Assessing enabling conditions and overcoming barriers	Knowledge and educational communities CSO, CBO and IPLC Financing institutions	Analytical Negotiation Social networking	Financial resources, technical capacities and infrastructure identified as barriers by stakeholders
Negotiating implementation and scaling and strengthening transformative capacity	Knowledge and educational communities National and sub-national governments (depending on the boundary of the system) CSO, CBO and IPLC Financing institutions	Negotiation Motivational Social networking Bridging	Stakeholders working in a collaborative, adaptive, context-specific and scale-sensitive way have shown success
Ensuring ongoing monitoring, evaluation and learning	Knowledge and educational communities CSO, CBO and IPLC	Social networking Bridging	Participatory assessments have been used for feedback from IPLC, civil society groups and others

7.3.1 Characterizing indirect and direct drivers of change

Problem identification is a key first step in the road map. As noted in **Chapter 2**, past trends in interactions among biodiversity, water, food, health and climate change have resulted in intensifying pressures on natural systems and inequitable outcomes. In particular, key indirect drivers, including economic growth, rising consumption, population growth, conflict and other indirect drivers have intensified the direct drivers of biodiversity loss (habitat destruction on land and at sea, direct over-exploitation, climate change, pollution and invasive alien species). These have manifested as pressures on the nexus elements such as depletion and contamination of freshwater, overuse of antibiotics, emergence of zoonoses, and continued GHG emissions (Richardson et al., 2023) (2.4.1). Underpinning these drivers are world views, values and behaviours which drive the intertwined challenges across the nexus and associated social-ecological injustices (Ivanova & Lele, 2022; Pascual, Balvanera, Anderson, et al., 2023; Pörtner et al., 2023).

Yet all of these drivers, particularly those related to economic and financial, technical, social, institutional, political, cultural and behavioral pressures, can facilitate as well as obstruct pathways to just and sustainable futures. In a complex adaptive system with many causal factors, making policy decisions and designing response options that aim to address the complex interactions between drivers and nexus elements requires careful identification of problems and drivers early on. To be able to do so, however, requires the existence of data and indicators on environmental change obtained through consistent monitoring (step 8, see Section 7.3.8). This highlights the iterative and potentially non-linear nature of the steps in the road map. This can be particularly challenging for identifying problems and drivers related to the complex interactions characterized by telecoupling whereby drivers in one region can results in impacts in other regions (Newig et al., 2020).

Problem identification, particularly to increase understanding of direct and indirect drivers, can and should involve many different actors and transdisciplinary work. Inclusion of diverse actors is a prerequisite for coordinated action in addressing key drivers, system interlinkages and power dynamics (Mason-D'Croz et al., 2016; Petersen et al., 2011). Examples include global platforms that bring together researchers, policymakers, civil society and the private sector to discuss and characterize problems and drivers (e.g., the EAT-Lancet Commission, the Earth Commission and other examples). For example, the EAT-Lancet commission has focused on common systemic drivers of obesity, undernutrition and climate change, including those driven by complex feedback loops (Swinburn et al., 2019). There are particularly important roles for the social sciences in helping to identify system boundaries and drivers (Jorgenson et al., 2019), alongside contributions of Indigenous and local knowledge holders, whose perspectives on environmental change are shaped by complex knowledge systems extending back generations (Lauer & Aswani, 2010; Reyes-García et al., 2023).

Collaborative methods to collect and analyze data, such as joint fact finding, citizen science and mediated modelling, where parties work together to jointly collect and interpret technical data, can be used to generate a shared understanding of the natural, social, economic and political interactions that may be driving the problem (Salmoral et al., 2019). These participatory systems thinking exercises have been identified as key tools to help change the dynamic of information flows from one-way to multiple (Bréthaut et al., 2019). Other

methodological tools that can encourage collaboration include use of causal models and pathways (Grafton et al., 2016), as well as experiments, games, workshops and participatory scenario development (Ghodsvali et al., 2019). (see also **Section 4.6** for an overview of decision-support tools supporting nexus governance.) For example, scenarios provide opportunities to think about what future pathways are possible that guide development away from current problems and towards more sustainable development. Such approaches include the identification of key drivers shaping the nexus and alternative trajectories for these drivers, and the associated trade-offs and co-benefits resulting from interactions between the drivers and nexus elements and their implications for the environment, people and economies at different scales (see **Section 3.7.1**). Methodologies that can be useful for scenario development and analysis are further discussed in Section 7.3.3. Iterative, continuous learning about drivers and their interconnectedness is also important, particularly as these drivers may change quickly over time, such as developments in indirect drivers like technology (see Section 7.4.3).

Table 7.3. Actor interactions and guiding questions for step 1 in the road map for nexus action on characterizing indirect and direct drivers of change, given the relevant setting and scale of intervention.

Actor interactions	Guiding questions for step 1
Drivers of decline in the nexus elements impact all governance actors, and all actors can play a role in enabling change, including government at different levels, Indigenous Peoples and local communities(IPLC). civil society, the private sector, international non-governmental organizations, media and the professional and research communities. This step draws on multiple knowledges, including Indigenous and local knowledge (ILK), humanities, technical, scientific and tacit knowledges. Developing shared understanding takes time and can be both intentional and emergent. It can take place in different arenas of engagement. Creating opportunities for building shared understanding and reconciling different perspectives among governance actors can help build trust for other steps of the road map.	• **What are the direct and indirect drivers of declines in nexus elements?** o Identify the range of possible direct and indirect drivers, including economic and financial, demographic, institutional, cultural, and technological, and interactions between drivers, that foster unsustainable resource use (see **Chapter 2**). o World views, values, norms and behaviours underpin and influence indirect drivers, including those that entrench negative outcomes as well as the capacity of people to influence change (i.e., agency). o Key conditions to be identified that may create barriers to change are those that: (i) result in compartmentalized, sectoral and siloed 'thinking', policy and practice; (ii) prioritize short-term over longer-term outcomes; (iii) prioritize private interests at the expense of public ones, including safety, justice, resilience and sustainability; (iv) do not account for non-economic values and contributions and the intrinsic value of nature. • **Why do these drivers persist?** • **Who stands to gain / lose from these drivers of negative change?**

	• **What opportunities could be harnessed to transform declines in nexus elements into positive change? Identify priority interventions in the short-, medium- and long-term and who needs to implement actions (see step 2)**

7.3.2 Identifying and convening governance actors

Given the interconnectedness of systems across scales, nexus governance approaches can help in mobilizing actors to work through each step of the road map in a negotiated collaboration, such as through multi-actor processes, whereby a variety of actors and social groups interacting in different arenas of engagement (deliberately or not) apply their knowledge, resources, capacities, values, strategies, interests and agency to promote or obstruct systemic change. Alignment of actors in addressing nexus challenges can increase adoption, policy support, equity outcomes and accountability (Petzold et al., 2023). This can create legitimacy and increase the opportunities for collective action and collaboration in visioning and planning, and around resolution of trade-offs, contested actions and priorities. Understanding and addressing power imbalances in decision-making processes can unlock opportunities for strengthening agency and capacities for collective action. Intermediaries, independent facilitators and knowledge brokers can help to enable collective action alongside knowledge co-creation. At the same time, these places and arenas of engagement should include space for disagreements and contestation and divergent visions of sustainability (Bulkeley et al., 2020; Lyall & Valdivia, 2019).

Different actors can play pivotal roles as transformative change agents in these processes. Some opportunities for transformation may be driven most efficiently by actors within a sector; for example, health sector actors working together can drive innovation and change with positive co-benefits across nexus, such as through reduction of the sector's environmental footprint and GHG emissions (**Chapter 5.6**; **Section 5.4.3.3**), or by mobilizing resources for preparedness, risk reduction and vulnerabilities related to public health events and pandemics, as is the case in countries that have a One Health platform (**Section 5.4.3.14**). Other opportunities will require collaborative action across multiple sectors and civil actors. For example, Brazil’s Unified Health System includes health professionals, veterinarians, ecologists and civil society as part of multidisciplinary teams for designing sanitary, environmental and epidemiological interventions for zoonoses prevention across food, biodiversity and health actors (**Section 5.4.3.14**). Other examples of multi-scalar and multi-stakeholder successes in addressing interlinkages among nexus elements include community-based watershed systems and city region food systems, among others (**Sections 5.1.3**, **5.2.3**, **5.3.3**). Such inclusive processes often need engagement of societal actors and arenas beyond those traditionally thought of, such as city planners deliberating alongside people working in the informal sector. This is reflected in the increasingly important emphasis on transdisciplinary in nexus literatures (Ghodsvali et al., 2019, 2022) and a core consideration in nexus governance (**Section 4.5**).

Yet some social groups are often invisible in public spheres and decision-making processes, due to processes of exclusion and marginalization along intersecting social dimensions such

as gender, ethnicity, disability, age, location or income. Putting such groups in central decision-making roles, or centring action on human-rights and social justice goals, have dramatically increased inclusiveness and knowledge diversity in decision-making interactions (Abbott & Porter, 2013; Bell, 2019; Dokumacı, 2023; Dominelli, Lena, 2023; Forsyth & Sikor, 2013; Henriksen & Larsen, 2023; Hickman et al., 2021; Pertiwi et al., 2022; Roelvink & Zolkos, 2011; P. J. S. Stein & Stein, 2022). Examples exist from diverse contexts of deliberative approaches that open up space for contesting prevailing knowledges, structures and practices, and engage with relations of power and domination that reproduce business-as-usual (Dominelli, Lena, 2023; Fazey et al., 2018; Görg et al., 2017; Henriksen & Larsen, 2023; Kakenmaster, 2019; Muok et al., 2021; Ojha et al., 2020; P. J. S. Stein & Stein, 2022; Ziervogel et al., 2022).

In particular, the knowledge, rights and aspirations of IPLC have historically been overlooked in many nexus decisions, creating injustices (**Section 4.5.2**, **Table 4.8**). IPLC have a unique understanding of nexus connections and provide alternative visions in terms of future outcomes, and their importance and value. Using the road map effectively can aim to centre these, and other marginalized, actors in these processes at every step, to ensure that they co-design nexus processes, co-develop archetype analysis, co-imagine futures and scenarios, co-evaluate synergies and trade-offs, co-identify preferred response options and their relevant indicators of success and co-evaluate effectiveness (IPBES, 2022c, 2023a). Such collective and collaborative arrangements can enhance nature's contributions to people and the well-being of IPLC as well as the wider global public (Sangha, 2020). As one example, diverse actors and their values have been key in driving transformative change in inclusive agroecological farms and protected areas co-management in India (see appendix 7.2, case study 3). This shift has involved enhancing the decision-making authority of farmers, community-based organizations, IPLC and other traditionally marginalized groups, including orphans and persons with disabilities (Balasubramanian & Sangha, 2021, 2023), while prioritizing integrated action in farm-forestry systems. Decision-making takes place in interactions with government authorities that regulate activities as well as private sector actors that form production value chain.

A crucial step is to identify actors who have the authority and capacity to convene other actors in an integrated manner (Artioli et al., 2017). Methods that can help identify such actors include social network analysis (see **Section 5.1.2** for an example) (Melloni et al., 2020; Salmoral et al., 2020); stakeholder mapping of different spheres of engagement across nexus systems and elements (Tye et al., 2022); and interest-influence matrices of stakeholders to identify where power is unevenly distributed (Hattam et al., 2020). Once actors have been identified, they can convene together in different ways. Workshops can be a simple tool (Treemore-Spears et al., 2016) particularly for co-production of knowledge and potential solutions (Lehmann, 2018). Co-production ideally focuses on diverse audiences, end users and non-experts in deliberative processes (Howarth & Monasterolo, 2016a). Existing multi-actor and multi-stakeholder platforms and organizations can be sites of engagement (Duncan et al., 2022). Although there may be high transaction costs for initial set up, these mechanisms to bring together actors and facilitate their interactions contribute to more sustained impacts over time (Ghodsvali et al., 2019; Kusters et al., 2018; Van Ewijk & Ros-Tonen, 2021). As these communities of practice on the nexus continue to expand (Khan et al., 2022), there is likely to be a need for better coordination and skill-building among actors and

networks, necessitating attention to strengthening capacity (see Sections 7.3.7 and 7.4 on capacity gaps).

Table 7.4. Actor interactions and guiding questions for step 2 in the road map for nexus action on identifying and convening governance actors. This step takes account of the arenas of engagement and institutional setting where planning and decision-making occurs.

Actor interactions	Guiding questions for step 2
Depending on the problem and intervention, governance actors play different direct and indirect roles. Identifying the primary governance actors influencing drivers of negative declines in nexus elements as well as those impacted and those able to shape more positive outcomes is crucial. This step needs to consider the full array of governance actors (e.g., Indigenous Peoples and local communities (IPLC), civil society, private sector and government), including stakeholders with direct and immediate interests, rights and responsibilities; interested and affected parties; and the general public. Particular attention should be paid to governance actors and groups that might be intentionally or unintentionally marginalized or excluded from processes but who are important for addressing nexus interactions.	• **Which governance actors are impacted by declines in nexus elements and their interlinkages?** • **Which governance actors could enable positive change?** • **How are different governance actors included or excluded from opportunities to advance positive outcomes?** o Considerations include: (i) the different arenas in which governance interactions take place; (ii) informal and formal institutional interactions that shape outcomes for the nexus, and ways for these interactions to be more inclusive of those impacted and those able to advance nexus outcomes; (iii) marginalized and vulnerable groups and ways to develop agency and voice in planning and decision-making; and (iv) norms and practices for convening and engaging governance actors, including ways to innovate and overcome negative practices. • **How might different governance actors work together to develop positive outcomes through deliberation and collaboration?** o This trust-building process takes time and requires patience, facilitated deliberation and possibly mediated negotiation. Different interactions may be needed in different settings at different scales over time. Contestation and bringing different values to these interactions is normal. o Who speaks on behalf of future generations, nature, the marginalized and oppressed? How might they secure voice and agency?

