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To cite this article: Danilo Borja, Jan Daněš, Julia C. Assis, Antonella Gorosábel, Carolyn Lundquist, Isabel Rosa, Fabio Rubio Scarano, Nino Tavares Amazonas, Silas C. Principe, Rob Alkemade, Adnan Arshad, Sandra Benavides-Gordillo, Rafael Cavalcanti Lembi, Tássia Rayane Ferreira Chagas, Diana Isabel Clavijo Rojas, Lara Cornejo-Denman, Viviane Dib, Simon Ferrier, Edberto Moura Lima, Luis Filipe Lopes, Matheus Camargo Silva Mancini, Juan Andrés Martínez-Lanfranco, Wladimir Moya, Julia Niemeyer, Unai Pascual, Alice Ramos de Moraes, Mercy Funke Salami, Carla Rivera Rebella, Fábio H. C. Sanches, Priyanka Sarkar, Juliana Siqueira-Gay, Raísa Romênia Silva Vieira, Catalina Zuluaga Rodríguez, Carlos Alfredo Joly & Rafael C. Borges (2025) Rethinking scenario building for sustainable futures: mobilizing conscientização, social learning and knowledge co-production, *Ecosystems and People*, 21:1, 2507247, DOI: [10.1080/26395916.2025.2507247](https://doi.org/10.1080/26395916.2025.2507247)

To link to this article: <https://doi.org/10.1080/26395916.2025.2507247>



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RESEARCH



Rethinking scenario building for sustainable futures: mobilizing conscientização, social learning and knowledge co-production

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ABSTRACT

Scenario building is a powerful tool for evaluating drivers of environmental change and assessing alternative socioecological pathways, helping integrate science-based information into decision-making. Nonetheless, this potential has not been fully embraced by scientists and decision-makers, in part owing to limitations of current scenario frameworks at representing the diversity of values for nature and potential transformative changes to bend the biodiversity loss curve. There is still a need to further develop scientists’ capacities to include a transdisciplinary perspective in scenario building to address the drivers of transformative

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 Supplemental data for this article can be accessed online at <https://doi.org/10.1080/26395916.2025.2507247>.

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change. This paper addresses these needs by reflecting on the role of scientists engaged in scenario building in the construction of sustainable futures through the lens of three key concepts: social learning, knowledge co-production and *conscientização* (a Portuguese term meaning to build sociopolitical awareness and take action). Drawing on a survey of participants of a Scenario Building School and a literature review, we suggest that scientists require capacity building to leverage these concepts together for the construction of transformative futures. This includes addressing power imbalances, improving inclusive and transdisciplinary participatory methods, reaching consensus and promoting action. We recommend that scientists engaged in scenario building focus on fostering transformative changes, challenging mainstream storylines, embracing diversity and addressing inequalities to pursue sustainable futures.

KEY POLICY HIGHLIGHTS

- Capacity-building initiatives should integrate social learning, knowledge co-production and *conscientização* to enhance the scenario-building process.
- Integrating these three concepts supports incorporating science-based information into decision-making processes aimed at developing sustainable futures.
- To achieve sustainable futures, efforts must prioritize fostering transformative changes, challenging dominant narratives, embracing diversity and addressing inequalities at all levels.

ARTICLE HISTORY

Received 6 September 2023
Accepted 9 May 2025

EDITED BY

Zuzana V. Harmackova

KEYWORDS

Ecosystem services; nature's contributions to people; biodiversity; capacity building; modeling

1. Introduction

Nature is under unprecedented pressure from human-driven changes, including land degradation, climate change, resource overexploitation, biological invasions and pollution (IPBES 2019). The demand for material goods transforms how nature is managed, negatively impacting ecosystems worldwide (Díaz et al. 2019; IPBES 2019) and causing biodiversity loss and ecosystem degradation, with direct consequences for human well-being (Díaz et al. 2019). Addressing these changes requires envisioning and pursuing alternative pathways toward sustainable futures (Dinerstein et al. 2019; Kim et al. 2023). While a rise in the production of inter- and transdisciplinary approaches is found in the current literature on the construction of future scenarios (Linnenluecke et al. 2017; Pereira et al. 2018; Rana et al. 2020), they focus rather on theoretical frameworks for achieving sustainability (Ketonen-Oksi and Vigren 2024) without addressing the role of scientists in translating theory into practical actions that enable changes and what capacities are required to operationalize these actions.

The development of scenarios has enhanced our ability to assess and project global trends and assess relevant policy strategies to achieve targets and 'bend the curve' of biodiversity loss and its societal consequences (Pereira et al. 2010; Kok et al. 2018; Chaplin-Kramer et al. 2019; Nicholson et al. 2019; Leclère et al. 2020). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) defines scenarios as representations of possible futures for one or more components of a system, evaluating the drivers of change in nature and its benefits, and including alternative policy or management options (IPBES 2016). The full set of

scenario types includes predictive scenarios (answering the question of what will happen, i.e. what if scenarios), exploratory scenarios (what can happen) and normative scenarios (what should happen, visions of desirable futures) (Börjeson et al. 2006). Thus, scenarios have the potential to explore the world's complexity, providing information to construct meaningful targets and policies to improve sustainability and conservation outcomes (Díaz et al. 2019; Nicholson et al. 2019; Sitas et al. 2019; Rosa et al. 2020).

