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SPECIAL FEATURE: ORIGINAL ARTICLE

Operationalizing the Nature Futures Framework to Catalyze the Development of Nature-Future Scenarios

Degrowth scenarios for biodiversity? Key methodological steps and a call for collaboration

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Abstract

Studies show that economic growth contributes to biodiversity loss and that, after a certain threshold, it does not contribute to wellbeing. Thus, when developing biodiversity scenarios, considering societal futures where economic growth is not a pre-condition deserves special attention. However, to date, degrowth scenarios have not been explored for biodiversity conservation and human wellbeing. In this paper, we explain how the Nature Futures Framework (NFF) and other approaches could be used to generate degrowth scenarios for biodiversity, nature's contributions to people (NCP) and good quality of life (GQL) based on multiple societal values. We present key methodological steps of such an endeavour, including: (i) producing degrowth visions for high-income countries; (ii) identifying leverage points and imagining degrowth pathways; (iii) identifying key social–ecological interactions; and (iv) modelling biodiversity, NCP, and GQL along degrowth scenarios. Our proposal is framed within current theoretical, empirical, and modelling work as well as within efforts to improve scenario development across the biodiversity and climate communities. To develop degrowth scenarios for biodiversity, NCP, and GQL, we call for collaboration across natural and social sciences, quantitative and qualitative approaches, and northern and southern perspectives. This collaboration could lead to a community of practice that tests and improves the degrowth scenarios in national and international science–policy interfaces as they set out to achieve the Convention on Biological Diversity's 2050 vision of living in harmony with nature.

Keywords Degrowth · Scenario · Biodiversity · Transformative change

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The need for degrowth scenarios for biodiversity

There is ample evidence suggesting that economic growth contributes to biodiversity loss, and that decoupling these two factors may not be feasible at the rate and scale necessary to conserve our planet's biodiversity (Marques et al. 2019; Otero et al. 2020; see a summary of the evidence in Supplementary Material 1). Thus, solutions to the biodiversity crisis need to consider economic systems where the priority is not growth, but the wellbeing of humans and nature. An emerging literature argues that it is possible to achieve prosperous societies without economic growth (Cosme et al. 2017; Jackson 2009; Kallis et al. 2018; O'Neill et al. 2018; Raworth 2017; van den Bergh 2017; van den Bergh and Kallis 2012). These authors suggest that policies can be designed to control unsustainable economic expansion while redistributing wealth within and across countries. Consequently, Otero et al. (2020) proposed that the IPBES Task Force on Scenarios and Models includes a degrowth scenario in its new set of scenarios for biodiversity and nature's contributions to people (NCP).[1] For this, they suggested a narrative for a new shared socioeconomic pathway (SSP) based on a degrowth transformation and illustrated how it could be used in the science–policy interface (Otero et al. 2020).

In a reply to Otero et al. (2020), the members of the IPBES Task Force on Scenarios and Models explained that whereas they used the SSP framework to inform the 2019 Global Assessment (IPBES 2019), their new framework for scenario development (Nature Futures Framework, NFF) is not based on the SSP (Lundquist et al. 2021). Rather, the NFF is based on the expression of multiple future pathways inspired by a diversity of human values and relationships with nature, where alternative economic systems are just one component (Lundquist et al. 2021). Hence, the question was raised as to how a degrowth scenario for biodiversity could be developed using the NFF. In parallel, other authors increasingly argued for the inclusion of degrowth scenarios in climate modelling and policy-making (Hickel et al. 2021; Keyßer and Lenzen 2021; Lenzen et al. 2022). A key challenge is thus how to develop degrowth scenarios that can simultaneously tackle biodiversity and climate in a way that is compatible with the IPBES and the IPCC frameworks (Pörtner et al. 2023; Mayer et al. 2023, this issue).

Degrowth has been defined as 'an equitable downscaling of [economic] production and consumption that increases human wellbeing and enhances ecological conditions at the local and global level, in the short and long term' (Schneider et al. 2010: 512). Emerging from radical ecological and cultural critiques to economic growth and development in the 1970s, the degrowth movement revived in the 2000s and is increasingly influencing mainstream sustainability scholarship (Asara et al. 2015; Bodirsky et al. 2022; Kallis et al. 2018; Keyßer and Lenzen 2021).[2] According to the IPBES Global Assessment, degrowth has high transformative potential for biodiversity conservation, but the evidence of its effectiveness is still inconclusive (IPBES 2019: XLVII, 138, 814, 953, 962). In turn, the IPBES Values Assessment states that degrowth is one potential strategy to more sustainable and just futures (IPBES 2022c). Against this background, the development of degrowth scenarios for biodiversity could help to clarify how a degrowth transformation could benefit biodiversity. In this paper, we present how the NFF and other approaches could be used to generate degrowth scenarios for biodiversity, NCP and good quality of life (GQL). We present key methodological steps of such an endeavour and call for strengthened interdisciplinary collaboration across research communities globally. Box 1 provides a glossary of the main terms used in the paper.

Box 1 Glossary of the main terms used in this paper

Biodiversity

The variability among living organisms from all sources including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part. This includes variation in genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities, and ecosystems (IPBES 2019: 1033).

Degrowth

Equitable downscaling of economic production and consumption that increases human wellbeing and enhances ecological conditions at the local and global level, in the short and long term (Schneider et al. 2010: 512).

[1] It should be noted that IPBES does not make scenarios, but catalyses the development of scenarios. Its Task Force on Scenarios and Models has developed methodological guidance to operationalize the new Nature Futures Framework (NFF) by scientific communities and other stakeholders so that scenarios can be developed, and models improved (IPBES 2022a). A set of examples has been developed to illustrate how the NFF can be used to produce narratives of desirable nature futures (Durán et al. 2023, this issue).

[2] An overview of degrowth's origins, premises, policy proposals and controversies is beyond the reach of this paper. For information on these points, the reader may find useful the following references, among others: Asara et al. (2015); Cosme et al. (2017); Demaria et al. (2013); Kallis et al. (2018); Martínez-Alier et al. (2010); Schneider et al. (2010).

Degrowth is considered a radical social–ecological transformation away from the pursuit of economic growth towards simpler, more just and more fulfilling lifestyles (Asara et al. 2015).

Good quality of life

It is a context-dependent state of individuals and human groups, comprising aspects such as access to food, water, energy and livelihood security, and also health, good social relationships and equity, security, cultural identity, and freedom of choice and action (IPBES 2019: 1041).

Model

Quantitative or qualitative representation of key components of a social–ecological system and of relationships between these components (IPBES 2016). In this paper, this translates mostly into quantitative metrics of biodiversity, nature's contributions to people, the economy, and good quality of life.

Nature's contributions to people

All the contributions, both positive and negative, of living nature (i.e. all organisms, ecosystems, and their associated ecological and evolutionary processes) to people's quality of life (IPBES 2019: 1046).

Pathways

Possible development trajectories of a social–ecological system leading to more or less sustainable futures (Elmqvist et al. 2019). In this paper, a *pathway* describes what needs to change, which drivers should be addressed and how, in order to move from the present to the desirable future, i.e. the vision (PBL 2018).

Scenario

A coherent and plausible story, told in words and numbers, about the possible evolution of social–ecological systems, which generally includes policy or management options, descriptions of the future, and identification of critical uncertainties (IPBES 2016; Swart et al. 2004). In this paper, *scenario* refers particularly to the state of biodiversity, nature's contributions to people, good quality of life, as well as their drivers of change. We consider that a scenario is composed of visions, pathways, and models.

Transformation

In general, it means a complete change in the appearance or character of something or someone, especially so that that thing or person is improved (CUP 2023). In the context of sustainability science, it refers to fundamental changes in structural, functional, relational, and cognitive aspects of socio-technical–ecological systems towards more sustainable and equitable futures (Patterson et al. 2017).