7.3.3 Understanding nexus elements and interactions

All the elements of the nexus - biodiversity, water, food, health and climate change - are intrinsically connected. Therefore, any change in any of these elements can lead to a series of consequential effects with potential feedbacks and cascading or compounding implications

within and between elements that can lead to trade-offs and/or synergies (**Sections 2.5.1 and 2.6**). However, most studies and evaluations carried out to date have focused on assessing these elements and their historical trends individually or in two-way interactions, ignoring the complexity and interconnections between them (**Section 2.5.1**). Furthermore, there is an imbalance in the way these elements have been studied, with water, food and climate change being the most researched elements, and with the most decision-support tools, and health the most neglected within the context of the nexus (**Section 2.5.1**; **Section 4.5**).

Nonetheless, substantial evidence shows that biodiversity plays a central role in the nexus, providing significant positive effects on other nexus elements through underpinning resilient ecosystems and human well-being (Kim et al., 2024). Biodiversity can thus be seen as maintaining the integrity of the other elements of the nexus as well as the quality and well-being of human populations – as ecosystems are essential for food production, climate regulation, the maintenance of the water cycle and human health (**Sections 2.3**, **2.5.1**, **2.6**) (Díaz et al., 2019; Parmesan et al., 2022). Biodiversity loss impacts not only crucial ecosystem functioning, but also social systems (relationships between individuals, groups and communities and their connections to place and livelihoods); cultural practices (ideas, rituals and practices that distinguish various groups of people in different environmental settings); human health (physical, mental and occupational health and well-being that is shaped in part by environmental quality); food security and nutrition (that depends on enabling environmental conditions); economic systems (employment, income, productivity that is a function of the natural resources and nature's contributions to people that support economic development); and political systems (how power is used to make societal choices, including formal and informal institutions and governance arrangements that reflect the distinctive social-ecological systems they are part of) (IPBES, 2019a, 2022e, 2022a).

A greater understanding of nexus interlinkages is therefore crucial for decision-making across diverse arenas of engagement to advance system transitions towards improving ecosystem and human well-being (**Section 6.3.2**). In practical terms, these interactions among nexus elements can be characterized effectively by different models and other tools. These range in complexity, including whether they are predominantly qualitative or quantitative in nature, and in how they are developed (see **Box 7.1**).

Box 7.1. Models, methods and other tools for characterizing nexus interactions and informing decision-making

A wide range of often complementary methods can be used to inform nexus decision-making, ranging from simple causal loop diagrams to more complex computationally demanding models (Albrecht et al., 2018; Namany et al., 2019) (**Figure 7.2**). As all methods have different strengths and weaknesses, these methods need to be tailored to the question at hand, to ensure that whatever methods are chosen reflect the breadth of the issues involved.

Scenario methods can highlight key relationships and connections in socioecological systems, especially for the future for which no observational data exist (**Chapter 3**). They can help to highlight the potential unintended consequences, such as trade-offs between nexus elements that may have escaped stakeholders' attention, but also to identify co-benefits across nexus elements. Methods can include the development of scenario framings, the

construction of narrative storylines within these framings and the use of qualitative and quantitative models (**Section 3.7.4**). Not all of these methods are equally integrated across the nexus elements, however. For example, scenarios based on the Shared Socioeconomic Pathways (SSPs) and the Representative Concentration Pathways (RCPs) have emerged primarily from the climate change assessment community and their fundamental climate-focus can limit applicability to biodiversity decision-making (IPBES, 2016). Consequently, more nature-focused scenario framings have emerged such as the IPBES Nature Futures Framework (NFF) (L. M. Pereira et al., 2020) (see **Chapter 3**, **Box 3.2**). Other scenario framings can be highly policy relevant by demonstrating the trade-offs and co-benefits of achieving policy targets (Henry et al., 2022).

Quantitative modelling tends to be developed by expert groups and requires substantial investments in data collection and model calibration and testing. These models are capable of simulating connections between environmental, social and economic systems (examples include water-energy-food models (Naranjo et al., 2023; Wu et al., 2021), Q-SCAN (Gjorgievski et al., 2022) and spatial analysis and remote sensing based models (Messerli et al., 2015; Singha et al., 2021)). Modelling in support of nexus decision-making typically applies some form of integrated assessment to represent the dynamics within socioecological systems (Rounsevell et al., 2021) to cover the range of nexus elements, using many different approaches (e.g., integrated assessment models at the global and regional scales such as IMAGE (Stehfest et al., 2014; Vos et al., 2021) and MAgPIE (Doelman et al., 2022), agent-based models such as CRAFTY (Brown et al., 2022) and systems dynamics models such as the Nexus_SDM (Laspidou et al., 2020). They can estimate magnitudes of change, which is important in determining the saliency of potential trade-offs and unintended consequences to stakeholders across the nexus. While connecting scenario narratives with quantitative models can provide additional insights, they can also reduce the complexity and nuance of future narratives depending on the dynamics models are capable of simulating (Siebenhüner & Barth, 2005; Volkery et al., 2008). The application of models can also imply greater levels of certainty than may be the case in practice since uncertainty is rarely presented as a model output (Reilly & Willenbockel, 2010; Saltelli et al., 2020). However, co-designing and co-creating models with relevant actors can ensure transparency and build trust and understanding in complex integrated models, such as the ERAMMP Integrated Modelling Platform that has been embedded into the policy cycle of the Welsh Government (Harrison et al., 2023).

Methods that rely on quantitative analyses and complex modelling would benefit from considering a wide range of value systems, including ILK (Moallemi et al., 2022). More flexible approaches that may be more broadly understandable to a wide range of actors across different contexts and scales include ***qualitative modelling,*** which focuses less on estimating specific outputs than on better describing important relationships and mechanisms of change. Examples include network analysis (Xu et al., 2022), consensus-based expert elicitation (van Soest et al., 2019), case study analysis (Pittock et al., 2015), policy analysis (Timko et al., 2018), meta-analysis (Terrapon-Pfaff et al., 2018), literature-based conceptual modelling (Tsimelas & Kofinas, 2023) and literature-based content analysis (Bandari et al., 2022) (see Moallemi et al., 2022 and **Section 4.6**). Other examples include system mapping and qualitative systems dynamic models (e.g., causal loop diagrams) that can simulate feedback loops and directions of change without needing to quantify the magnitude of change. Many

qualitative methods can be based on either expert judgement or through participatory approaches with key stakeholders (Gerritsen et al., 2020; Harrison et al., 2015), and grounded bottom-up approaches to scenarios can make important contributions to global assessments (L. Pereira et al., 2021). Participatory approaches aim to legitimize narrative development by drawing on knowledge from outside of academic communities, and such approaches are generally based on stakeholder workshops or focus groups and other means of knowledge elicitation, such as surveys. Literature-based approaches are also used as a qualitative method, such as the green shoots approach for visualizing literature-based scenario evidence on nexus interactions between biodiversity, food and climate change (Arneth et al., 2023).

Other flexible and pragmatic approaches have been suggested for creating ***narrative storylines***, such as archetype analysis, which can be used to qualitatively frame and evaluate interactions and potential trade-offs (Meadows, 2008; Moallemi et al., 2022). Such an approach can be used to shift trade-off analysis away from correlations and towards a more generalized understanding of patterns, goals and interactions across nexus elements and knowledge systems (Kroll et al., 2019; Sietz & Neudert, 2022). Futures thinking and participatory scenario planning have also been suggested as alternative approaches for building common visions for the future, while collaboratively identifying the actions and pathways members of society can collectively take to get there (Hamann et al., 2020; Oteros-Rozas et al., 2015). Futures thinking is intentionally designed to imagine new and pluralistic futures, widen the understanding of what is possible, test assumptions in the system, identify synergies, navigate trade-offs, highlight the value of plural knowledges and inform strategic dialogue and decision-making (Baker et al., 2023; Weisbord et al., 2000; Wyborn et al., 2021).

Decision-support tools can also be highly useful for understanding nexus interlinkages (**Section 4.6**) (Rounsevell et al., 2021). In **Chapter 4**'s systematic review of decision-support tools for nexus governance, these tools address nexus challenges related to scaling, evidence, knowledge and monitoring. They help decision makers synthesize available information and evaluate policy options often by weighting value and trade-offs. In particular, decision-support tools that address policy and sociopolitical options, including assembling data and knowledge, assessment and evaluation, and selection and design of policy instruments, are the most relevant to assessing nexus interactions (**Section 4.6.3**). While these tools, collectively, were found to have lower transformative and holistic potential and inclusivity than other tools reviewed, their needs for technical capacity often make them simpler to implement (see **Chapter 4**, **Tables 4.13**).

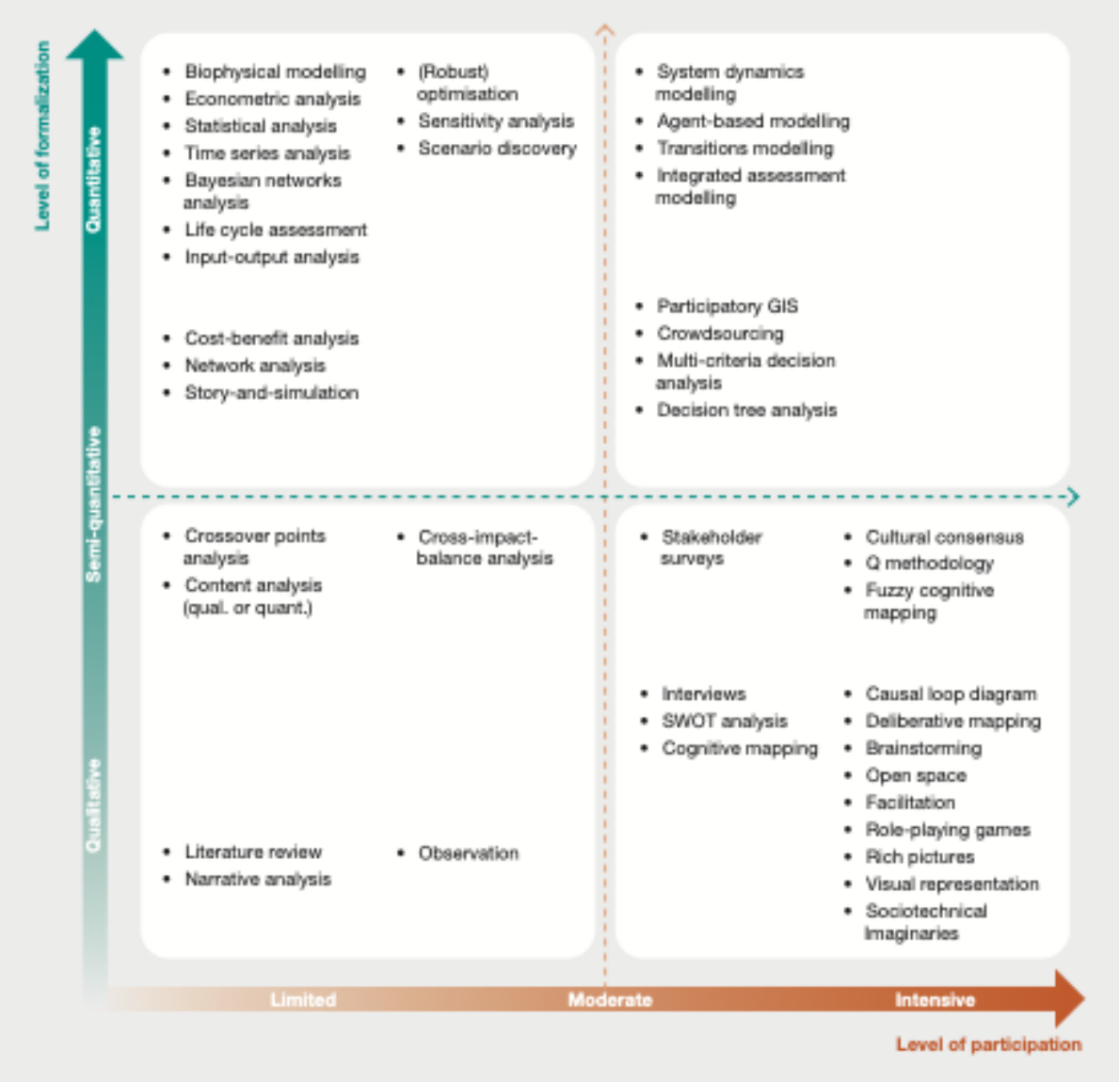

Figure 7.2. Models and tools for characterizing nexus interactions can range from qualitative to quantitative and from limited to more intensive participation. Source: Moallemi et al. (2021) Reprinted with permission under licence CC BY-NC-ND 4.0.

Table 7.5. Actor interactions and guiding questions for step 3 in the road map for nexus action on understanding nexus elements and interactions. In particular this step focuses on decision-making contexts and identifying challenges and opportunities.