The process of scenario building has created opportunities for researchers to extend science-based information into decision-making processes (Rieb et al. 2017; Linnenluecke et al. 2017; Nicholson et al. 2019; Pereira et al. 2020). Here, we broadly define scenario building as an umbrella term that encompasses a wide array in which scenarios can be developed and use it as a synonym for other terms, such as scenario development, scenario planning and scenario analysis (Reed et al. 2013). Several authors highlight challenges that current scenario building is facing, such as subjectivity in interpretation, oversimplification of information (geographies and time scales), addressing uncertainties and diversity, communicating to a broader public and limited applicability (including implementation in decision-making), and suggest ways to overcome them (Sitas et al. 2019; Elsworth et al. 2020; Rosa et al. 2020). Nevertheless, one has to be aware that although scientific tools for scenario building, foresight and forecasting are increasingly sophisticated (Iwaniec et al. 2020; Harmáčková et al. 2023; Cork et al. 2023), decision-making remains poor on several fronts, such as climate change, biodiversity loss, health and social inequality (Scarano 2024).

Grasping the multidimensional socio-environmental dynamics behind environmental degradation also requires the use of multiple methods and perspectives and developing the capacity to use scenario tools in new and transformative ways (van Vuuren et al. 2016; Lundquist et al. 2016; Lazurko et al. 2023). Transformation and the construction of transformative futures refer to alternative futures that are just and sustainable (O'Brien 2012; Patterson et al. 2017) and are reached by a collective learning process, where each individual is capable of learning, expanding and changing their perspectives and worldviews to achieve the desired outcomes (Ketonen-Oksi and Vigren 2024). To support this process in scenario building, it is important to go beyond the current methods and decolonize future praxis to support the just and inclusive participation of all actors (Cork et al. 2023; Lazurko et al. 2023; Terry et al. 2024).

Interdisciplinary and transdisciplinary approaches (as defined by Lawrence and Després 2004; Lyall et al. 2015) can improve our understanding of social-ecological systems, including the complexity of social and physical contexts that affect management and conservation actions (Carpenter et al. 2009). In particular, transdisciplinary approaches can facilitate the integration of the knowledge of scientists, local communities and decision-makers to cooperate in transformative actions aimed at sustainability, including halting the loss of biodiversity and reducing social inequalities (Nicholson et al. 2019). In addition, participatory approaches have been largely conceived as game-changing tools to understand and integrate the value of nature for people across cultures and worldviews (Becker and Ghimire 2003; Yanow 2003; Elwood 2006; Harmáčková et al. 2022). We hold that scenario building can become a powerful tool for integrating these approaches in the pursuit of sustainable futures (Pereira et al. 2020; Wyborn et al. 2020) while incorporating new concepts and the diverse values of nature that emerge from scientific publications, policy documents and Indigenous and local knowledge sources (IPBES 2022). The diverse values of nature refer to the diverse worldviews and knowledge systems established by people across the globe. They range from broad values (e.g. prosperity, belonging, harmony with nature) to specific values, which are classified as instrumental (e.g. fish to eat, aesthetic enjoyment), intrinsic (e.g. the right of species to exist) or relational (i.e. meaningful human – nature relationships, such as the cultural meaning of nature) (Pascual et al. 2023).

Although many inter- and transdisciplinary approaches have been proposed (c.f. Pereira et al. 2018; Rana et al. 2020; Lazurko et al. 2023; Scarano 2024), and some, such as coproductive agility (reflexive engagement of diverse actors to grow shared ideas) (Chambers et al. 2022) and the interdisciplinary journey (balancing methodological groundedness

to produce rigorous science) (Haider et al. 2018), address the use of critical reflection in sustainability research, there remains a mismatch at the interface of science and practice (Metzger et al. 2024). The role of scientists in this process is unclear and presents key challenges in practice (such as the capacity to perform transdisciplinary research and increase its potential for implementation).

The aim of this study was to investigate the role of scientists in the process of building scenarios that contribute to future transformative changes. We explored what capacities (attitudes and skills) are needed to enable scientists to address the identified challenges regarding scenario building. First, we evaluated the perspective of early career researchers on scenario building by applying a survey in a specific context. Second, we examined previously identified challenges and general applications of scenario building through literature reviews. We argue that mobilizing the concepts of social learning (acquiring new capacities from interactions) (Oteros-Rozas et al. 2015), knowledge co-production (collaboration to integrate scientific and social needs) (Moallemi et al. 2023) and *conscientização* (bridging awareness and empowerment to take action) (Freire 1970) can contribute to advancing the usefulness of scenarios while enhancing the role of early career scientists in scenario building.