Transformative change

A fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals, and values (IPBES 2019). It is thus closely linked to the concept of transformation.

Vision

Desirable future state for nature and people (Pereira et al. 2020; Rana et al. 2020; Wiek and Iwaniec 2014). Visions are the desired normative end point of scenarios (Mayer et al. 2023, this issue). Good visions are utopian but plausible; they are systemic, coherent, and able to motivate key agents of change (Wiek and Iwaniec 2014).

Key methodological steps

We suggest four key methodological steps to develop degrowth scenarios for biodiversity, NCP, and GQL (Fig. 1). In the following sections, we briefly describe each step while situating it in current theoretical, empirical, and modelling efforts.

Producing degrowth visions for high-income countries

The NFF was specifically designed to be able to bridge the diverse ways in which humans value nature in the efforts to create more nature-centred visions (Pereira et al. 2020), echoing the key role of value pluralism in enabling transformative change (IPBES 2022b). The NFF provides a tractable way of organising multiple types of nature values across diverse social, geographical, and sectoral contexts (Fig. 2). This is especially important when developing scenarios because different values of nature continually

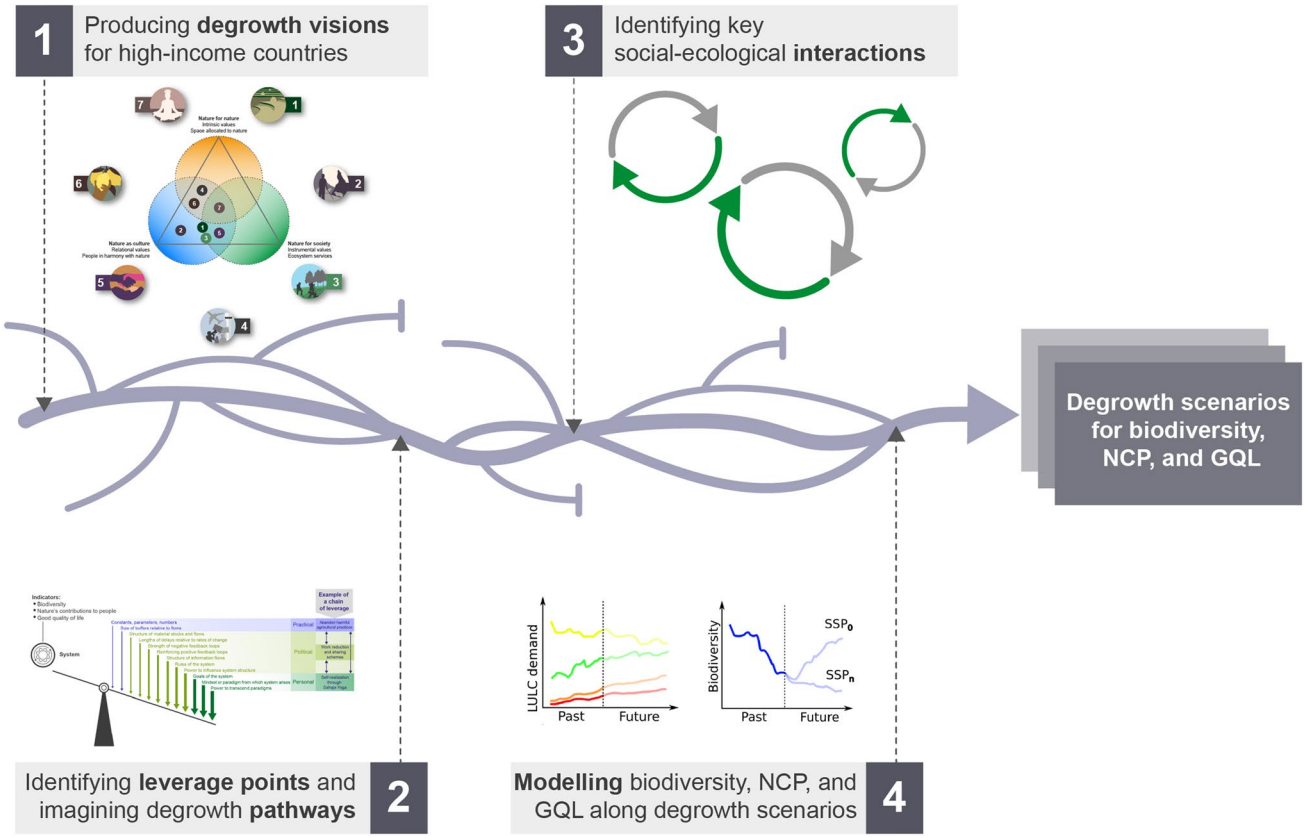
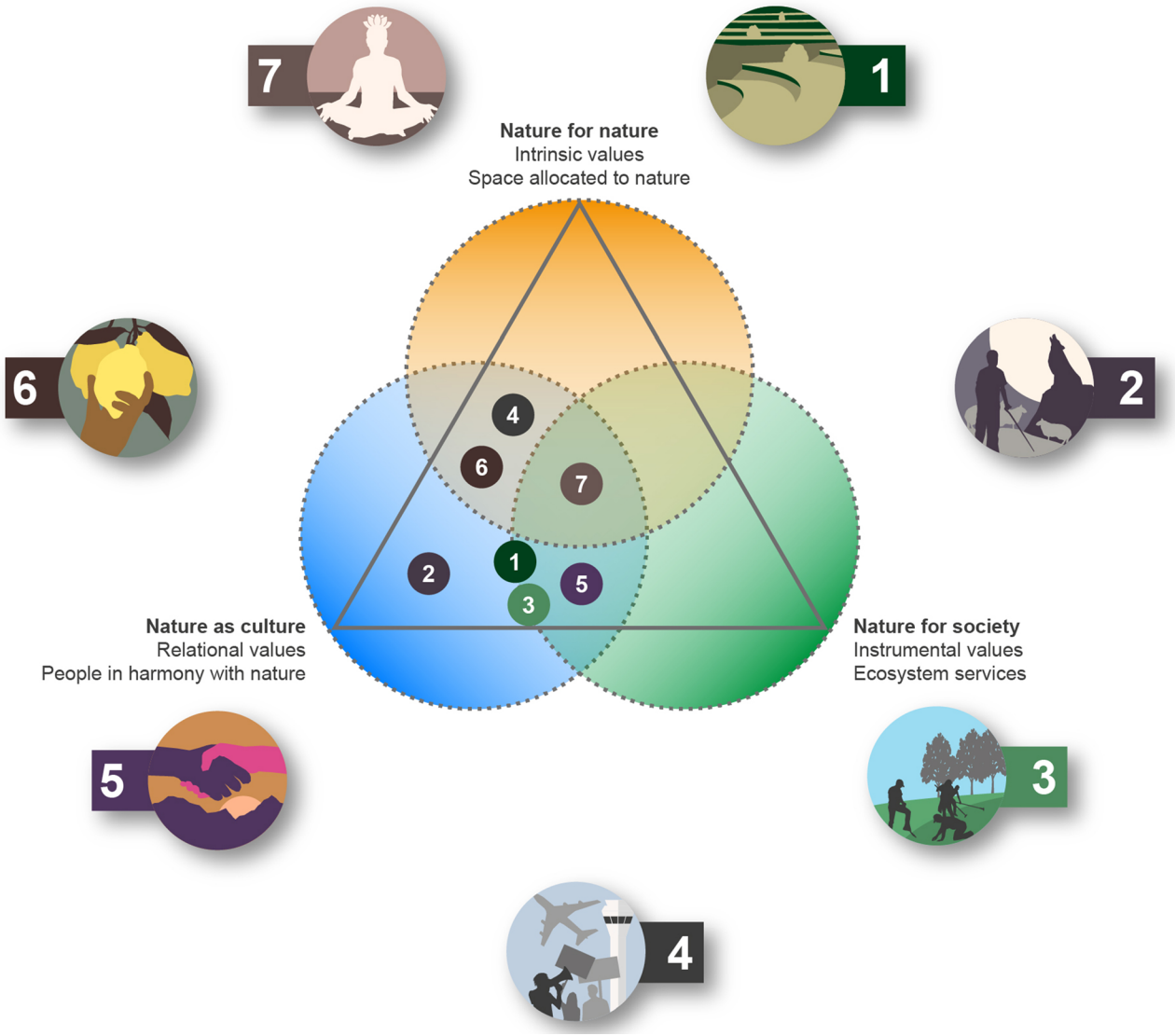


Fig. 1 Key methodological steps to develop degrowth scenarios for biodiversity, nature's contributions to people (NCP), and good quality of life (GQL). Each step is explained in its corresponding section. Source: Designed by Andy Sier based on the ideas from the paper

coexist, conflict, combine, and result in diverse configurations of human–nature relationships (Durán et al. 2023).