Actor interactions	Guiding questions for step 3
Depending on the setting, focus and scale of nexus intervention(s), different nexus elements and interactions will be more or less important. A nexus approach accounts for 'the whole being greater than the sum of the parts' including proximal and distant interconnections.	• **What are the most relevant nexus elements and interactions, taking account of the views of all governance actors? How can these be best characterized and through what processes?** • **What key nexus challenges should be addressed now and over time, by whom and how?**

	• **What models, methods and tools exist to support understanding of nexus interactions and challenges?** • **What holistic opportunities are possible to improve the status of multiple nexus elements now and over time, by whom and how? What trade-offs and synergies are present?**

7.3.4. Co-creating visions and aligning values

Conflicting values underpin many of the decision-making processes that have led to the current unsustainable situation (Harmáčková et al., 2023; Horcea-Milcu et al., 2023; Pascual, Balvanera, & Christie, 2023). Powerful actors have prioritized decisions based on a narrow set of values (e.g., often around assets and market values (Colgan et al., 2021)) that have created today's environmental and social challenges. The IPBES Methodological Assessment on Diverse Values and Valuation of Nature (Values Assessment) highlighted how an appreciation of diverse and plural values linked to nexus elements and associated governance mechanisms can better foster just and sustainable futures (Pascual, Balvanera, & Christie, 2023). Values are founded in world views and understandings of the people-nature relationship as separated or connected. For example, confronting dualistic framings of nature and society that promote maximizing the utility of nature for human consumption and relations of domination over other humans and non-human species can support values of ecosystem stewardship and care (Ives et al., 2017, 2020; Nightingale et al., 2020). Hence, transformational change for just and sustainable futures needs to engage with the deeper levels of interconnection that shape intent and the direction of development through underlying world views, values and mental models which, in turn, shape societal institutions (**Section 4.2.5.2**) (Beery et al., 2023; Dawson et al., 2023).

Changing existing unsustainable institutions, knowledge systems, practices, power relations and human-nature relations through new visions can transform development (Feola et al., 2021). Engaging with diverse values, world views and visions of the future can support better governance of nexus interactions, improved understanding of the role of nature in underpinning human well-being, improved resource management approaches and an enhanced understanding of nature-people relationships that leads to more just outcomes (**Section 6.3**). In opening up these deliberative spaces, ILK, lived experiences and other forms of knowing, including those by groups often marginalized in decision-making, can provide perspectives on nature and society as inseparable and help realize people's dependence on nature, as expressed in daily relations, actions and emotions (Fazey et al., 2020; Görgens & Ziervogel, 2019; Leipoldt, 2006) (**Section 1.2.2**). There is evidence that connectedness and meaningful encounters with others and nature not only strengthens people's health and well-being but also provides opportunities for ethical action and radical transformation (Duffy et al., 2019; Roelvink & Zolkos, 2011; Ryan, 2016). For example, Indigenous scholars in New Zealand highlight the crucial importance of governance interactions and institutional change that draws on well-being centred frameworks and transformative Indigenous tools (Yates et al., 2023). The wisdom and practices of Indigenous Peoples can help to strengthen human-nature resonance and nourish relational capacities like empathy, compassion, dignity and respect for the inherent value of nature (Artmann, 2023;

Winter, 2019). Reconfiguring the fundamental nexus of human-nature interactions includes opening up opportunities and arenas of engagement for the voice of nature to be expressed (e.g., through legal personhood and agency (Dionisio et al., 2023; M. Parsons et al., 2021; Yates et al., 2023)) (see appendix 7.2, case study 2 on *The Whanganui River in New Zealand*).

Related perspectives are prominent in Indigenous-led efforts around the world. For example, some forest conservation efforts in Kenya invoke traditional sacral law and reverence for nature in the face of dispossession and displacement (Nyagwalla Otieno et al., 2023). Forests in India are held as sacred assets, with more than 4000 sacred groves across the country, and this has guided their use through history (Dandabathula et al., 2021). Water governance actors in parts of the United States of America are seeking to reconcile colonial regulatory frameworks that denigrated Tribes and Indigenous Peoples and adversely impacted sacred sites with efforts to reconfigure water governance founded on recognition of Indigenous knowledges, reciprocal relationships, authentic inclusion and the sacredness of nature (Ellis & Perry, 2020). Examples of lessons learned from the summaries of cross-chapter cases studies on Indigenous food systems (appendix 7.1) have further highlighted the transformative potential of actions grounded in IPLC values that foreground community and ecosystem togetherness over nature-society disconnect as well as sharing and solidarity over individualism.

7.3.4.1 Transformative visions and value systems

There is increasing evidence that fundamental changes to underlying values, world views, ideologies, structures and power relationships underpinning actions and systems are a powerful leverage point to transform development to recognize nexus elements and their interlinkages (Dawson et al., 2023). Values guide the direction of development, but also the ways that actors collaborate in actions for transformative change, such as coming together around values like equity and justice, stewardship and care, reciprocity and solidarity (Bond & Barth, 2020; Bulkeley et al., 2020; O'Brien et al., 2022). Such attention to values is increasingly included in modelling and scenario development (see **Box 7.1**) (Harmáčková, 2022).

In the Transformative Change Assessment, over 1000 visions that inspire positive, transformational changes to desired futures for nature and people were identified from wide-ranging sources and across diverse themes, perspectives and world views. Purposefully transformative visioning processes were found to be more effective when participatory and combining (i) clarity of scope and purpose, (ii) inclusion and balancing of people with diverse perspectives and roles, (iii) use of imagination to break out beyond the norm, and (iv) a flexible, adaptive process. Four main categories of visions were identified: integrated/holistic visions simultaneously addressing multiple ecological and social issues; ecological visions encompassing human-nature relations; socially-oriented visions aimed at achieving equity, for example, and more global-scale visions that do not veer far from the status-quo.

The most transformative visions are both feasible and multidimensional, addressing multiple direct and indirect drivers of biodiversity loss. Of this sub-set, over half promote sustainability, close to 60% are directed towards enhancing human well-being, and nearly

two thirds aim to improve quality of life. Of the visions addressing direct drivers, two thirds focus on natural resource use, compared to around 45% focused on climate change, sea use, pollution and land use change. Of the most potentially transformative visions, several reflect a balance of the instrumental, relational and intrinsic values comprising the IPBES Nature Futures Framework. However, there is a scarcity of intrinsic (nature for nature) visions, reflecting people's reliance on nature for economic (instrumental) and cultural (relational) motives. Although no existing global scenarios were identified that would be likely to achieve the transformation required for the 2050 Vision of living in harmony with nature (Díaz et al., 2015), promising scenarios are emerging to explore intrinsic (nature) values (Durán et al., 2023).

7.3.4.2 Visioning pathways: processes and approaches

Different kinds of alternative futures and visions can help inform and interrogate transformation processes (Mangnus et al., 2021; Muiderman et al., 2020). These include efforts that consider what alternative futures tell us about current sociocultural, political and economic dynamics, efforts that imagine plausible futures and what challenges and opportunities these futures suggest and efforts that build shared visions of desirable futures to inspire action (Cork et al., 2023). Many organizations have worked to develop processes to vision sustainable transition pathways that engage with both complexity and uncertainty (Bill Sharpe et al., 2016). These processes, similar to structured expert elicitations, are iterative; they can, but do not have to, build consensus as they can also be used to explore opposing world views in alternative futures, helping to highlight where there are common goals and interpretations, and where there is less agreement (Hemming et al., 2018). This requires (i) envisioning alternative futures, which are plausible and logically consistent, and (ii) developing a shared understanding of the present (A. Wilkinson, 2009; Vervoort et al., 2015). Both these exercises are challenging, given that socioeconomic and biophysical systems are complex, dynamic and deeply intertwined with linkages across spatial and temporal scales. How the present and future are envisioned are intermediated by social processes and values, often highlighting the challenges and injustices that need to be addressed. Developing shared understanding of the present and views of plausible futures are therefore a critical precursor to the development of road maps of change, as they focus attention on addressing a particular set of problems.

One framework suggests that accelerating sustainable transformation requires efforts that establish permission to change (building trust, transforming mindsets, enabling social license); develop responsive enabling environments (policies and regulations, market incentives, stable finance); and focus on responsible transitions (considering power dynamics and undesirable consequences) (Herrero et al. (Herrero et al., 2020, 2021). As another example (Costanza, 2000) describes a shared vision of a sustainable society, encompassing diverse visions that share some ethics and values and providing an alternative to other basic less desirable visions of the future. A diversity of values and knowledges are required to build such a broad shared vision of sustainability because the process itself involves deliberation, embracing uncertainty and reconciling divergent interests in order to generate wisdom to act in just, inclusive, interconnected and transformative ways. Choices about the future are grounded in ethical judgments, hence going beyond an integration of diverse strands of technical knowledge to a thickening of knowledge (Fazey et al., 2020; Hulme, 2018).

Methodologically, these steps towards common visions of the future can be taken using a range of approaches such as participatory scenarios to develop logically consistent alternative futures (viability and desirability); backcasting (Robinson, 1990, 2003); and three horizon approaches (Bill Sharpe et al., 2016) that explicitly consider the actions that would be required to move from the present to a desired future (achievability and viability) (see also **Box 7.1**).

Table 7.6. Actor interactions and guiding questions for step 4 in the road map for nexus action on co-creating visions and aligning values among actors to guide long-term planning and decision-making, embracing diverse perspectives and knowledges.

Actor interactions	Guiding questions for step 4
Convening key stakeholders and building a shared vision for the future and aligning values, with respect for diverse knowledges, world views and perspectives, opens up opportunities for enduring collaborative governance interactions and transformative institutional change. All governance actors can play a constructive role in building more positive interactions.	• **What prevailing world views, norms and values shape current and future nexus outcomes?** • **How could different perspectives help or hinder positive change for the nexus elements?** • **What processes facilitate openness to surface novel and even contrary perspectives.** • **What 'ideal futures' or 'visions' do different governance actors hold for the future** (e.g., 10 or 50 years from now)**?** • **How might governance actors work together to co-create a shared vision for the future? Where and how could this co-creation take place?** • **How can actors align their values and norms as a foundation for long-term planning and improved decision-making?**

7.3.5 Identifying response options and assessing synergies and trade-offs

Chapter 5 has highlighted 75 response options that originated within one nexus element but which have been shown to benefit several other elements while minimizing negative impacts, suggesting that actors have a broad choice of options to move forward towards sustainability pathways (**Chapter 5.6**, **Table 5.6.1**). These options can be found in all continents of the world (apart from Antarctica), with many of them having broad scale applicability to large geographical areas. Examples include integrated land/seascapes (**B06**, **Section 5.1.3.6**), restoration of the productive capacity of managed lands (**B07**, **Section 5.1.3.7**), agroforestry (**C01**, **Section 5.5.3.1**), sustainable and/or ecological intensification (**F03/F04, Sections 5.3.3.3 and 5.3.3.4**), groundwater governance (**W03**, **Section 5.2.3.3**), sustainable healthy diets (**F1**1, **Section 5.3.3.11**), management of zoonoses (H11, **Section 5.4.3.11**), marine/coastal nature-based solutions (**B05**, **Section 5.3.1.5**) and the circular bioeconomy (**C13**, **Section 5.5.3.13**). For example, circular food systems that recycle and reuse food waste as a source of feed and/or fertilizer are emerging as a real opportunity to reduce land use, increase yields of crops and mitigate climate change (Van Selm et al., 2022; Van Zanten et al., 2023). Actions in financial and economic arenas, such as natural capital accounting,

tools for non-market values assessments, innovative finance mechanisms or subsidy reform, can support the implementation of response options by transforming decision-making in other arenas, enabling transformative, interconnected and just response options to advance nexus outcomes (**Sections 6.2.7**, **6.4.1**, **Figure 6.12**).

Effective response options are largely dependent on a range of criteria and attributes evaluated in this assessment (**Section 5.0.3**), including context, desired impacts on the nexus elements, scale (spatial and temporal), social acceptability, alignment with political priorities and international frameworks, technical feasibility, equity, governance, transformative change potential, cost and ability for implementing them (**Chapter 5.6**) (see online **Annex 7.2**, case study 3 on *Community-driven initiatives for agriculture and biodiversity conservation in India* for how options to enhance synergies and increase equity were deployed). Co- designing response options with diverse actors and institutions through transparent and equitable processes and approaches are likely to lead to more successful implementation (**Sections 4.3**, **4.5**).

Bundles and sequences of response options are also crucial design elements for achieving multiple benefits and avoiding trade-offs (**Chapter 5.6**) as well as for achieving more transformational outcomes. There is ample evidence from this assessment and from recent literature (Barrett et al., 2020, 2022; FAO, 2023a; Herrero et al., 2020) that creating bundles of response options can improve the effectiveness and comprehensiveness of the desired positive impacts, as many options act as enablers for others, and can amplify benefits over time (**Section 5.6.3**, **Box 7.6**). As an example, response options that reduce competition across resources can often contribute to successfully achieving multiple outcomes and co-benefits. For instance, dietary change could be bundled with waste reduction strategies and sustainable intensification to increase yields. This bundle could simultaneously reduce emissions from the food system by 29%, reduce premature deaths of 11 million people/per year, halt land use expansion and contribute to halting species extinction, while in the process reduce pollution, zoonotic disease risk and freshwater withdrawals from agriculture (Springmann, Wiebe, et al., 2018; Tilman & Clark, 2014; Willett et al., 2019). Dietary change could also limit non-CO_2 emissions from the food system to under 5 Gt/per year, a 56% improvement over a business-as-usual scenario (**Sections 5.3.3.11**, **5.4.3.6**, **5.5.3.14**). However, changing diets is not easy, but novel economic instruments and enablers like repurposing of subsidies (Damania, Balseca, et al., 2023; Ding et al., 2021; Springmann & Freund, 2022) and true cost accounting of food (De Adelhart Toorop et al., 2021) could help reshape consumer behaviours.

Ensuring that economic costs and benefits are aligned with goals is an important part of identifying and selecting response options. Leveraging policies for realizing nexus-wide impacts can help illuminate the full consequences of implementing a specific policy, supported through more robust and transparent evaluation of impacts and critical for informed decision-making (Baldwin-Cantello et al., 2023). While some options may have upfront costs, many pay for themselves quickly, particularly if nexus-wide benefits are considered. As one such example, the costs and benefits of nature-based solutions in Costa Rica (building an infiltration area in the form of an urban riparian park that will also contribute to wastewater treatment) showed that while the costs were higher than considered alternatives in the first year, the benefits quickly surpassed costs in the second year, with a

total estimated value of social and environmental benefits nearly three times the initial costs in just three years (V. A. Neumann & Hack, 2022).

While response options can be driven by specific actors within a sector, acting with more attention and understanding of other sectors, others will likely require collaborative and coordinated action across multiple sectors and actors (**Chapter 5.6**). Nexus response options are likely to be most effective when co-designed with a variety of actors and institutions and through processes and approaches that acknowledge and address context-specific tensions and trade-offs (**Sections 5.1.5**, **5.2.5**, **5.3.5**, **5.4.5**, **5.5.5**, **5.6.4**). Alignment of actors across biodiversity, water, food, health and climate change can foster a shared understanding of challenges and opportunities, and aid in moving away from current misaligned, duplicative and inconsistent policies (**Section 4.2.2**). Engagement around nexus response options can help reduce contestations and conflicts arising over trade-offs, improving cost-effectiveness and supporting collective action and collaboration across actors. Response options not co-created with relevant actors can lack credibility and legitimacy, leading to poor performance, low adoption rates and poor equity outcomes (**Section 4.3.5**).

There is also a strong need to balance between addressing the risks inherent in continuing business-as-usual, alongside the risks associated with choosing certain response options. The extreme nature of some current impacts may push actors to reach for riskier, non-nexus response options aimed at a single element, like climate change mitigation, with the understanding that doing something, even if from a single sector and not taking into account nexus approaches, is better than nothing (P. McElwee, 2023). Yet these choices can have far reaching and unanticipated consequences across the nexus elements. For example, narrow approaches to climate action that do not consider equity and off-site effects on societies and ecosystems can lead to maladaptation (Reckien et al., 2023). Furthermore, choices on renewable energies that do not take into account nexus interactions run the risk of exposing vulnerable people, especially from marginalized or low income communities to increased air, water or noise pollution, loss of lands or water resources, and inequities in access to renewable energy benefits and their distribution (Levenda et al., 2021; Sovacool, 2021).

Additionally, there can be problems with poor implementation of nexus response options, such as the risks associated with over-depending on a small set of response options without addressing drivers of decline in the nexus elements; mis-applying response options where they are inappropriate or unlikely to succeed; or failing to understand the enablers and contexts that are crucial for successful implementation of the response options. For example, in some regions in the world poorly planned marine conservation response options may result in loss of access to fishing resources and violation of traditional rights of IPLC, with concomitant impacts on well-being and health (Bennett et al., 2021). In other parts of the world marine conservation is well planned as legal frameworks are in place, however, poor implementation and ineffective enforcement can lead to limited protection, as has been in the case in some European Marine Protected Areas (Dureuil et al., 2018; ECA, 2020).

Depending on economic and sociocultural context, response options implemented poorly could lead to marginalization. For example, nature-based solutions like blue-green infrastructure and housing energy efficiency policies in cities can lead to increasing social differentiation (Anguelovski et al., 2022; Bouzarovski et al., 2018; Grossmann, 2019;

Polanska & Richard, 2021) (see appendix 7.2, case study 4 for how to overcome these challenges). In some contexts, conservation that combines climate change mitigation with biodiversity conservation have played into colonial and elitist processes that exclude IPLC from access, exacerbating dispossession (Benjaminsen & Bryceson, 2012; Jodoin, 2017; Koné, 2023). For many response options, the 'how' of doing an action makes all the difference in terms of whether social and economic risks can be overcome (Kirschbaum et al., 2024). Actions aligned with large goals or targets (e.g., 'net zero' or 'zero deforestation'), without clarity on the ensuing steps, processes and likely affected actors, run these risks of perpetuating injustices (McDermott et al., 2023).

In other words, while there is an urgent need to address current risks, doing so at the necessary scale and rate is likely to simultaneously entail some degree of implementation risk across nexus elements. This highlights a need for caution with regard to suggesting an ostensibly 'optimal' or universal suite of response options for implementation as widely and rapidly as possible without constraints or without detailed consideration of local socioecological contexts. Indeed, the world is replete with examples of how certain response options can entail highly asymmetrical distributions of costs and benefits (Bluwstein & Cavanagh, 2023; Doelman et al., 2020; P. McElwee, 2023) – a challenge compounded by the fact that response option choices are often not made by actors who are most exposed to risks. Given this unevenness of risks and of choices, it is important to highlight that the process of transformation is likely to create winners and losers, and these unequal impacts can be anticipated through centering of different aspects of equity to ensure just transformations (Bennett et al., 2019; Sovacool, 2021). Trade-offs between human well-being and nexus elements have often negatively affected the latter, requiring actors seeking solution pathways to understand and anticipate potential welfare impacts of changes in the status quo. There are also risks of political pushback from either vested interests (e.g., corporate shareholders, parastatal firms) or from actors negatively impacted by mitigation costs (e.g., farmers, land users), who may seek to obstruct response option implementation (Douenne & Fabre, 2022; Martin & Islar, 2021). Such challenges stress the importance of understanding and attempting to manage for trade-offs across scales, actors and elements.

As the road map (**Figure 7.1**) has noted, one way to avoid risks of poor implementation and deviation off course are to ensure safeguards along the road map to assist with 'course correction' and to ensure recalibration back to sustainable pathways. Safeguards can include those that enhance equity like the use of informed consent procedures such as Free, Prior and Informed Consent (FPIC) as an ongoing process, including the right to withhold consent; the application of human-rights based approaches (**Section 4.5.3**, **Box 4.11**); public grievance and accountability mechanisms; gender, equity and social inclusion analyses; mechanisms for access and benefit sharing; land and resource audits; environmental impact assessments; and other examples. These safeguards are ideally developed at local levels to address contextual needs, yet can be shaped by following global guidance (e.g., the CBD Voluntary Guidelines for Safeguards) (Ituarte-Lima et al., 2018).

Table 7.7. Actor interactions and guiding questions for step 5 in the road map for nexus action on identifying response options and assessing their synergies and trade-offs. This includes bundles of response options or policy mixes of sociopolitical options.

Actor interactions	Guiding questions for step 5
A wide range of response options can help reverse declines in nexus elements and enable positive outcomes for people and nature (**Chapter 5**). There are no single silver bullets for many problems and thus bundles of response options can be used in different settings at different points in time – depending on their synergies and trade-offs. Taking account of perspectives from governance actors impacted by or responsible for implementation over time will be essential to make these options enduring. Interventions need to be feasible, including financially, technically, culturally, socially, politically and institutionally, and different actors play roles in identifying, supporting, selecting, implementing and monitoring the outcomes (**Chapter 5.6**). Response options will need to be adapted over time and new options identified through continuous monitoring and learning (see step on monitoring (**Section 7.3.8**).	• **What possible response options, and option combinations in bundles and sequences, could enable more positive outcomes for the nexus, accounting for diverse views?** • **How feasible are different response options and bundles of responses for the existing context, and potential future pathways?** • **What are the most significant direct and indirect synergies and trade-offs between these options and response bundles?** • **What risks might occur from certain response options? What safeguards might be needed?** ○ These include risks of over-depending on a small set of options without addressing drivers; mis-applying response options where they are inappropriate or unlikely to succeed; or failing to understand the enablers and contexts that are crucial for successful implementation. Well-intentioned but poorly or narrowly conceived interventions can reinforce negative outcomes. • **What are the priority interventions for the short-, medium- and long-term, and what monitoring and evaluation will be needed?**

7.3.6 Assessing enablers and overcoming barriers

Nexus response options need enabling conditions to work most effectively, including institutional, financial and economic capacities, attention to needed changes in behaviours and values, technological readiness and material endowments (**Section 4.2**; **Chapter 5.6**). These can take the form of policies and rules, local context and norms, equity and participation by affected communities, and the overall social acceptability of the response option under consideration as mediated by social license and trust. Key enablers identified by **Chapter 4** include policy design and implementation, equity and diversity, institutional capacity, behaviour and lifestyles, technology and material endowments, and transformation of economic and financial systems to enable financial flows towards response options that benefit people and nature over maximizing financial returns. These enablers in turn allow response options to be implemented with stronger effectiveness. For example, response options with high social acceptability and that support equity were scored as having higher positive impacts across other nexus elements, indicating benefits that are more likely to be

broad and long-lasting (**Chapter 5.6**) (see online **Annex 7.2**, case study 4 on *Enablers and barriers in urban nature-based solutions*).

Institution design and policy has been a key enabler in many examples of nexus approaches (see **Section 4.3**) For example, for public investments in science and technology, the need for proactive engagement with issues of social acceptability requires a much greater use of responsible innovation principles and investing much more in public dialogue (Caniglia et al., 2020; Douthwaite & Hoffecker, 2017; Van Mierlo et al., 2010). Rising public awareness of issues may create pressure from different actors to push innovation in different directions, while in other cases policy design and support (e.g., role of public procurement policy in supporting sustainable food systems) is a crucial design and enabling condition for certain pathways to be pursued. Financial enablers similarly are often crucial and require acknowledgement and facilitation as they may not be open or available to all actors. Case studies in the online **Annex 7.2** highlight that both top-down and bottom-up processes can create conditions for institutional and financial enablers to be recognized and supported by multiple actors.

Nexus response options that are designed with equity in mind also tend to be more successful as they foster collaboration among diverse and sometimes conflicting actors and incentivize cooperation (**Sections 4.2.4**, **4.5.2**; **Chapter 5.2**; **Sections 5.1.5** and **5.6.4**). Many of the response options that were assessed in **Chapter 5** have high potential to facilitate equity, and these response options were also able to deliver higher potential nexus-wide benefits. Examples of bundles of policy instruments and response options with high equity potential include rights-based approaches, inclusive protected areas, eliminating harmful subsidies, or expanding market transparency, with the inclusion of specific actor constellations and the co-development or acceptance of norms and standards to improve outcomes (**Chapter 5.6**). However, actual equity impacts depend strongly on how response options are implemented: for example, in ways that account for diverse knowledge and evidence, including ILK, and mobilizing that knowledge in ways that account for intersectionality, thus, fostering inclusivity (**Section 4.5**, **Box 4.12**).

Distributional dimensions of equity can be addressed if response options are implemented through more inclusive decision-making processes accounting for the specific needs of marginalized communities and surfacing who benefits or is burdened by interventions. Procedural dimensions of equity include acknowledging and addressing how response options can be implemented in ways that foster nexus governance and foreground participation and inclusion in decision-making processes. Contextual and restorative dimensions of equity can be addressed by how response options can be implemented in ways that account for historical injustices (**Section 4.5.3**). However, global inequities, historical injustices, patterns of poverty and social inequality shape which response options, means of implementation and governance arrangements are available and feasible, with response options being unavailable in some contexts or for some groups (Bulkeley et al., 2020; O'Brien et al., 2022). For example, new alternative production initiatives have emerged from socially just interaction between governance actors as well as knowledges and values that support deep nature-society interlinkages rather than dualism and siloed approaches (Dawson et al., 2023). Actions that are grounded in stewardship values and that are developed and implemented through equitable collaboration between IPLC, government and research actors

can together transform development trajectories towards positive people-nature and nexus outcomes over time (Dawson et al., 2023a; Sangha 2020) (see case study 3 in appendix 7.2).

Enabling conditions can help serve to overcome challenges with aligning values as noted in step 4. Change in values may not necessarily be a precondition for action if enablers can be mobilized; for example, in case studies of urban NbS in appendix 7.2, urban dwellers in many European cities who adopted green roofs were largely motivated by the economic savings on their energy bill as opposed to necessarily reflecting shared values or a common world view. In contrast, in China the importance of government support in policy design, institutional capacity and technology and material endowments for expansion of urban NbS were most important, with more limited focus on equity, behaviour or economic enablers. Such differences underscore that importances of attention to local political context.

There are number of tools, methods and approaches to help recognize, facilitate, and scale positive enablers and overcome barriers; for example, many of the decision-support tools identified in **Section 4.6** are specifically aimed at selection and design of policy instruments, as well as social learning and innovation to ensure that response options are durable. These tools can help identify the contextual enablers that will be most relevant to particular decision-making processes, as well as suggested more participatory and informed responses where barriers may be creating roadblocks to action.

Table 7.8. Actor interactions and guiding questions for step 6 in the road map for nexus action on assessing enabling conditions and overcoming barriers in context-specific circumstances, alongside other governance and institutional challenges.

Actor interactions	Guiding questions for step 6
A barrier is a constraint or challenge that hinders change but can be overcome with focused effort. An enabler is a setting, action, process, or actor(s) (often in combination) that facilitates improvements. Relevant barriers and enablers for nexus approaches include policy design and implementation, equity and diversity, institutional capacity, behaviour and lifestyles, technology and material endowments, and economic and financial systems (**Chapter 4**). Identifying and understanding the barriers and enablers for implementing priority response options over time helps them become enduring interventions. An actor- and institution-centred analysis helps identify the relevant barriers and enablers, including how and who should address them.	• **What are the key barriers?** o Consider the spectrum of potential barriers and their interactions to reveal how and why barriers emerge, persist, can be mutually reinforcing, evolve over time, and ways to address them, and by whom. • **What are the key enablers for change?** o Consider the spectrum of potential enablers in the light of identified barriers. Enablers can unlock incremental and/or transformative changes, including mainstreaming nexus approaches into existing systems and processes as well as creating institutional change. Incentivizing and mobilizing enablers depend on clearly identifying roles and responsibilities for different governance actors.