The first methodological step consists in generating degrowth visions for high-income countries using the NFF triangle. We focus on high-income countries (World Bank Group 1994) because they are responsible for the majority of global material–energetic flows and associated biodiversity impacts (Hickel et al. 2022a,b; Marques et al. 2019). In addition, the concept of degrowth has its origins in high-income countries of the Global North and is therefore more suited to this geographic and cultural context than that of the Global South. However, the literature has highlighted that North and South are intricately linked through unequal flows of resources and power relationships (Hanaček et al. 2020). Therefore, the necessary transformations and the transformative movements—degrowth, environmental justice, post-development, etc.—are interconnected and potentially synergistic (Dengler and Seebacher 2019; Escobar 2015; Martínez-Alier 2012). Alternative economic systems potentially appropriate for the Global South contexts like wellbeing economy (Fioramonti et al. 2022) or circular economy (Muchangos 2022) should also be explored in the future.

The starting point to generate degrowth visions for biodiversity, NCP, and GQL would be to undertake a workshop with experts in degrowth economics, wellbeing, ecology, biodiversity, climate, and social–ecological systems. The workshop would use the NFF triangle (Fig. 2) and could follow the participatory method developed in a national park in the Netherlands that is based on the *seeds* approach (Kuiper et al. 2022). In the first exercise, seeds of degrowth relevant to biodiversity, NCP, and GQL would be identified (Pereira et al. 2018). *Seeds* refer to current positive and inspiring social, technological, economic, or social–ecological initiatives that hold potential to shape a more prosperous, just, and sustainable future. These initiatives exist, at least in prototype form, and represent a diversity of worldviews, values, and regions, but are not currently prominent (Bennett et al. 2016). The seeds would be identified through a brainstorming session with the workshop participants and then mapped onto the NFF triangle (Fig. 2) to illustrate how a degrowth economic system could emphasize different values of nature. In the second exercise, the seeds would be clustered into three groups within the NFF following the method of Rana et al. (2020). The clustered seeds would then be transformed



Seeds:

1. Recovery of Satoyama (traditional agricultural landscapes) by involving urban inhabitants in Japan (Bennett et al. 2016)
2. Enhancement of the social and historical conditions facilitating human coexistence with wolves in Europe (Pettersson et al. 2022)
3. Strengthening of Indigenous and Community Conservation Areas for the wellbeing of humans and nature in several countries (Borrini-Feyerabend and Campese 2017)
4. Oppositional activism to stop the expansion of highways, airports, and other infrastructures in several countries (Demaria et al. 2013)
5. Reparation of dispossessed communities due to protected area formation in the Global South (Büscher and Fletcher 2019)
6. Creation of consumers' cooperatives sourcing local organic food as an alternative to capitalist food practices (Conill et al. 2012)
7. Time allocation to self-realization, meditation and collective lifestyle away from materialism by Sahaja Yogis (Baijnath 2008; de Kalbermatten 2003)

Fig. 2 The IPBES Nature Futures Framework (adapted from Pereira et al. 2020). Each corner of the triangle represents a different perspective on nature (*Nature for nature*, *Nature for society*, and *Nature as culture*). These perspectives emphasize different value types (*Intrinsic values*, *Instrumental values*, and *Relational values*) and manifest in different ideas or management proposals (*Space allocated to nature*, *Ecosystem services*, and *People in harmony with nature*). Examples of seeds from degrowth and synergistic approaches are shown and preliminarily mapped onto the NFF triangle according to their underlying perspectives and values of nature. The mapping was done by the first author based on the sources quoted in the figure. In the workshop, the mapping would be done in a participatory way. Source: Designed by Andy Sier based on the ideas from the paper

into vision descriptions by combining the different seeds using a matrix to identify the potential impacts of one seed on another, and then employing *Verge,* which provides an adaptable set of guiding questions such as 'How do people relate to nature?' or 'What technologies do people use?' (Lum 2015; Pereira 2021). The resulting vision descriptions would encapsulate what a degrowth future may look like for biodiversity, NCP, and GQL. Besides taking written notes to document the process, the seeds and the visions can also be recorded with live illustrations (Mayer et al. 2023, this issue; Pereira et al. 2020; Rana et al. 2020).

While developing the visions, the workshop participants should address at least two crucial points: (1) the sectors, products, and landscapes where efforts of scenario development should focus on; and (2) the spatial and temporal scales at which it is relevant to model the effects of specific degrowth scenarios on biodiversity, NCP, and GQL.

Identifying leverage points and imagining degrowth pathways

The development of scenarios needs pathways linking the present to the visions of the future through concrete interventions targeting direct and indirect drivers of change. The interventions can be conceptualized in terms of leverage points, i.e. *places* in a system where small actions have high transformative effects (Meadows 2016; Chan et al. 2020). Shallow leverage points (e.g. system parameters) have only the capacity to effect superficial changes, whereas deep leverage points (e.g. the societal mindsets from which system goals arise) can lead to radical transformations (Meadows 2016; Fig. 3a). The deepest leverage points fall within the *personal sphere* which includes the values, beliefs, assumptions, worldviews, and paradigms of people (O'Brien and Sygna 2013; O'Brien 2018). These factors are considered to shape the ways in which the social–ecological systems are viewed and constructed—the *political sphere*—and to influence what types of management practices are considered possible—the *practical sphere*. In turn, both the political and practical spheres shape the context in which the elements of the personal sphere are maintained or transformed (O'Brien and Sygna 2013; O'Brien 2018). Shallow and deep leverage points thus interact in so-called *chains of leverage* relevant to particular geographical and historical situations (Abson et al. 2017; Riechers et al. 2021). For example, a combination of self-realization through meditation, the enactment of work reduction and sharing schemes, and the abandonment of harmful agricultural practices can be hypothesized to help destabilize the system at a given scale (Fig. 3a).

To systematically identify leverage points for degrowth pathways that are relevant for biodiversity, NCP, and GQL—as well as the actors that could activate them—we suggest conducting a literature review. For example, the literature connecting degrowth and biodiversity (Martin et al. 2016; Büscher and Fletcher 2019; Fletcher and Büscher 2020; Otero et al. 2020; Moranta et al. 2022; Pueyo 2024) and the literature on transformative change for biodiversity conservation (Bennett et al. 2016; Chan et al. 2020; IPBES 2019, 2022b) could be reviewed to identify leverage points. These sources could be complemented by other methods like: a survey to degrowth and transformative change experts asking which leverage points should be included in degrowth scenarios for biodiversity, NCP, and GQL; a Delphi poll (Pohl 2020) to these experts with the same objective; serious games (Bruley et al. 2021; Lorig et al. 2016); or real-world laboratories (Bergmann et al. 2021; Schäpke et al. 2018). Some examples of leverage points that could be useful to build degrowth scenarios for biodiversity, NCP, and GQL are: use of indicators other than gross domestic product (GDP) to guide national policies (e.g. wellbeing indicators), policies to promote work reduction and sharing, the adoption of nationally binding caps to resource imports and exports, and the establishment of moratoria on resource extraction in highly biodiverse areas (van den Bergh 2009; Alcott 2010; Kallis et al. 2013; Kubiszewski et al. 2013; Videira et al. 2014; Otero et al. 2020; Neubert et al. 2022).

The leverage points derived from these sources could be mapped onto the Three Horizons framework (Fig. 3b), which helps participants develop agency while exploring complex change pathways and distinguishing between incremental and transformative changes (Sharpe et al. 2016). Following Sharpe et al. (2016), this exercise would involve five steps. In *Present concerns* the participants would identify why the current economic system is not fit for purpose, for example because it has high impacts on biodiversity and a low performance in terms of human wellbeing. Next, in *Future aspirations* they would explore the visions developed in Sect. "Producing degrowth visions for high-income countries" that would replace the current system: a post-growth wellbeing economy with fulfilling jobs and thriving biodiversity. *Inspirational practice* would identify pockets of the future in the present, i.e. concrete examples where new ways of doing things are visible at the margins of the present system, like the seeds used to develop the visions (Fig. 2). Next, in *Innovations in play* the participants would identify innovations that are happening in response to the failings of the current system and the possibilities of the new one. This is where the leverage points fall. For example, simulations suggest that with a high enough carbon tax, Canada could reduce its carbon emissions by 80% in 2035; while income would contract to the levels of 1976, employment would not decrease if working hours were to be reduced to one-fourth of their present level (Victor 2012). Some seeds that begin to have transformative effects as they spread (Bennett et al. 2016)

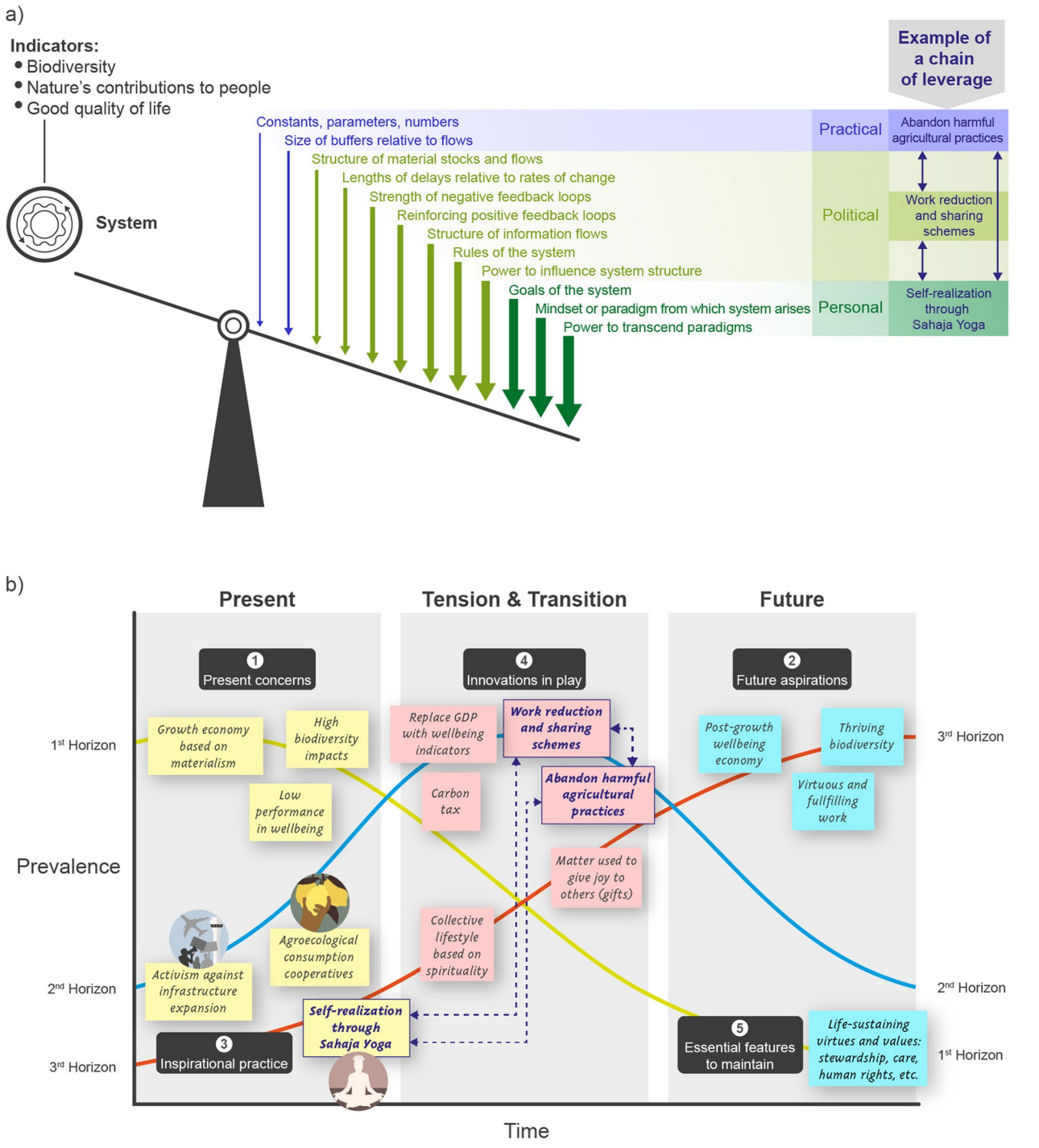


Fig. 3 **a** Leverage points identified by Meadows (2016) from lower (left) to higher (right) transformative potential. Leverage points are classified in three spheres of transformation (*practical*, *political*, and *personal*) after O'Brien (2018). An example of *chain of leverage* is given where three leverage points pertaining to different spheres interact. Leverage points lead to system's transformation, which can be tracked with indicators. Source: Designed by A. Sier based on ideas from this paper. **b** The Three Horizons Framework. Each horizon represents a pattern in the way things are done regarding the relationship economy–biodiversity. The vertical axis indicates the prevalence of each pattern in a relative way, while the horizontal axis represents time. Horizon 1 (H1) represents the way the economy works now, which is losing fit given current trends in biodiversity loss and human wellbeing. Horizon 3 (H3) represents the emerging pattern that will substitute the current one. Horizon 2 (H2) represents the transition activities and innovations that people are trying out in response to the current trends, which provide the opportunities for H3 systems to emerge. Key methodological steps (1–5) and exemplar sticky notes are shown. The chain of leverage of panel *a* is indicated with dotted arrows (see text for details). Source: Designed by Andy Sier based on Sharpe et al. (2016) and ideas from this paper

could also be included here. Finally, *Essential features to maintain* would be filled with desirable aspects of the current system that need to be retained during the transformation. These include virtues and values that sustain human and non-human life such as stewardship and care (Chan et al. 2016) or notions of human rights.