7.3.7 Negotiating implementation, including scaling and strengthening transformative capacity

An important part of negotiations over implementation of response options once they have been selected will involve innovations and piloting new ideas. For example, case studies in Basel and China on NbS (appendix 7.2, case study 4) show the important role of testing and then scaling what works. These cases note that policymakers and implementers need to be involved in such projects for a long time and invest time in building social trust and acceptance. In the case of Basel's green roof initiative, the successful implementation was supported by a synergetic combination of diverse policy instruments and mixes, including *economic incentives* (a subsidies programme), *legal mandates* (creation of a law to support the Energy Saving Fund and amendments to the Building and Construction law), and *social and cultural approaches* (communication in the media, and research generating useful knowledge about green roofs). Implementation was sequential, and took place over more than thirty years, with iterative improvements based on monitoring and evaluation. The inclusive governance of the initiative, which included consultations with various stakeholders before designing the incentive programme and the law, was a key factor of success which has also enabled scaling, along with the championship of the project by a committed researcher from Zurich University of Applied Sciences. This leadership role for a key actor(s) can be seen in other case studies as well (**Annex 7.1** case study 3), arguing that nexus approaches may need to identify 'champions' who can push initiatives forward.

Initial successes in negotiation and adoption of response options can be followed by scaling to embed sustainability and create wide possibilities for transformative change. Scaling, in its multiple dimensions of up, out, deep and down (see **Section 4.4**), has emerged as an important contributor for effecting transformative change across the nexus. Many of the response options have been found to show transformative potential (**Chapter 5.6**), and scaling such efforts up involves institutionalizing these successful interventions through policy, rules and laws to embed them firmly into the institutional frameworks, ensuring political commitment and catalysing widespread adoption and impact. Concurrently, scaling out involves horizontal expansion, fostering partnerships and collaborations across diverse sectors and stakeholders to disseminate innovations and best practices. This approach spreads nexus approaches, facilitating their uptake across various contexts to benefit a larger number of people. Transformative change also necessitates scaling deep, delving into the underlying norms, values and power structures that shape behaviour and decision-making, thereby effecting systemic shifts. Moreover, scaling down, e.g. by engaging grassroots initiatives and IPLC, ensures contextual relevance and sustainability, fostering resilience and equity within the nexus.

Decision-support tools can assist with scaling; in **Chapter 4**'s systematic review of tools supporting nexus governance (**Section 4.6**), tools that address context and those that address scaling, as opposed to those that address specific response options, had high transformative potential (**Chapter 4**, **Tables 4.8** and **4.9**). This includes tools supporting implementation, outreach, reporting and enforcement (e.g., Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+) Web Platform ; (UNFCCC, 2024), Data Reporting Tool for MEAS – DaRT; (UNEP, 2020),

https://www.forestcarbonpartnership.org/; (Forest Carbon Partnership Facility, 2023), social learning, innovation and adaptive governance tools (e.g., QUICKScan; (Verweij et al., 2016), and public discussion, involvement and participatory process tools (e.g., The SHARE concept; (Branche, 2017).

While there are increasing calls for transformative actions across sectors, systems and scales in order to avert environmental disruption, achieve equity and justice outcomes, and advance sustainability goals, transformation does not have to happen everywhere, for everyone (Shi & Moser, 2021; Vogel & O'Brien, 2022). Understanding where transformative actions could alter governance, political economies, development logics and knowledges that extend unsustainable and unjust actions and outcomes can identify key places to intervene that can unlock transformative potential for others (Massarella et al., 2021; Patterson et al., 2018; Shi & Moser, 2021). While some decision makers already factor the nexus in their decision-making processes (e.g., holistic views of the interconnections between biodiversity, water, food, health and climate change are considered in many approaches taken by a wide range of IPLC (IPBES, 2022b, 2023a)), other decision makers often have more siloed approaches to decisions around nexus elements and identification of indicators, while others still need to be motivated to build awareness of the need for change.

Mobilizing and strengthening specific capacities have been shown to facilitate the inclusion of nexus thinking in decision-making (**Section 4.5**, **Figure 4.19**). These capacities include: enhancing *analytical capacities* which enables actors to select, understand and use suitable knowledge and tools to assist with nexus decision-making; mobilizing *bridging capacities*, which enhances the ability to bring together different ways of knowing and doing through knowledge co-production approaches based on plural and diverse values (Pascual, Balvanera, & Christie, 2023); building *negotiation capacities,* which can assist with surfacing and navigating trade-offs between values and interests of different actors and institutions to improve the uptake of nexus response options; ensuring *social networking capacities,* which can facilitate co-learning, adaptation and acting together (IPBES, 2022a) to create more equitable governance and fair processes and institutions; and lastly *motivational capacities,* which are vital for building awareness and desire for change and for 'seeing outside the box' or broadening decision maker realms of understanding of what nexus opportunities and transformative potentials exist and are possible (L. Pereira et al., 2019).

In addition to these capacities for nexus decision-making highlighted in **Chapter 4**, the IPBES Values Assessment highlights the importance of capacities for transformative governance in different decision-making contexts and scales, stating that mobilizing transformative capacities can act as an important lever of change for addressing indirect drivers (Förster et al., 2021; IPBES, 2019a, 2022d). Beyond the conventional idea of one-way, top-down knowledge transfer, the approach to understanding capacities used in this assessment emphasizes that capacities for change are best mobilized and strengthened through adaptive learning and action (Ernst, 2019; Lotz-Sisitka et al., 2016) and knowledge co-production (Howarth & Monasterolo, 2016b; Reyers et al., 2015; Vallet et al., 2023) also highlighted in the IPBES Transformative Change Assessment. These theories view knowledge as outcome of an interactive, context-specific social process that develops over time rather than something that can be given, received or transferred. Four capacities have

been shown to foster transformative change (Hölscher, 2020; F. Westley, 2017; F. R. Westley et al., 2013) which relate to distinct transformation dynamics:

- Stewarding capacity: Anticipating, protecting and recovering from uncertainty and risk;
- Unlocking capacity: Recognizing and dismantling unsustainable path-dependencies;
- Innovation capacity: Enabling, diffusing and embedding radical innovations;
- Orchestrating capacity: Coordinating multi-actor governance processes.

These capacities are not sequential steps but can be strengthened iteratively. This approach allows for continuous involvement and adaption, ensuring each dimension of capacity can evolve and reinforce the other over time. By developing these capacities concurrently, actors can more effectively foster and scale the transformative potential of nexus response options to achieve systemic impacts. (**Annex 7.3**, **Table A.7.1** provides case study examples of how these capacities can enhance governance capacities for transformative change).

However, several barriers have been identified that hamper efforts, these include: insufficient funding and investment to catalyse change, especially change requiring cultural and value shifts (Pascual, Balvanera, Anderson, et al., 2023); institutional inertia (Rosenschöld & Rozema, 2019) and vested interests (Avelino, 2017; Loorbach, 2022) both of those resisting change, but also those resisting the abandonment of established but unsustainable practices; and fragmented institutional landscapes and competing interests among diverse stakeholders (Bai et al., 2016; Hermans et al., 2016; F. R. Westley et al., 2013).

Table 7.9. Actor interactions and guiding questions for step 7 in the road map for nexus action on negotiating implementation of response options. This includes scaling response options and strengthening transformative capacity.

Actor interactions	Guiding questions for step 7

The preceding steps are foundational for determining the best way forward to enable enduring action. Implementing response option interventions involves intentional and coordinated effort by diverse governance actors. In many circumstances, well-coordinated actions are necessary.
 	
After consulting key actors, there needs to be sufficient will to advance implementation efforts. Change can be contested because of divergent world views, values, interests, needs and responsibilities. Implementation takes place in the face of complexity, uncertainty, change and urgency.
 	
Different modes of governance interaction influence the pace and direction of nexus action. Opening up opportunities for governance actors to interact in arenas of engagement that are purposeful, inclusive and meaningful improves prospects.
	• **Who needs to be directly involved for effective and enduring action?**
	  ○ Consider different possible roles and responsibilities for co-designing and implementing response options. It is not practical to involve everyone in these deliberations. Who is best placed to legitimately represent different governance actors? What needs to be done to ensure meaningful feedback?
	• **Given capacities and needs, when is the best time to initiate this negotiated process?**
	• **What is the best way to carry implementation in specific circumstances?**
	  ○ Carefully appraise the suitability of different approaches, including collaborative planning, consensus-building, mediated negotiation and co-production. Seek advice from an experienced process design expert where necessary.

Enduring action is founded on relationships of trust amongst different actors and practices that foster, among other things, dialogue, deliberation, reflexivity and social learning. Critical reflection on what works and does not work as implementation unfolds is a key to success, as is strengthening capacities for improvements over time.	○ Account for under-represented groups and governance actors. What capacity-strengthening, communication, awareness raising, training and educational interventions are necessary to maximize prospects for success, including required institutional change? • **What are the most appropriate and effective ways to scale the implementation and diffuse response options across space and time and sectors and institutions?** ○ Scaling up, out, deep, and down as appropriate can help expand response option impact and make it more enduring over time. • **What capacities are necessary to co-design, implement, and sustain adaptive implementation over time?** ○ Consider different capacity needs, including analytical capacities, bridging capacities, negotiation capacity, social network capacities, and governance capacities. More transformative capacities include stewarding, unlocking and orchestrating capacities.

7.3.8 Ensuring ongoing monitoring, evaluation and learning

The final step of the road map for nexus action is monitoring, evaluation and learning, which should be undertaken continuously and in conjunction with other steps so as to embed lessons for more durable successes. This will require attention to how monitoring can be improved within existing policy goals, as well as what new types of indicators, data and processes might need to be put in place to ensure more effective nexus outcomes.

7.3.8.1 Representation of the nexus in existing monitoring frameworks

Compared to previous policy frameworks such as the Millennium Development Goals, complex interlinkages among nexus elements are increasingly part of the design of the SDGs, the Kunming-Montreal Global Biodiversity Framework and the Paris Agreement, indicating a growing recognition by decision makers of the importance of such interactions. However, there are substantial gaps when it comes to the design and operationalization/ implementation of the nexus approach in these frameworks. These gaps are linked to the nexus challenges and opportunities of high complexity, siloed governance, multiple values, inadequate scaling and lack of finance (introduced in **Section 1.1.2**).

Different monitoring frameworks typically still prioritize isolated sustainability dimensions, potentially overlooking the complex interconnectedness and potential trade-offs among different nexus elements and societal goals, which can result in unintended consequences or conflicting management actions. The SDGs, for example, are intended to consider different nexus elements as well as their complex interactions, but their implementation and

monitoring continues to be designed in a siloed way (Allen et al., 2018). This is reinforced by how the achievement of the SDGs is commonly assessed using combinations of different indicators within composite indices, an approach that does not allow for the consideration of complex SDG interactions (Nilsson et al., 2018) (see also **Section 2.6.2**).

Furthermore, the scaling of nexus approaches and response options down, up, out and deep requires coordination across multiple levels, stakeholders and contexts. Most frameworks show considerable gaps when it comes to monitoring progress towards achieving goals across different scales (i.e., spatio-temporal; multi-level governance, etc), and a spatial disconnect exists between global data and the scales at which many nexus elements and systems are managed (Scanlon et al., 2017). Compounding this, the tendency to assess progress within national boundaries often leads to oversimplified conclusions since environmental costs of resource consumption are frequently externalized (Biber-Freudenberger et al., 2018; Downing et al., 2021). This is highlighted by various existing measures for environmental footprints, including the Ecological Footprint, which illustrates a significant increase in human demand for resources, surpassing the planet's bioproductive capacity (Lin et al., 2018). Furthermore, externalization of environmental costs leads to issues of global (in)justice related to the global monitoring system. Countries producing, for example high amounts of biomass, which is being exported to other countries as food or non-food biomass, are at a disadvantage in global monitoring frameworks, as environmental costs including emissions, deforestation and biodiversity loss are predominantly attributed to the producing, not the consuming country (Lenzen et al., 2012; Wilting et al., 2017).

While global policy frameworks play a crucial role in international governance, they face criticism for failing to meet set goals and targets (Mace et al., 2018); for example, currently low- and middle-income countries are falling short of reaching targets on most SDGs including health, poverty and inequality (UN Economic and Social Council, 2023). The governance of many frameworks, and the nexus concept within them, is limited as they do not explicitly require collaboration between different siloed decision-making entities. Instead, individual institutions often cherry-pick specific goals and work towards them (Forestier & Kim, 2020). Furthermore, the significance of national and subnational monitoring programmes and systems, such as those led by IPLC and citizen science initiatives, can be neglected (Reyes-García et al., 2024), with global observation systems often prioritized (Gonzalez et al., 2023).

Additionally, acknowledging and considering diverse values among different stakeholders is necessary to move towards just and sustainable futures but this is not sufficiently implemented in all monitoring frameworks (Pascual, Balvanera, Anderson, et al., 2023). For example, there are no indicators in the SDGs which measure the extent to which stakeholders have been involved in policy designs, yet integration of different stakeholders, including civil society and the private sector, is important to ensure legitimacy and contribute to systemic socioeconomic transformation (IPBES, 2022a).

Finally, while substantial financial resources have been provided at least for some of the frameworks, and actual estimates of overall funds necessary to achieve the goals vary between different studies, it is evident that current funds are insufficient to meet any of the global sustainability frameworks (Kulkarni et al., 2022) (**Section 6.2.2**). Furthermore, many of the existing financial measures do not sufficiently consider nexus interactions but follow a

siloed approach focused on a single nexus element (6.2.3) This fails to take advantage of the cost savings of approaches that facilitate synergies and reduce trade-offs between different goals related to sustainable development, biodiversity conservation and climate change mitigation and adaptation in the long-term.