The Three Horizons framework can also be used to visualize *chains of leverage*, i.e. combinations of personal, political, and practical leverage points along degrowth pathways (Fig. 3b). For example, a minimum number of spiritual pioneers gets their self-realization through Sahaja Yoga meditation. Self-realization leads to the experience of blissful non-dual states where oneself, nature and the universe are perceived as one simultaneous reality by the nervous system (Baijnath 2008; de Kalbermatten 2003; Shri Mataji 2013). This generates positive effects on their brain structure and wellbeing, favors character strengths such as forgiveness and hope, and improves sustainability-related decisions (CEL 2017; de Kalbermatten 2003; Hendriks et al. 2021; Hernández et al. 2020; Zollo et al. 2020). These pioneers gradually allocate more time to collective life and less to alienating jobs. Mimicking nature, they use matter to give joy to others for example through gifts within the community (Shri Mataji 1986). As their lifestyle spreads, the societal support for work reduction and sharing schemes grows. These schemes are approved by regional or national governments in collaboration with companies and trade unions. Spending the time liberated from work in meditation or producing handicrafts (Shri Mataji 1985, 1981) avoids the rebound effect that could occur if this time was dedicated to energy-intensive leisure activities (Shao and Rodríguez-Labajos 2016) and eventually provides an extra income if the handicrafts can be sold in regional markets. Work sharing schemes and enhanced handicraft production help to contain unemployment during the delicate transition between the growth and the post-growth economy, whereby a new type of work—virtuous and fulfilling—emerges. As a reaction to nature degradation and declining resource availability, a regenerative agriculture is increasingly practiced by farmers. Harmful agricultural practices like pesticide use are no longer socially justifiable and thus they are abandoned.

Such combination of visions (Sect. "Producing degrowth visions for high-income countries") and pathways (Sect. "Identifying leverage points and imagining degrowth pathways") would then be consolidated into scenarios for use in the modelling options presented in Sect. "Modelling biodiversity, NCP, and GQL along degrowth scenarios".

Identifying key social–ecological interactions

Understanding key social–ecological interactions is crucial to find out what value-based interventions can transform the systems towards the identified visions, and to improve the predictive capacity of the models (Kim et al. 2023b). For this, new research is required that improves our understanding of the relationships between economic (de)growth, biodiversity, NCP, and GQL. This research applies to the landscapes of the Global North, in particular those under intense pressure, as well as to the landscapes of the Global South that supply resources and products to the Global North. Table 1 provides some guiding questions for this interdisciplinary endeavour, as well as methods and approaches that could be used to answer them. Supplementary Table 1 develops one of these guiding questions in detail (#1: relationships between GDP and the state of biodiversity). Resulting key social–ecological interactions relevant for biodiversity, NCP, and GQL can be integrated in the visions and pathways (Kim et al. 2023b). Next, we comment on each guiding question from Table 1.

It is well established that higher GDP is correlated with more impacts on biodiversity (Otero et al. 2020; Supplementary Material 1). However, degrowth scenarios for biodiversity can benefit from more and better knowledge of this correlative link; a clarification of the direction of the causality; a differentiation between degrowth and recession in their effects on biodiversity; and an estimation of the delay of the biodiversity response to a cessation of GDP growth (Supplementary Table 1). These results can be used to strengthen the capacity of the models to calculate biodiversity and NCP outcomes of degrowth pathways. In turn, the degrowth policy proposals need to be scrutinized in terms of their transformative potential and effects on biodiversity. This can be assessed based on systems thinking research on degrowth pathways. Such research illustrates, for example, how removing harmful subsidies and issuing a moratorium on resource extraction can change the rules of natural resource exploitation, limit the growth of material and energy flows, and improve the state of biodiversity (Videira et al. 2014). More research on the effects of increasing and decreasing global trade on biodiversity is likewise crucial so that the new scenarios can properly account for the telecoupled nature of contemporary biodiversity conservation (Bjelle et al. 2021; Carmenta et al. 2023; Marques et al. 2019).

Agricultural land-use changes driven by economic growth and cash crop expansion are a main driver of biodiversity loss (IPBES 2019; Otero et al. 2020). Thus, degrowth scenarios must build on sound knowledge about the transformative potential of the agri-food system. Current research sheds light on strategies and geographies of such transformation, but pays insufficient attention to the ecological conditions and the energy and material flows of alternative agri-food initiatives (Guerrero Lara et al. 2023). More studies on the social metabolism of agriculture and its effects on landscape (Gomiero 2018; Padró et al. 2020) as well as quantitative

land system modelling projections (Bodirsky et al. 2022) are needed to assess to what extent degrowth-inspired agri-food systems can meet nutritional needs while conserving biodiversity. Related to this is the question of time allocation across economic sectors (Manfroni et al. 2021). In high-income countries, the availability of cheap fossil energy has so far allowed massive increases of agricultural labour productivity and a consequent shift of farmers to other economic sectors (Sorman and Giampietro 2013). Conversely, a degrowth scenario with reduced energy availability and reduced imports of crops (Poux and Aubert 2018) may require an increase in the number of farmers in these countries. This may contribute to the restoration of the agro-sylvo-pastoral mosaics and the cultural landscapes present before the spread of industrial agriculture (Fullana Llinàs et al. 2021; Otero et al. 2015, 2013). In turn, these changes in landscape structure may have important consequences for biodiversity by providing new open habitats and through feedbacks with wildfire regimes (Aquilué et al. 2020; Marull et al. 2015; Pais et al. 2020).

Degrowth embraces voluntary simplicity and frugality to reach a lifestyle that is more respectful with the environment and more fulfilling as compared to a materialistic lifestyle (Cosme et al. 2017; Demaria et al. 2013). However, degrowth scenarios for biodiversity need quantitative and qualitative knowledge on how a shift towards these values and lifestyle by certain societal groups may influence biodiversity and NCP at different scales. Better and more systematic knowledge is also needed on the links between economic activity, biodiversity, and wellbeing. The development and improvement of combined metrics such as the Sustainable Wellbeing Index (Costanza et al. 2016), the Socio-Environmental Index (Rigal 2022), or the Safe and Just Space (O'Neill et al. 2018; Raworth 2012) would allow to account for ecosystems' positive contributions to wellbeing along degrowth pathways.

Modelling biodiversity, NCP, and GQL along degrowth scenarios

In this section, we explain different approaches that could be used to model the implications of degrowth scenarios for biodiversity, NCP, and GQL. The decision on which approach to use will depend on available data and funding, economic sector(s) of interest, chosen scale, expected outputs, goal of the exercise (exploratory research, support to decision-making, scenario inter-comparison, etc.), and the skills present in the partnership. The modelling approaches presented here are mostly useful for ex ante policy screening and design, but they can also be used for ex-post policy review (Kim et al. 2023b). We distinguish between top-down approaches relying on decisions taken by scientists, and bottom-up approaches that require an input from other stakeholders (Fig. 4). Box 2 stresses the importance of checking the feasibility of the modelled scenarios in terms of biophysical flows and time allocation.

Top-down approaches

Simulating degrowth policies with macroeconomic models Macroeconomic models at the national scale (e.g. EUROGREEN, D'Alessandro et al. 2020; LowGrow SFC, Jackson and Victor 2020) can be used to simulate the effects of degrowth policies (or leverage points) in high-income countries. For example, they can be used to simulate the effects that work time reduction and limits to imports would have on GDP, economic structure, inequality, greenhouse gas emissions, and wellbeing indicators. Strengthening the biophysical component of these models is crucial to highlight the need for deep structural changes in the economy (Box 3). This requires closer collaboration between degrowth macroeconomists and conservation ecologists. For example, EUROGREEN can calculate the demands on land deriving from a particular degrowth-like economic structure and its related material and energetic flows. Land demand can be translated into future land-use changes at a regional scale using equilibrium models, and then downscale them into spatially explicit land-use changes at finer scales (up to 1×1 km) with a spatial disaggregation model (Vernon et al. 2018) or a land-use simulation model (Liu et al. 2017). The resulting spatially explicit land-use change data can then be linked to biodiversity data using e.g. the PREDICTS dataset (Hudson et al. 2017; Purvis et al. 2018). This dataset relates local biodiversity (including essential biodiversity variables such as α, β, and functional diversity, Pereira et al. 2013) to different levels of human pressures like land-use and land-use intensity.

Modelling the effects of a new SSP on biodiversity and NCP All currently available SSP assume positive economic growth rates (O'Neill et al. 2017). There is no SSP whereby high levels of biodiversity are achieved with low or negative economic growth rates (Otero et al. 2020). The degrowth scenarios sketched in the previous steps can be used to characterize a new SSP across economic, demographic, institutional, technological, and environmental factors. This can be done by translating the visions and the leverage points into assumed GDP growth rates, inequality levels, carbon intensity, or agricultural productivity. For example, establishing national caps to imports and a high carbon tax under conditions of limited energy availability in high-income countries can be assumed to reduce agricultural labour productivity and GDP growth rates. It can trigger land-use conversions from forest to agriculture to produce within the countries' borders the food that was previously imported. Assumptions for the Global South

Table 1 Examples of guiding questions on the relationships between economic (de)growth, biodiversity, nature's contributions to people (NCP), and good quality of life (GQL), as well as methods and approaches to address them. Source: Based on the authors' knowledge of the relevant literature

	Guiding questions	Methods and approaches
1	What are the relationships between GDP and the state of biodiversity?	• Partial least square regressions, convergent cross mapping, control-impact approach (Supplementary Table 1) • Extended input–output analysis and new ecological macroeconomic modelling (Nieto et al. 2020)
2	What are the effects of degrowth leverage points on biodiversity at different scales?	• Systems thinking, causal loop diagrams (Videira et al. 2014)
3	What are the effects of increasing/decreasing global trade on biodiversity across taxonomic groups?	• Impending bird extinction driven by production activities (Marques et al. 2019) • Biodiversity footprint (Bjelle et al. 2021) • Land-use change and emissions embodied in trade (Henders et al. 2015; Hong et al. 2022) • Connected conservation (Carmenta et al. 2023)
4	How is the agri-food system transformed along a degrowth pathway and with what effects on biodiversity and NCP?	• Quantitative land system models (Bodirsky et al. 2022; Poux and Aubert 2018) • Comparative analysis of the social metabolism of old and new agricultural systems (Gomiero 2018) • SAFRA modelling (Padró et al. 2020)
5	How does a degrowth transformation change working time allocation across economic sectors, paid/unpaid work, and gender, and with what consequences for biodiversity?	• Multiscale integrated analysis of societal and ecosystem metabolism (Sorman and Giampietro 2013; Manfroni et al. 2021; Kallis 2013)
6	How does a shift towards voluntary simplicity and frugality influence biodiversity, NCP, and GQL?	• Theories of environmentally significant behaviour (Stern 2000) • Frameworks to understand how diverse values can be leveraged for transformative change (IPBES 2022b)
7	What are the links between economic activity, biodiversity, and wellbeing?	• Sustainable wellbeing index (Costanza et al. 2016) • Socio-environmental index (Rigal 2022) • Safe and just space (Raworth 2012; O'Neill et al. 2018)

can be produced based on estimated minimal resource use thresholds for decent living and global convergence in resource use and wealth between high and low-income countries (Capellán-Pérez et al. 2015; Millward-Hopkins et al. 2020; O'Neill et al. 2018; Oswald et al. 2021). All these assumptions can be paired with quantitative projections of land-use (Bodirsky et al. 2022) and a Representative Concentration Pathway (i.e. a pre-defined scenario of emission/concentration of greenhouse gases and land-uses; van Vuuren et al. 2011). The new SSP and related land-use and climate projections can be used to run models of biodiversity and NCP such as those used in the BES-SIM intercomparison exercise. Such models yield spatially explicit metrics of biodiversity (extinctions, abundance-based intactness, proportional change in suitable habitat extent) and 10 NCP at global and regional scales (Kim et al. 2018). This approach would allow to model the effects of degrowth policies in high-income countries on the state of biodiversity and NCP of countries in this and other income categories.

Comparing degrowth scenarios with other scenarios We see two potential ways to compare the modelling outputs of degrowth scenarios—in terms of biodiversity, NCP, and GQL—with those from other scenarios. One way is by comparing the outputs of the previous approach—spatially explicit metrics of biodiversity and NCP under an SSP akin to degrowth—with those obtained from the same set of BES-SIM models run under other scenarios. Results from BES-SIM models are available for these scenarios: SSP5-RCP8.5 (*Fossil-Fuelled Economic Growth*: medium land-use pressure and very high level of climate change), SSP3-RCP6.0 (*Regional Rivalry*: high land-use pressure and moderately high level of climate change), and SSP1-RCP2.6 (*Sustainability*: moderate land-use pressure and low level of climate change) (Kim et al. 2018; https://portal.geobon.org/home). Another way to compare the outputs of degrowth scenarios with those from other scenarios is by developing a green growth scenario with the method explained in this paper ('green growth' asserts that continued economic expansion is compatible with our planet's ecology, as technological change and substitution will allow us to absolutely decouple GDP growth from resource use and carbon emissions; Hickel and Kallis 2020). This would require producing green growth visions with the NFF, identifying the leverage points, and modelling the outputs in terms of biodiversity, NCP, and GQL. Illustrative visions recently produced with the NFF suggest that both post-growth and green growth