7.3.8.2 Options for monitoring nexus interactions and outcomes

Monitoring frameworks that have clear nexus perspectives and address complexity alongside different actors' values at relevant spatial and temporal scales and levels of decision-making are particularly suited to support effective monitoring of nexus interactions and outcomes. **Systems thinking** provides an analytical framing of integrated monitoring that is particularly useful for capturing the complex interplay among nexus elements, including synergies and trade-offs. Since monitoring frameworks tend to oversimplify complex ecosystem dynamics and interactions by focusing on a limited set of indicators, important nexus interactions are often not adequately captured. Working with quantitative and qualitative data can be helpful to identify common trends as well as idiosyncrasies, both of which are important to understand global trends in the myriad of nexus interactions across the world. Inter- and transdisciplinary monitoring approaches (e.g. International Long Term Ecological Research Network, ILTER) are more likely to provide the currently missing evidence needed to develop systemic solutions for interlinked problems like the nexus. This includes also monitoring systems that have a stronger focus on consumption-based indicators including externalized environmental costs (e.g., ecological footprints of consumption) to capture transboundary effects of human-environment interactions (Vanham et al., 2019).

Participatory monitoring systems that integrate diverse stakeholders and knowledge systems in their design, implementation and evaluation are more likely to capture relevant nexus interactions while strengthening the credibility and suitability of findings for decision-making. This is particularly important regarding IPLC who face specific nexus challenges and are key for local monitoring (**Section 2.6.2.6**). They can provide locally accurate, reliable and valid information about interacting nexus elements and changes in these interactions over time (Kipp et al., 2019; Savo et al., 2016; Williams et al., 2018). Participatory monitoring offers opportunities to complement and enrich data collected in non-participatory monitoring schemes (Mandeville et al., 2023). Increased sharing of data gained through participatory monitoring (Johnson et al., 2021; Kühl et al., 2020) and citizen science (De Sherbinin et al., 2021; Tengö et al., 2021), while respecting data sensitivity, Indigenous data sovereignty and local data governance (Pritchard et al., 2022; Reyes-García et al., 2022), can further enhance the contribution of small, more thematically focused monitoring efforts.

Continuous monitoring over long time scales enables data on trends in nexus elements and their interactions to be gathered consistently, including non-linear dynamics and cascading effects (**Chapter 2**). This helps overcome the persistent lack of spatially explicit data and enables non-linear (eco)system dynamics to be better represented in (economic) evaluation of management options and social-ecological modelling. As illustrated for Land Degradation Neutrality, one of the SDG targets (SDG15), continuous monitoring can help identify appropriate management timings, windows of opportunities and risks and cost-effective management measures that align with the vision and expectations of land users (Sietz et al., 2017; van den Elsen et al., 2020). The scientific conceptual framework of Land Degradation

Neutrality provides further guidance on the continuous monitoring of state and process indicators reflecting underpinning processes and their interactions (Cowie et al., 2018). When organized in networks of monitoring sites, such long-term monitoring can capture the same processes in various locations, increasing opportunities for linking place-based and generic knowledge (Dick et al., 2018). For example, long-term, standardized monitoring in Landscape Monitoring Networks is proposed to better draw generic conclusions along a gradient from place-based to generic insights and reveal common levers and barriers for collectively managing landscapes (Petit et al., 2023).

In analyzing nexus dynamics, a well-motivated choice of the baseline period which is used as a reference for assessing future nexus change is important as it can affect the resulting findings (Liersch et al., 2020). Recent advances in technology and collection of data with high spatial and temporal resolution from conventional (e.g., remote sensing, online fora) and newly emerging sources (e.g., X, Flickr, mobile phone traces, app-based sites) provide opportunities to fill gaps in currently scattered data and empirical evidence (**Chapter 2**). Based on these high-resolution data, fine-scale nexus changes which may not be detectable in coarsely grained data and infrequent observational data, such as census data, can now be better revealed. For example, Landsat data combined with multi-sensor fusion efforts have enabled more detailed time series analysis, e.g., for small-scale land cover change (e.g., tree plantations) which is difficult to detect (Hurni et al., 2017). This supports causal analysis at high spatio-temporal resolutions and a more precise evaluation of transformative pathways.

Validation of crowdsourced data against conventional sources (e.g., (Edwards et al., 2013)) is important to address challenges in these data, such as those related to the uncertainty of the contributors' motivation, ambiguity or lack of geospatial information and unclear reliability of content (De Craemer et al., 2020; See et al., 2016). Despite leveraging existing data sources, monitoring frameworks may still face challenges related to data availability, quality and consistency. In some cases, relevant data may be lacking or unreliable, which can undermine the accuracy of assessments and decision-making. Moreover, due to the current diversity of nexus drivers, relations and outcomes and expected future changes, relevant interactions cannot be immediately monitored in-depth everywhere. Archetype analysis (Oberlack et al., 2019; Sietz & Neudert, 2022) can help identify regions and social-ecological systems with typical interaction patterns to prioritize the monitoring of the most pressing or promising patterns and iteratively expand efforts.

Future nexus thinking in the context of biodiversity and nature's contributions to people would benefit from a more in-depth assessment of monitoring requirements and best practices including in-situ and remote sensing techniques, community-based monitoring, citizen science and cutting-edge technologies for estimating and monitoring biodiversity and its interactions with humans (e.g., environmental DNA analysis, ecological acoustics, camera-traps, hyperspectral imagery and artificial intelligence applications). Additional efforts to link and thereby recognize both global observation systems and national and subnational monitoring programmes, including those led by IPLC and citizen science projects, would support an integrated approach across different contexts, scales and disciplines.

7.3.8.3 Evaluation and learning

Evaluation of post-hoc implementation of response options and other solutions to nexus challenges has often been difficult, as traditional evaluation methods and approaches are restricted to narrow boundaries and miss interconnections between systems and overall complexity (Uitto, 2019). Different types of impact evaluation programmes that can be used to understand nexus complexity range from experimental to theory-based, case-based and participatory approaches. Attention to embeddedness, institutions and stakeholders, and dynamics of causality and change characterize these more flexible approaches (Bamberger et al., 2016). A series of 10 propositions to evaluate outcomes influenced by complexity, such as those likely to be encountered in nexus approaches, has been suggested by (Preskill & Gopal, 2014):

- Design and implement evaluations to be adaptive, flexible and iterative.
- Seek to understand and describe the whole system, including components and connections.
- Support the capacity of the system to learn by strengthening feedback loops and improving access to information.
- Pay particular attention to context and be responsive to changes as they occur.
- Look for effective principles of practice in action, rather than assessing adherence to a predetermined set of activities.
- Identify points of energy and influence, as well as ways in which momentum and power flow within the system.
- Focus on the nature of relationships and interdependencies within the system.
- Explain the non-linear and multi-directional relationships between the initiative and its intended and unintended outcomes.
- Watch for patterns, both one-off and repeating, at different levels of the system (Preskill & Gopal, 2014).

Examples from existing programme evaluations that relate to nexus approaches, such as the evaluations done for the Global Environment Facility funding cycles, suggest that key lessons learned from successful evaluations include: have a theory of change that is relevant to the nexus intervention; make sure evaluations prioritize assessing multiple benefits; ensure system boundaries are relevant to the scale of the problem; and recognize time lags in long-term benefits (Uitto, 2019). Using mixed methods approaches, including experimental, quasi-experimental or counterfactual designs as needed, paying attention early to programme evaluation at the design stage, and use of emergent technologies, including big data, can all help improve evaluations (Bamberger et al., 2016).

In addition to formal evaluation of interventions, social learning can help embed the positive lessons learned from nexus governance and approaches. Social learning refers to institutionalization of structural change within multi-actor settings such that capacities for management are improved (Pahl-Wostl et al., 2010). Barriers to social learning include inflexible and centralized structures, as well as lack of accessible or public information (Pahl-Wostl, 2009). Institutional change within nexus governance has been associated with actors' perceptions of their roles and their mental models of system dynamics that they use to put themselves within systems (Märker et al., 2018). These mental models can be changed

through new information or new methods; for example, simulation games have been successfully used to help embed lessons about nexus interactions and outcomes in creative ways (Mochizuki et al., 2021).

The impacts of social learning on institutionalizing nexus approaches depends on the type of learning that takes place (Armitage et al., 2008). For example, theories of learning have pointed out differences between so-called "single-loop learning", which creates and improves processes without deeper reassessments of why these processes occur or how they are constrained, as compared to "double-loop learning" which leads to questioning of principles and reframing of principles. Advancing to triple-loop learning processes, which are focused on changing structures as well as transforming values and norms, can lead to deeper changes, such as who has power and how it is used (Pahl-Wostl, 2009).

Table 7.10. Actor interactions and guiding questions for step 8 in the road map for nexus action on ensuring ongoing monitoring, evaluation and learning to re-negotiate and update planning and implementation over time as needed.

Actor interactions	Guiding questions for step 8
Assessing how well implementation advances the shared vision and values and anticipated benefits and trade-offs is an ongoing process, with iterations back to previous steps and ongoing social learning and adaptation. Monitoring, evaluation and learning is key to enabling robust review and adaptive revision of implementation efforts, taking into account the diverse roles and responsibilities played by different governance actors and institutions. Creating opportunity for inclusive monitoring and evaluation enables timely review and revision. It helps identify signals for when a change is necessary and allows for making changes in pre-emptive ways. This step can facilitate ongoing dialogue, deliberation and community conversations that deepen learning and joint problem-solving, addressing conflict in productive ways and anticipating surprises.	• **What are the best ways to monitor and evaluate nexus implementation efforts; and who should be involved and how?** o Consider different types of monitoring that reflect nexus interactions and systems thinking, including participatory monitoring and continuous monitoring. • **How can monitoring and evaluation findings inform review and revision of decision-making? Who should be involved and how?** • **How might social learning about nexus-positive change be deepened and extended and by whom and how?**

7.4. Capacity, knowledge and technology gaps

7.4.1. Capacity gaps

Many capacity gaps exist for implementing decision-making in more inclusive, integrative and harmonized ways aligned with the governance of nexus interactions in ways that address nexus challenges (see **Sections 4.2 and 4.6**; **Section 7.3.7**). However, a number of platforms have been developed that seek to highlight opportunities to bridge capacity gaps and create

global partnerships to facilitate implementation. For example, mechanisms aligned with the CBD include the BioBridge Initiative (https://www.cbd.int/biobridge/platform); Clearing House Mechanisms to support parties to improve on capacity gaps by sharing capacity-building resources (https://chm.cbd.int/); High Ambition initiatives, such as the NBSAP Accelerator Partnership (https://nbsapaccelerator.org/) and the High Ambition Coalition for Nature and People in support of the Kunming-Montreal Global Biodiversity Framework (https://www.hacfornatureandpeople.org/). These initiatives support the creation of global networks to strengthen capacities, improve on knowledge gaps and facilitate global implementation. While they are CBD-specific, CBD Decision 15/13 acknowledges the need for synergies and the sharing of these tools to achieve synergetic implementation.[2] These CBD-specific tools can be used to achieve the aims of other biodiversity-related conventions, and set out steps to facilitate a nexus approach.

Capacity strengthening initiatives aligned with the UNFCCC include the Paris Committee on Capacity Building (PCCB), Nairobi Work Programme which is the UNFCCC knowledge-to-action hub for climate resilience and adaptation focusing on capacity strengthening initiatives through enhancing access to evidence and knowledge and Action for Climate Empowerment (ACE), which supports work under Article 6 of the Convention and Article 12 of the Paris Agreement with the aim to empower all members of society to engage in climate action, through the six ACE elements: climate change education and public awareness, training, public participation, public access to information, and international cooperation on these issues, especially in relation to changing behaviours in relation to sustainable consumption and production. In terms of addressing the impacts of climate change within the context of the nexus, the UN Alliance on Climate Change seeks to bring various UN organizations together to build green and climate-resilient societies

Despite these expanding initiatives, this assessment identified several capacity gaps (**Table 7.11**) that if addressed can enhance the governance of nexus interactions and strengthen capacities of diverse actors to identify and implement policy and sociopolitical options, including response options, and the scaling of these options that show transformative potential.

Table 7.11. Capacity gaps identified in the Nexus Assessment chapters with traceability to the assessment chapter sections.

Category	Capacity gap	Chapter sections
Enhanced learning and engagement	Training and capacity strengthening on application of the nexus approach, in particular understanding and overcoming the nexus challenges (high complexity, inadequate scaling, siloed governance, multiple values and lack of financing)	{1.1.2, 2.7, 4.2, 4.5, 4.6, 5.4.6, 6.4.1}
	Approaches for development and adoption of educational curricula on nexus approaches (including designing, implementing and evaluating nexus response options) across all levels of education from primary education through professional training programmes	{2.7, 5.4.6}

[2] Review of progress in the implementation of the Convention and the Strategic Plan for Biodiversity 2011-2020 and the achievement of the Aichi Biodiversity Targets adopted by the Conference of the Parties to the Convention on Biological Diversity in decision 15/13.