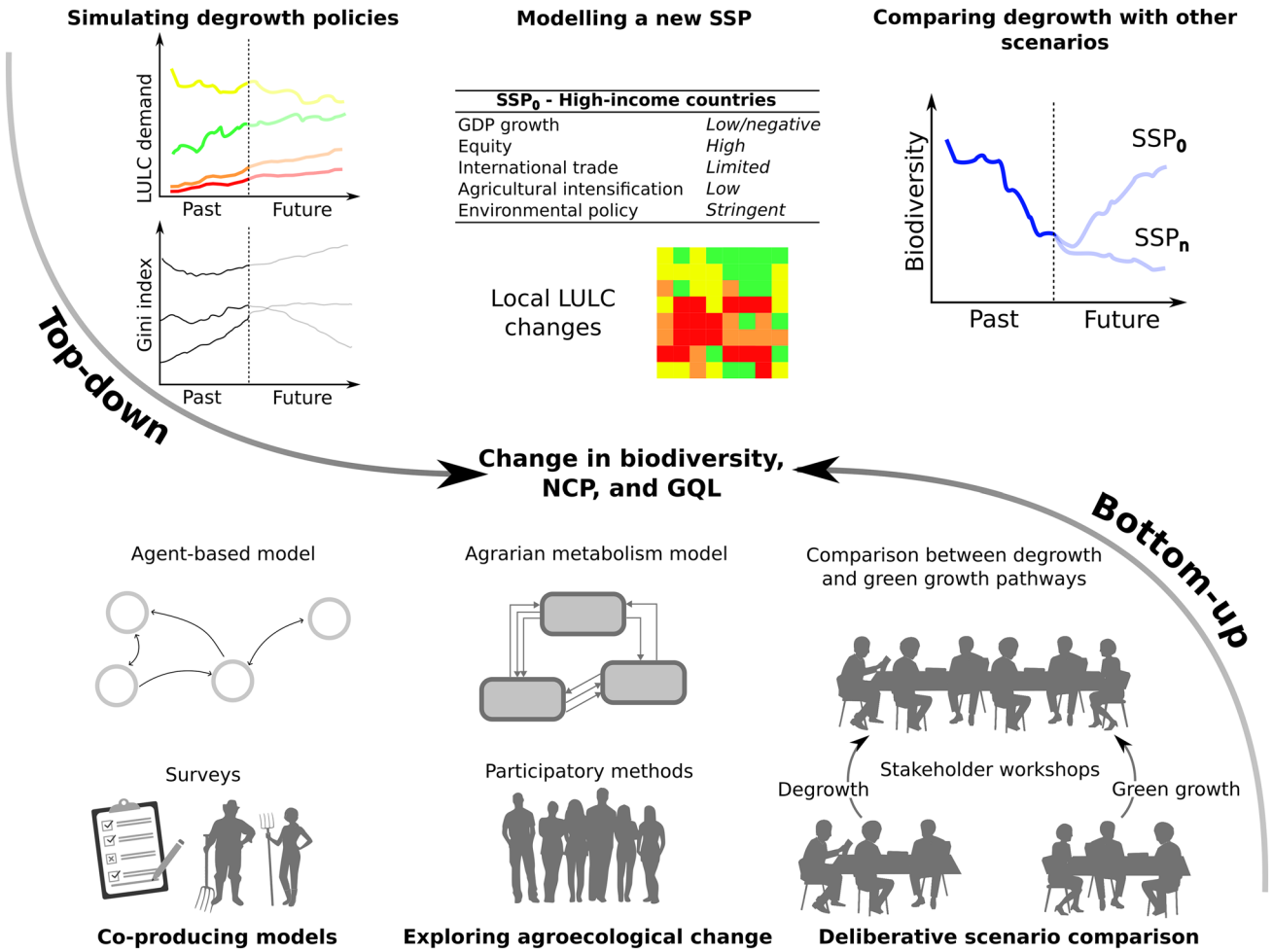


Fig. 4 Different approaches to model changes in biodiversity, nature's contribution to people (NCP), and good quality of life (GQL) along degrowth scenarios. See Sect. "Modelling biodiversity, NCP, and GQL along degrowth scenarios" for an explanation of each approach. Source: Designed by Stanislas Rigal based on the ideas from this paper

can contribute to a desirable future for nature and people (Durán et al. 2023, this issue). The comparison of modelling outputs between degrowth and green growth scenarios can elucidate whether the futures described in both are desirable or not and in what ways, i.e. what is the state of biodiversity, NCP, and GQL in each of them.

Bottom-up approaches

Co-producing models The steps explained above (Sects. "Producing degrowth visions for high-income countries, Identifying leverage points and imagining degrowth pathways, Modelling biodiversity, NCP, and GQL along degrowth scenarios") can be conducted in a participatory mode, whereby degrowth scenarios would be co-produced in a context-based, pluralistic, goal-oriented, and interactive way (Norström et al. 2020). In practice, this means inviting degrowth-minded stakeholders from specific regions to co-produce degrowth visions and identify leverage points and pathways. Such stakeholders can include activists opposing the expansion of large infrastructures (high speed trains, airports, etc.), practitioners developing alternatives (co-housing, consumer cooperatives, etc.) or agroecological farmers (Demaria et al. 2013). This lays the ground for the co-production of the models. For example, global and regional land-use models sensitive to different policies can be used to identify land-use transitions to the degrowth visions (e.g. Verkerk et al. 2018). Within these models, agent-based modules parametrized with data from surveys and interviews with farmers simulate their decision-making processes (e.g. Brunner and Grêt-Regamey 2016). These modules often assume that farmers wish to maximize income, but they can also model other behaviours like that of farmers without a commercial orientation (e.g. Murray-Rust et al. 2014). In this exercise, they could be parametrized with empirical data from degrowth-minded farmers that grow food with

the goal of self-sufficiency or autonomy (Calvário and Otero 2014; Gomiero 2018). Model outputs can then be coupled to indicators of biodiversity and NCP.

Exploring agroecological change with models of agrarian metabolism The shift from agro-industrial to agroecological production can largely improve the biodiversity of agricultural landscapes along degrowth pathways (Perfecto and Vandermeer 2010). Models of agrarian metabolism can be used to explore feasible options of agroecological change in participatory strategic planning processes. Top-down backcasting models that plan a territory as 'one single farm' can be used to demonstrate the feasibility of such change (Poux and Aubert 2018). However, agroecology rejects one-size-fits-all approaches (Altieri 2002). Solutions must rather be discovered in each place by scaling out and up existing best practices. Bottom-up models based on site-specific restrictions and capabilities can help advance agroecological change along degrowth pathways. Restrictions and capabilities refer to the available land of different types and slopes, irrigation capacities, agricultural practices that are restricted or welcomed in protected areas, etc. SAFRA (Padró et al. 2020) and similar models allow to identify the optimal configuration of land uses, livestock densities, diets, and human population size to maximize a given societal priority (e.g. local production of a large share of food baskets vs. partial specialization and trade). Different priorities give rise to different landscape configurations that are sustainable, i.e. where all living components of the agroecosystem can be reproduced in a healthy state while keeping all the restrictions set in the model. The capacity of the resulting landscape configurations to host biodiversity can be compared.

Deliberative comparison between degrowth and green growth pathways Within a specific region, stakeholders adhering to degrowth and green growth paradigms can be invited to jointly deliberate about the region's future spatial planning strategy. An iterative process can be designed whereby stakeholders' paradigms and values frame the choices in terms of demand analysis, option design, impact analysis, and trade-off analysis (Wissen Hayek et al. 2016). In a first phase, stakeholders adhering to degrowth (activists against urban expansion, agroecological farmers, researchers, etc.) and stakeholders adhering to green growth (industrial ecologists, small and medium enterprises interested in circular economy, etc.) work separately to identify what are their spatial demands, development options, and corresponding impacts and trade-offs. In a second step, the two groups work together particularly in the analysis of trade-offs between targets (e.g. protecting peri-urban agriculture vs. expanding industrial areas). For this, a multi-criteria evaluation tool can be used to collectively weight different targets and to iteratively test the effects of different weightings on indicators of biodiversity, NCP, and QGL (Wissen Hayek et al. 2016; Honeck et al. 2020). Participatory multi-criteria evaluation can also be used to prioritize the protection of the region's most valuable areas in the face of natural hazards while transforming its landscape along a degrowth pathway (Gamboa et al. 2023).

Box 2 Are degrowth scenarios feasible in the current social–ecological system?

The allocation of human activity (HA) to different economic sectors may represent a constraint to economic growth (Manfroni et al. 2021), but also to degrowth. Let us consider the degrowth scenario of an agro-food system with reduced energy availability and reduced imports of commodities. This may entail an increase in the number of farmers and the HA allocated to produce food. This new agricultural sector may change the demographic structure of rural areas due to the arrival of different types of farmer families, which would imply different requirements for the education, health, commerce, and other services. For example, would the education sector have enough teachers for a growing number of children, or would it be necessary to hire new teachers? Besides a certain amount of HA (e.g. skilled labour), the new agricultural sector would also require land to perform the expected function of delivering a certain quantity and quality of food to the rest of the society. Thus, it would compete with other sectors for the resources needed to perform its functions. It is important to check whether the coexistence of different sectors (agriculture, health, education) performing different functions (food provision, health care, teaching) is compatible with the available HA, land and other resources in the study area.

The MuSIASEM accounting framework can be used to check the implications of these constraints for the feasibility of degrowth scenarios. The MuSIASEM approach (Giampietro et al. 2014, 2011; Giampietro and Mayumi 2000a, 2000b) is the operationalization of the fund-flow model (Georgescu-Roegen 1971). According to it, at a given temporal scale, fund categories (e.g. capital, people, Ricardian land) transform input flows into output flows. Flows (e.g. added value, water, energy, matter) are either consumed or generated to reproduce the funds. One of the key features of MuSIASEM is that it accounts HA in hours of human time. This makes it possible to track HA across sectors and levels of the socioeconomic system. *Sectors* refer to distinct socioeconomic activities, e.g. the paid work sector, which can in turn be divided into smaller sectors like agriculture, education, health, commerce, etc. *Levels* are organizational units that define the grain and extent of observation, e.g. individual/

community/society. A matrix can be used to characterize the flow of energy and materials from production to end-use activities across sectors and levels (Velasco-Fernández et al. 2018) and to check the biophysical feasibility of future scenarios (Serrano-Tovar et al. 2014).