	Education on the importance of health-related nexus approaches, including shared training for professionals in the health, veterinary and ecological sectors	{5.4.6}
	Novel programmes for capacity strengthening and capacity transfer on the use of data, methods and technology, including digital developments/Artificial Intelligence, for assessment of interlinkages among nexus elements and the efficacy of nexus response options	{2.7}
Facilitated access to expertise and information	Guidance on appropriate methods for consistent collection of nexus-related data, especially for countries and regions that currently lack capacity	{5.2.5, 5.5.5}
	Greater dissemination and communication of knowledge and good practice gained from implementation of nexus approaches and nexus response options	{2.7}
Strengthened national and regional capabilities	Strengthened partnerships to achieve more harmonized and holistic approaches among actors in the biodiversity, water, food, health and climate change sectors	{5.4.6}
	Capacity strengthening for multi-actor processes, including participation and recognition equity	{5.1.5, 7.4.1}
	Training and capacity strengthening on boundary (bridging) work, negotiation and methodologies for incorporating multiple types of knowledge	{4.5.4, **Table 4.13**, 7.3.2}
	Greater support and funding for transdisciplinary research focused on co-creating holistic nexus solutions and overcoming barriers to their implementation with relevant stakeholders, including involvement of the media/arts	{4.3.4, 4.5}

7.4.2 Knowledge gaps

A number of knowledge gaps were identified throughout the assessment, and detailed descriptions of these gaps are provided at the end of each chapter. A synthesis of these knowledge gaps across **Chapters 2** to **6** is presented in **Table 7.12**.

Table 7.12. Knowledge gaps identified in the Nexus Assessment chapters with traceability to the assessment chapter sections.

Category	Knowledge gap / Research need	Chapter sections
Nexus interlinkages	Studies on higher-order nexus interlinkages involving three or more nexus elements, particularly studies involving health	{2.7, 3.7.5, 5.1.5, 5.2.5, 5.3.5, 5.4.5}
	Studies on the nexus approach in the freshwater and marine realms	{5.2.5}
	Studies on nexus interlinkages spanning across the terrestrial, freshwater and marine realms	{3.7.5, 5.2.5}
	Studies on nexus interlinkages spanning distant regions (telecoupling effects)	{2.7, 5.3.5}
	Studies on nexus interlinkages at regional and local scales, particularly in relation to food systems	{2.7, 3.7.5, 5.3.5, 4.3}
	Studies on cross-scale and cross-habitat interlinkages within and among the nexus elements	{2.7, 5.2.5}
	Studies focusing on interlinkages among a greater number of drivers (e.g., pollution) and sectors (e.g., energy) with the five nexus elements included in this assessment (biodiversity, water, food, health and climate change)	{2.7, 5.2.5}

Category	Knowledge gap / Research need	Chapter sections
Data and quantitative information availability and access	Studies providing quantified information on nexus interlinkages, including trade-offs and synergies among three or more nexus elements	{2.7, 5.2.5, 5.3.5, 6.3.2}
	Data and indicators on the status of, and trends in, the nexus elements (biodiversity, water, food, health and climate change) and, in particular, their interlinkages, spanning space and time scales	{2.7, 5.2.5, 5.3.5, 5.5.5}
	Studies quantifying the role of biodiversity in interlinkages among nexus elements that go beyond simple indicators based on presence of certain ecosystems or species (e.g., take into account ecosystem functioning, genetic diversity, etc)	{2.7}
	Standardized and robust metrics that capture the full range of benefits (ecological, social, economic) of biodiversity-focused and other nexus response options	(5.3.5, 5.5.5, 6.2.2, 6.2.7}
	Studies to identify indicators that can be used to assess and quantify linkages and interactions between indirect and direct drivers and their impact on interlinkages among nexus elements	{2.7}
	High-resolution, sector-specific climate data to facilitate comprehensive climate change adaptation strategies that take into account the complex interlinkages with biodiversity, water, food, health and climate change mitigation	{5.5.5}
	Data on mortality and morbidity attributable to negative impacts on biodiversity, water and food systems, in line with that now available for climate change impacts	{5.4.5}
	Data on economic costs and benefits of nexus response options, particularly those in biodiversity and health	{5.1.5}, {5.4.5}, {6.3.2}
	Aggregated data on national-level spending on biodiversity and the nexus, including aggregate spending on different response options across the nexus	{6.2.2}, {6.4.1}
	Metrics and/or methods that enable comparison of the quality and quantity of finance for biodiversity and the nexus, for example, finding a common denominator that allows comparative analysis	{6.3}, {6.4.2}, {6.2.5}
	Data and indicators to inform improvements in the design of nexus governance, including new empirical research on nexus governance arrangements and policy instruments, including their combination into various policy mixes	{4.5}
Assessment methods, tools, scenarios, models	Scenarios that explore sustainable outcomes, solutions or visions across nexus elements	{3.7.5}
	Modelling tools that better account for nexus interlinkages and can simulate pathways to sustainable outcomes across multiple nexus elements at a range of spatial scales (global, regional, local), as well as accounting for inherent modelling uncertainties	{2.7, 3.7.5}
	Advances in models and scenarios to better understand the consequences of biodiversity loss on other nexus elements (water, food, health, climate) and capture feedbacks between biodiversity loss and other nexus elements	{2.7, 3.7.5}
	Development of One Health collaborative models to promote interdisciplinary approaches for optimizing human, animal and ecosystem health	{5.4.5}
	Integrated, interdisciplinary approaches in climate change adaptation planning to avoid maladaptive outcomes where actions in one sector exacerbate vulnerabilities in another	{5.5.5}

Category	Knowledge gap / Research need	Chapter sections
	Advances in models to better represent more nuanced and specific response options, their interlinkages and outcomes among three or more nexus elements	{3.7.5}
	Policy implementation scenarios representing multiple response options and interlinkages among three of more nexus elements that could assist in understanding how targets might be realized across different scales, including realizing synergies or co-benefits between sectoral response options	{3.7.5, 5.2.5, 5.3.5}
	Evaluation methods and tools for supporting implementation of nexus response options and assessing their efficacy, including evaluation of path dependencies that may lead to lock-in, reduced effectiveness or missed nexus opportunities	{5.2.5}
	Novel methods, models and decision-support tools for assessing interlinkages among three or more nexus elements and actors in the implementation of nexus governance options, including methods focused on spatial/temporal dynamics and scaling up, out, down and deep of response options and their long-term outcomes for the nexus	{5.2.5, 5.3.5, 4.6}
	Methodological studies on nexus governance research, including mixed-methods and qualitative methods	{4.6}
	Comprehensive valuation of the damages of prevailing economic systems to biodiversity and other nexus elements	{6.2.7, 6.4.2}
	Globally standardized methods to estimate, report and account for direct and indirect nexus financing by governments and the private sector	{6.2.7}
	Innovative tools to improve understanding of the barriers and enablers for realizing the transformative potential of nexus-positive financial mechanisms, including consideration of both monetary and non-monetary values in nexus investment and financing	{6.3}
ILK/IPLC	Studies to improve understanding of IPLC-managed systems that have nexus-wide benefits, their importance, monetary and non-monetary value, and potential to scale up, including consideration of contested property rights and traditional rights	{5.2.5, 5.3.5, 6.1, 6.2.5}
	Quantitative information on ILK systems, including documentation of traditional ecological knowledge on biodiversity (e.g., plants and animals) that are used in ILK food systems	{2.7, 5.3.5}
	Scenarios that better account for the visions embedded in ILK and include the participation of IPLC	{3.7.5, 5.2.5, 5.3.5}
	Studies on ILK-based response options that consider the role of IPLC cultural practices and innovation for the implementation and efficacy of nexus response options, their context dependency and feasibility for scaling	{5.1.5, 5.3.5, 6.3}
	Studies on bridging gaps between Indigenous and biomedical health systems, including the implementation and scaling of intercultural health programmes, their effects on biodiversity and climate change, and economic analysis of financial benefits and broader budget impacts	{5.4.5}
	Transdisciplinary research on IPLC decision-making and governance that considers how to incorporate ILK into the definition and development of nexus-informed approaches to governance, such as nature-based solutions	{5.3.5, 5.2.5, 4.5.2, 5.4.6, 6.3, 6.4}
Nexus response options	Empirical evidence evaluating the impacts of response options on multiple nexus elements before and after implementation to understand synergies and trade-offs and how these are influenced by the implementation process, including across multiple scales and contexts	{3.7.5, 5.1.5, 5.2.5, 5.3.5, 5.4.5}

Category	Knowledge gap / Research need	Chapter sections
	Studies assessing the economic and social costs and benefits, financing and distributional equity (including justice and distributional outcomes) of nexus response options and how they enable or hinder response option implementation	{5.1.5, 5.3.5, 6.3.2}
	Studies focusing on the social acceptability and social considerations of nexus response options, focusing on the extent to which response options align with or shape the social norms and values of diverse stakeholders, including IPLC	{5.1.5}
	Evidence on successful examples of scaling out response options plus evidence on where options are non-scalable due to context-dependencies	{5.2.5}
	Studies on how the transformative potential of nexus response options can be operationalized	{5.4.6}
	Evidence / scenarios on the impact of financial system transformations (with regard to short termism, fiduciary duties beyond shareholders) on nature and equity	{6.4.3}
	Studies on the impact and success of health-related nexus response options on multiple nexus elements and their transferability to more locations and populations	{5.4.6}
	Long-term monitoring and assessments of the effects of response options on ecosystem functioning, nature's contributions to people and related socioeconomic benefits	{5.1.5, 5.5.5}
	Studies focusing on effective options for promoting behaviour change needed to shift consumption patterns	{5.3.5}
	Studies synthesizing the social, economic and environmental goals of specific types of nature-based solutions and reporting both their positive and negative effects (i.e., synergies and trade-offs with nexus elements), cases of imperfect implementation or failures in planning and implementation, and comparison to other response options. Cases studies in the Global South are a particular knowledge gap.	{5.1.5, 5.2.5, 5.3.5, 5.5.5}
	Studies including interlinkages of response options in the energy sector with the nexus elements studied in this assessment (biodiversity, water, food, health and climate change)	{5.5.5}
	Case studies of implementation of financial response options that have nexus-wide benefits, for example, removal of fossil fuel subsidies	{5.5.5, 6.2.5, 6.3}
	Evidence and knowledge on the role of business in spearheading nexus response options and reducing existing trade-offs	{6.4}
	Studies on the role of trade in driving or constraining response options	{5.3.5}
	Scenario and modelling studies on how climate change mitigation and adaptation and nature conservation response options interact with the nexus elements and other response options in terms of synergies and trade-offs, especially in the context of confounding factors and complex future dynamics	{3.7.5, 5.1.5, 5.5.5}
	Evidence on the design and aggregate outcomes of combinations (bundles and/or sequences) of response options at landscape, national, regional and global scales. This should include improved understanding of strategies and pathways to sustainable futures, including path dependencies for individual and combined response options	{3.7.5, 5.1.5}
Nexus governance	Studies on alternative and innovative approaches to nexus governance, including improving understanding of what comprises good nexus governance, for whom and under which conditions it takes place	{5.2.5, 4.3, 4.5}

Category	Knowledge gap / Research need	Chapter sections
	Studies on how governance and policy can enable improved engagement, alignment and collaboration between actors from different nexus elements across a variety of scales taking account of actor networks across the nexus, power dynamics and effects on reducing inefficiencies and promoting inclusiveness	{5.1.5, 5.2.5, 5.3.5, 5.4.5, 5.5.5, 4.5.4}
	Studies that explore how power dynamics affect representativeness, inclusion and decision-making in nexus governance and how this affects the prioritization of response options	{5.3.5}
	Studies on the equity dimensions of nexus governance and implementation of nexus response options, including rights-based and sociocultural approaches to equity/justice	{5.1.5, 5.2.5, 5.3.5, 4.5}
	Studies to improve understanding of governance dynamics across various scales and regions for effective implementation of nexus response options	{5.3.5, 5.5.5}
	Studies on the effectiveness of different community governance approaches and their ability to achieve policy coordination at the local scale, including better understanding of community values, conservation attitudes and drivers of resistance by local communities to conservation efforts in impoverished settings	{5.2.5, 4.5}
	Empirical studies on certain types of approaches (e.g., community engagement, traditional institutional arrangements, bio-cultural and customary approaches), and the incorporation of traditional values systems of IPLC in the implementation of response options	{5.1.5, 5.3.5}
	Policy studies to advance understanding on how existing policies converge or conflict with the nexus approach	{5.2.5, 5.5.5}
	Studies on linking nexus approaches to their implications for multilateral agreements, such as the Kunming-Montreal Global Biodiversity Framework and the Paris Agreement, including consequences for the nexus elements (biodiversity, water, food, health and climate change) and their interactions	{5.1.6, 5.2.6, 5.3.6, 5.4.6, 5.5.6}
	Studies on nexus interlinkages and transnational dynamics across geopolitical borders, especially between nation states, and how these dynamics impact nexus governance	{2.7, 5.2.5, 5.3.5, 4.6}
	Improved understanding of incentives to motivate the private sector to drive positive changes towards a more sustainable management of the nexus	{4.6}
	Studies to gain a better understanding about direct and indirect drivers of illegal/illicit activities that impact biodiversity and the nexus elements (e.g., poaching, illegal fishing, illegal mining)	{6.2.3}
	Improved knowledge on the nexus-wide benefits of anti-tax evasion measures and initiatives to improve governance/ transparency of offshore financial centres	{6.2.1}, {6.4.1}
Nexus financing	Empirical evidence and understanding of the scale and distribution of financial flows impacting nexus elements and interlinkages among them, including invisible / unreported financial flows in the Global South	{5.4.6, 6.2.2, 6.2.4}
	Information and improved understanding of subsidies that have the potential to harm other nexus elements or trade-off against other response options	{5.5.5, 6.2.1, 6.2.2, 6.2.3, 6.3.2, 6.4}
	Information on the costs of inaction in monetized terms (e.g., USD) arising from negative impacts (losses/damages) to nature and society	{6.4.3}

Category	Knowledge gap / Research need	Chapter sections
	Development of consistent and accurate methods for assessing current financial flows to biodiversity and other nexus elements to help inform future investments	{6.2.2}
	Studies to improve understanding of the risks from siloed governance and development for the financial system	{6.2.7, 6.3.2, 6.4.3}
	Global, standardized and enforceable benchmarks for nature- and climate-related risks for financial disclosures and investment decisions	{6.2.6, 6.2.7}
	Approaches for monitoring and evaluation of budget performance across different sectors using multiple metrics that account for nexus interlinkages and outcomes (i.e., beyond carbon) and may be measured in different units (i.e., beyond monetary value)	{6.3, 6.4.2}
	Studies of the spatial distribution of drivers of sustainable investments/ disinvestments and the impacts of such investments/ disinvestments on biodiversity and the other nexus elements, including their ability to reduce inefficiencies in resource management and outcomes	{6.2.4}
	Studies on how to integrate nexus benefits into financial decision-making and asset pricing, including how to scale-up and amplify public-private investment and financing in synergistic outcomes among nexus elements	{6.2.6}
	Studies to improve understanding of barriers and enablers for establishing robust regulatory systems and appropriate instruments to enable financing with nexus-wide benefits	{6.2.2, 6.2.4, 6.4.2}
	Studies to improve understanding of finance mechanisms that enable system transitions	{5.4.6, 5.5.5, 6.4.1}

7.4.3 Technology gaps

The assessment suggests a need to find ways to improve the effectiveness of the current innovation ecosystem, not only to increase the development of novel ideas, but to improve the translation of existing ideas into practice. This requires increased focus on the sociotechnical processes of adaptation and adoption that characterize the technological diffusion process (Sartas et al., 2020). This means going beyond just which technologies are technically ready, but also considering the sociocultural and economic constraints that can determine the applicability, accessibility and perceived desirability of these innovations (Barrett et al., 2022; Herrero et al., 2020).

For example, as shown by **Chapter 5**, current technologies and practices as realized through response options have demonstrable potential to contribute to the integrated management of nexus elements. Two-thirds of the identified response options have most of the conditions required for their successful deployment at scale (**Chapter 5.6**); however, many others have not been implemented as well or as extensively, and they share common factors preventing their success related to policy and institutional, equity and/or behavioural barriers (**Figure 5.6.6**). Technology was assessed as an enabler of many response options, but very rarely as a barrier, indicating that these options are not reliant on technological breakthroughs for improved implementation and scaling.

Co-creating evidence and guarantees of changing policies and regulations are essential enablers to overcome existing technological gaps**.** Expectations about future policies are essential, for both public and private sector investments in many elements of the nexus

(Barrett et al., 2022; FAO, 2022; Herrero et al., 2020). For example, investing in research and development of low-carbon technologies is more attractive for private investors if they believe that carbon emissions will have a price in the future. Once new low-carbon technologies are in place, carbon policies (including carbon pricing) will become cheaper and thus more likely to be implemented. Without this, however, few will find it worthwhile to invest in the technology that would have made it feasible. Perverse incentives may arise, in which case current policies can help steer expectations in a desired direction – in particular through substantial subsidies or direct investment.

In addition, pre-emergent technologies, or those innovations that are in the process of being developed but have not yet been applied in the real world (FAO, 2022), hold additional promise to contribute to the integrated management of the nexus elements in the coming years and decades. Trying to identify ex-ante which innovations will be adopted and which ones will be impactful is difficult. Nevertheless, ongoing work that explores the potential of pre-emergent innovations can be critically important in identifying early on the potential consequences of novel innovations on the nexus elements to inform future R&D and integrated policies. Methodologies to explore and assess pre-emergent innovations can help to identify and test the potential of targeted response options and bundles of options which can help to prioritize actions, as well as investments that can foster the development of more mission-oriented innovation (Herrero et al., 2021). Similar to processes described in road mapping and the development of shared visions, these should be built on best futures practices that incorporate diverse perspectives to more broadly consider the potential benefits and ramifications of novel innovations.

These could for example seek out evidence on innovative response options (e.g., new technologies for water quantity and quality management), effectiveness of emerging technologies in delivering outcomes across the nexus, and their justice implications. For example, an assessment and guidance for decision makers on environmental sustainability of emerging technologies has suggested that any transition to sustainability needs to be accompanied by the development of suitable political, governance and management guidance concerning such technologies. Steps for such a process can include: framing risk management in an appropriate way, making sense of uncertainty and ambiguity, developing and implementing methods to assess potential future impacts, working to address systemic impacts, and creating and assigning responsibility (Florin, 2023). These suggested steps are in alignment with the road map for nexus action in this chapter (Section 7.3) to ensure buy-in, suitable understanding of risks and benefits, and forward-looking decisions that recognize the systemic nature of nexus challenges for any technology development.

7.4.3.1. Digital technology gaps and links to monitoring

Technology, in particular digital technology, is having a significant impact on improving understanding of the natural environment and has untapped potential in understanding the complex interlinkages in nexus assessments. For example, recent advances in areas such as computational infrastructure, cloud computing and artificial intelligence (AI) are allowing the realization of data-intensive science at scale (Hey & Trefethen, 2020). These have created new opportunities, as well as highlighted continuing technology gaps, particularly those related to modelling and monitoring.

Technology is having a major impact on all areas of scientific investigation starting with the **acquisition of data**. There has been a dramatic increase in the availability of remote sensing data from satellites, e.g., by 2023, Copernicus was delivering 16 terabytes of high-quality data every day through its Sentinel satellites. There is also a significant increase in data from the deployment of UAVs (drones), including the potential to deploy such technologies on demand. This remote sensing capability is matched by a similar dramatic increase in the deployment of in-situ monitoring networks as science takes advantage of innovations around the Internet of Things. This is also supplemented by the rise of participatory monitoring/citizen science (Fraisl et al., 2022) (see Section 7.3.8.2), and the ability to mine data from the internet and social media (Gibert et al., 2018). There are also other important areas of innovations including the use of eDNA (the identification of DNA from environmental samples from water, soil or air), and automated biodiversity monitoring combining AI with vision and/or acoustic data (Besson et al., 2022; Van Klink et al., 2022). As discussed in Section 7.3.8.2, steps towards integrated monitoring frameworks, taking advantage of all these elements in a coordinated manner, are particularly important for nexus assessments, but remain now at incipient stages.

There have been similar advances in **computational infrastructure**. In terms of High-Performance Computing (HPC), technology is on the cusp of delivering exascale supercomputers, capable of executing 10^{18} floating point operations per second (exaFLOPS), offering the potential for more complex modelling (P. Neumann et al., 2019). Such computing power could improve integration of models across nexus elements, increase the resolution of models and/or understand sensitivities and uncertainties. The emergence of cloud computing is also having a profound impact on science, delivering on-demand computational and storage capabilities combined with the rapid innovations around cloud services at different levels. As an example, recent advances in data lake and data warehouse services offer innovative approaches to the storage of highly heterogeneous datasets (Grossman, 2019) that could be highly valuable for supporting cross-scale and integrated approaches for management across nexus elements.

Building on the above, there is now a strong emphasis on the role of data science in making sense of environmental data. It is now recognized that there is a need for tailored techniques given the complexities of environmental data (Blair et al., 2019; Zammit-Mangion et al., 2023), with a strong emphasis on integrating data across scales. Research is needed to develop new techniques that understand the spatio-temporal nature of data in this field, and the importance of extreme events. AI is also having a profound impact in this area, offering a range of powerful techniques to analyze and understand complex data sources (Zhong et al., 2021). There have been significant advances in the use of AI-based computer vision techniques to analyze and interpret visual imagery with application in areas such as land cover classification and species identification. Similar AI techniques can also be used with acoustic data, with the potential to also combine image and acoustic data, e.g., in biodiversity monitoring as discussed above. There has also been huge interest in generative AI, including Large Language Models, with interest in how such techniques can be applied in science (Birhane et al., 2023).

Finally, there is growing interest in the role of AI in modelling and prediction. For example, the AI 4 Soil Health project is using AI to monitor and predict soil health, recognizing the importance of healthy soils in capturing carbon, improving yields, reducing flooding and

boosting biodiversity. Researchers from Google DeepMind recently developed GraphCast, a trained AI model for medium-range weather forecasting, that is both faster and more accurate compared to industry standard process models (Lam et al., 2023). Given the efficiency of such models, it is also possible to couple multiple models in integrated modelling platforms allowing richer analyses of complex systems and their interactions, an area of high potential for nexus approaches and assessments (Harrison et al., 2023). There is also untapped potential in developing environmental digital twins that achieve a synergy between process and data understanding whereby process models can be improved over time following discovery of patterns, insights and new interactions from data (e.g., modelling as a learning process (Blair & Henrys, 2023). For example, the BioDT project is developing use cases that investigate systemic issues such as species response to climate change and species interaction with each other and with humans (Trantas et al., 2023). Similarly, the Destination Earth (DestinE) project is developing a highly accurate model of the Earth and investigating how the resultant digital twin can address use cases such as climate change and flood risk mitigation/adaptation (Nativi et al., 2021).

Underpinning this, one major gap remains the need for open science and FAIR data practices, and importantly to ensure findability, accessibility, interoperability and reuse of data across disciplines (particularly important for nexus approaches given the need to integrate socioeconomic, environmental and health-related data) (G. Boulton, 2012; Wilkinson et al., 2016). Despite some emerging positive examples, this remains a major barrier to ambitious, cross-disciplinary science. The Australian Research Data Commons (ARDC) offers one example of what can be achieved in this area with its emphasis on thematic research data commons with intrinsic support for interoperability across the fields of health, earth and environment and humanities and social science (including data from Indigenous research), all underpinned by a common cloud infrastructure.

7.5 Conclusion

This concluding chapter has focused on the why, how and who of action to address nexus challenges that have been the focus of the entire assessment. Ensuring that future pathways and options for sustainability remain open by acting now across key governance actors in tackling multiple systemic, compounding and cascading crises can be enabled through the processes and steps outlined in the chapter. Selecting, negotiating and implementing response options, such as those identified in **Chapters 4**, **5** and **6**, are key actions that can help actors achieve more synergistic, coordinated and enhanced outcomes. Yet as the entire assessment has noted, many interlinkages continue to be unaddressed by policies, actions and options, and a range of actors and institutions not represented in decision-making, due in part to the persistence of key nexus challenges around complexity, governance, values, scaling and finance as well as lack of capacities.

Addressing these problems head-on can lead to both important incremental steps forward as well as facilitating shifts towards transformative change, which will involve transforming the way new structures, practices and values are reflected in response options and governance that underpins decision-making. Such transformative change is both an appropriate response and a future target, given the large costs of inaction in not resolving existing crises, including very large amounts of monetary and non-monetary damages from current and projected climate change to nature and people and rising welfare impacts of disasters, biodiversity loss

and ecosystem degradation. The costs of not acting are creating not only current problems and foreclosing future decisions, but also ultimately will require larger amounts of money to fix at a later time point if deferred.

The road map for nexus action has provided a use-inspired process and set of sets that can help actors from many different sectors, regions and backgrounds to approach nexus challenges in a consistent, iterative and inclusive manner, consistent with the components of nexus governance needs that the assessment (and particularly **Chapter 4**) have identified. Clusters of steps cover exploration of the contexts of nexus problems, coordination and strategic action to address problems using a nexus approach, and implementation and scaling of solutions, with decision-support tools available along the way. Other steps in the road map aim to shift power dynamics and vested interests blocking transitions and transformations to just and sustainable futures, including through expanding enablers for nexus approaches and response options.

Decisions about what response options to pursue and how to do so can be enabled by co-design with diverse actors and institutions through transparent and equitable processes and approaches, which can be enabled by structured decision-making through the road map, and which are likely to lead to more successful implementation. A road map process can also help facilitate acting with more attention and understanding of other sectors through collaborative and coordinated action across multiple sectors and actors. Building shared visions of alternative futures is a key goal of road map use, with many processes and models available to envision sustainable transition pathways that recognize complexity and uncertainty and help find futures through these.

Drawing attention to enabling conditions, such as institutional capacities, financial and economic enablers, changes in behaviours and values, technological readiness and material endowments can help ensure better response option choice and implementation. Many response options are highly cost-effective or provide livelihood and income opportunities, and others pay for themselves in cost savings and higher efficiencies. While no response option is likely to be a simple win-win, the road map steps can help with understanding of the limitations, trade-offs and potential inequities involved in any policy choice. Additionally, appropriate scaling of response options accelerates their adoption elsewhere. These processes can be helped by a focus on improved capacities for actors using the road map, including helping developed more transformative capacities of stewarding, unlocking, innovation and orchestrating.

The assessment has also revealed a number of knowledge gaps across key areas of nexus interlinkages; data availability and access; assessment methods, tools, scenarios and models; ILK/IPLC issues; nexus response options; nexus governance; and nexus financing. There are also capacity gaps related to enhanced learning and engagement; facilitating expertise and information; and the need for strengthened national and regional capabilities. Technology gaps (e.g., effectiveness of emerging technologies in delivering outcomes across the nexus) exist and need attention, particularly around creating enabling conditions and policies; the importance of identifying pre-emergent technologies; assessments of technology-equity links; and attention to the emerging digital technology challenges of complexity, consistency and need for open science approaches. However, on-going research is filling many of these gaps, and in many cases, better understanding of these gaps can be accomplished through active co-

production of knowledge while simultaneously taking action (e.g., through iterative experimentation), providing further evidence for the reasons for acting now.

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