To check the biophysical feasibility of a degrowth scenario for the agro-food system we could start by calculating the budget of HA of the specific society considered. This is calculated as $Population \times 24\ h/day \times 365\ days/y = Population \times 8.760\ h/year$. This budget of HA can be split in time allocated to activities performed in the paid work (PW) sector and activities performed in the household (HH) sector. HA_{PW} can be split in the time allocated to different sectors, such as agriculture (HA_{AG}), education (HA_{ED}), health (HA_{H}), commerce (HA_{C}), etc. These sectors are providing goods and services to the society, and at the same time are using HA, skilled labour, technology, land, and energy. If changes in the agro-food system bring about changes in the demographic structure of a rural area, the HH sector would require different amounts of goods and services provided by the rest of sectors. This new requirements could be met through several strategies. One option would be to redistribute HA across sectors, i.e. allocate more time from the HH sector to the rest of sectors to meet its increased requirements. Another option would be to keep the HA allocated to different sectors while increasing their productivity through improved technology and skills (potentially at the cost of consuming more resources). A third option would be to decrease the quality of the goods and services provided to society. With MuSIASEM, the consequences of these options can be evaluated to assess their biophysical feasibility and social desirability.

Box 3 Highlighting structural changes with biophysical macroeconomic modelling

Structural changes are key to addressing biodiversity loss. Making this apparent requires extending GDP, which can be done using environmentally, socially and gender extended input–output analysis (EIOA) (Capellán-Pérez et al. 2020; Solé et al. 2020). EIOA allows to identify the main nexuses between the drivers of biodiversity loss (land-use changes, pollution, natural resource use and exploitation, etc.), sectoral GDP flows, and components of consumption budgets. Socially-EIOA would mean splitting the column of domestic final consumption into income deciles, and gender-EIOA would mean including household non-market labor (caring and reproduction) through time-use surveys. This would allow relating value-added incomes with the main drivers of biodiversity impacts to know who does what, receives what in return, and causes what impacts to biodiversity. This deeper and wider analysis within nation-states and regions would complement current efforts tracking the origin and responsibilities of global environmental impacts through trade flows between nation-states (Infante-Amate et al. 2022). EIOA can be integrated as a module into macroeconomic models when simulating degrowth pathways for biodiversity, as it is done by the MEDEAS model (https://www.medeas.eu/model/medeas-model). This new type of macroeconomic modelling could help stress the deep structural changes needed by the regional, national, and global economic structure to address drivers of biodiversity loss. For example, MEDEAS has been used to show that the Paris Agreement's goal of not exceeding 1.5 ℃ can only be met under two conditions: *i*) a degrowth pathway; and b) a systemic structural change that allows to extend decarbonization beyond the energy system to the rest of the economy (Nieto et al. 2020).

A call for collaboration

Filling the critical gap of what degrowth scenarios for biodiversity, NCP, and GQL could look like should be a mid-term, interdisciplinary collaborative effort. The methodological steps that we have laid out are a preliminary framework of what could be done to bridge quantitative and qualitative approaches from varied research communities. The actual involvement of experts from these communities in a collaborative effort is vital for the soundness of and buy-in to such scenarios. A joint discussion is for example needed on what existing indicators could be used to characterize and model the visions and the transformations towards them, as well as what new indicators need to be developed, especially for unpacking relational values (Kim et al. 2023b). There are also big gaps in terms of what alternative economic metrics are available, as well as their connection to the state and trends of biodiversity and NCP. Supplementary Table 2 provides a list of potential indicators, which can be further elaborated and customized. In turn, models can be linked to national ecosystem accounting systems. This can build on efforts to link the essential biodiversity and ecosystem services variables with the UN SEEA Ecosystem Accounting framework (Kim et al. 2023a). A standardized workflow from primary data to models to national ecosystem accounting systems could help decision-makers align policies with degrowth pathways.

Although we have included some participatory approaches, for the sake of clarity we have mostly focused on researchers-led scenario development. Yet the involvement

of non-academic experts (policymakers, practitioners from different sectors, local knowledge holders) is crucial to give legitimacy and transformative power to the new scenarios. We have suggested that both stakeholders akin to degrowth and those akin to green growth have a role to play in the development of the new scenarios. Science–policy interfaces like IPBES are well positioned to serve as a meeting point between academic and non-academic experts of different political orientations. They can and should host more transdisciplinary deliberations of such scenarios towards transformed national and international biodiversity and sectoral policies (Beck et al. 2022; Gustafsson and Hysing 2022; Otero et al. 2020).

However, what we have presented here is mostly intended for high-income countries and it needs to be explained with care in international forums. Poverty alleviation is in the agenda of many countries that still consider economic growth as a necessary condition to reach this goal. Thus, we need transformative scenarios that are synergistic to ours but embedded in the cultural settings and historical trajectories of the Global South. Post-development and environmental justice approaches (Escobar 2015; Martínez-Alier 2012) are well positioned to provide such scenarios. It is also worth noting that the degrowth scenarios for high-income countries presented here would likely be beneficial for the biodiversity, NCP, and GQL of the Global South. We believe that researching and communicating about these benefits have the potential to increase the legitimacy of the degrowth scenarios. Overall, the nascent scenarios should envision a convergence in levels of resource use and GQL between the Global North and the Global South (e.g. Capellán-Pérez et al. 2015) to correct the unacceptable inequality occurring nowadays (Hickel et al. 2022a, b).

Concluding remarks

The increasing evidence of the environmental impacts of an ever-growing economy has prompted some scholars to call for the integration of degrowth in scenario development (D'Alessandro et al. 2020; Otero et al. 2020; Hickel et al. 2021; Keyßer and Lenzen 2021; Bodirsky et al. 2022; Lenzen et al. 2022). The IPCC has likewise stressed the need to include degrowth pathways in the new climate scenarios (IPCC 2023). Pioneering research shows that degrowth scenarios can be not only more sustainable, but also more feasible than green growth or technology-driven ones (Bodirsky et al. 2022; D'Alessandro et al. 2020; Keyßer and Lenzen 2021). However, the latter research still lacks an explicit description of the degrowth visions and how transitioning to them would quantitatively affect biodiversity, NCP, and GQL. Our proposal to use the NFF to generate these visions based on multiple values and to translate them into models can thus strengthen the scope and applicability of the nascent degrowth scenarios.

With regard to the biodiversity scenarios currently in place, the ideas presented in this paper can contribute to increase their policy relevance by accounting for a key indirect driver of biodiversity loss—economic growth—and the necessary transformative changes to address it (Kim et al. 2023b; Rosa et al. 2020).

While the IPBES is encouraging the use of the NFF (Lundquist et al. 2021), the climate community may continue using the SSP-RCP matrix (O'Neill et al. 2020; IPCC 2023). Thus, our proposal to derive a new SSP from the NFF-produced degrowth visions is timely because it facilitates comparison between degrowth and other scenarios across the domains of biodiversity and climate. However, this is a temporary solution, and we call for increased attention on how to ensure the comparability between IPBES and IPCC scenarios (see also Pörtner et al. 2023, 2021).

To concretize the methodological steps suggested here, we have called for a community of practice composed by experts from different academic and non-academic communities all over the world to develop degrowth scenarios for biodiversity, NCP, and GQL. Our work aligns with the NFF's key goal of catalysing the development of pluralistic scenarios of more desirable futures for nature and people. Since a key alternative for the future lies in how our economies function, a concerted effort to develop legitimate degrowth and like-minded scenarios could make a significant contribution to the option space for decision-makers, as they set out to achieve the Convention on Biological Diversity's 2050 vision of living in harmony with nature.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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