In this paper, we begin by describing our conceptual framing and methodological approach. We then present the results of the review and the survey and discuss the current trends in scenario building through the lens of the three concepts. Finally, we synthesize the limitations and challenges in scenario building and propose recommendations for designing sustainable futures.

2. Conceptual framing

We use three complementary core-guiding concepts, i.e. social learning, knowledge co-production, and Paulo Freire's *conscientização* (a Portuguese word that refers to the process of building awareness and taking action), to analyze the results and propose approaches that can help advance scenario building. We propose the implementation of these concepts as a nonlinear process (Figure 1) in which social learning, knowledge co-production and *conscientização* can co-occur and interact (e.g. Armitage et al. 2011).

Social learning (SL) encompasses the continuous dialog involved in acquiring new behaviors by observing and/or interacting with others (Reed et al. 2010). SL can promote the collective development of an awareness of social-ecological linkages (Folke et al. 2011; Colding and Barthel 2019), a better understanding of others' interests and viewpoints (Sims

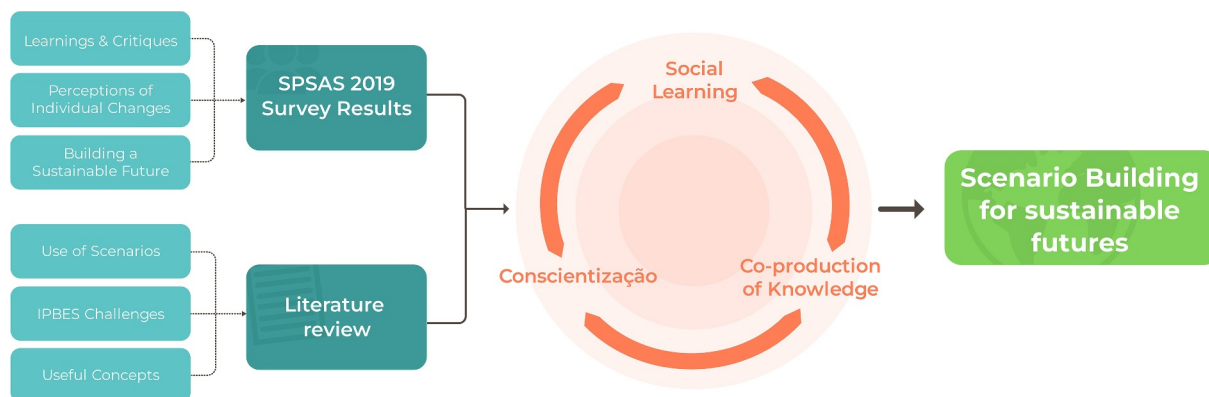


Figure 1. Diagram of the development of this study. The interrelation between social learning, knowledge co-production and *conscientização* is presented as a continuous process, since awareness, learning and production of knowledge are iterative processes without clear boundaries.

and Sinclair 2008; Menzel and Buchecker 2013) and the acquisition of a more critical understanding of one's roles (Sinclair et al. 2013). In the process of scenario building, SL can be useful in facilitating adaptation to change by fostering the exploration of diverse opportunities and knowledge systems.

Knowledge co-production is a collaborative process that effectively addresses socio-environmental problems through the integration of scientific research and societal needs (Pohl et al. 2010; Armitage et al. 2011; Mauser et al. 2013; Beier et al. 2017). Knowledge co-production is summarized as an *'iterative and collaborative process involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways toward a sustainable future'* (Norström et al. 2020). It usually starts with a joint definition of the scope and context of the problem being addressed to build a comprehensive understanding of it (Armitage et al. 2011; Beier et al. 2017). Collaboration among actors for knowledge co-production depends on the creation of mechanisms and conditions that foster iteration and eliminate possible constraints, such as power imbalances (Pohl et al. 2010; Norström et al. 2020) or cultural differences (Djenontin and Meadow 2018).

Conscientização refers to *'the process in which human beings, not as recipients, but as knowing subjects, achieve a deepening awareness both of the socio-cultural reality that shapes their lives and of their capacity to transform that reality'* (Freire 1970, p. 452). This concept goes beyond the meaning of empowerment, as it includes the active process through which a critical understanding of social-political-economic circumstances enables actors to actively shift uneven power relationships. According to Freire (1987), the development of a critical consciousness goes beyond a simplistic comprehension of reality. It is the generation of a consciousness that perceives reality as an object to be transformed. In

the context of scenario building, *raising awareness* tends to focus on the collective exercise of acknowledging an existing reality (e.g. conceptualized as NCP) and the diversity of values that people give to nature (Gómez-Baggethun and Barton 2013; Pascual et al. 2017, 2023), while *conscientização* focuses on the active role of actors in shaping reality.

Conscientização also contrasts with the idea of social learning because it is centered within an individual's experience of reality and therefore has consequences for how they interact with their sociocultural and political environment, whereas social learning reflects learning experiences as a result of social interactions. Complementary to social learning, knowledge co-production ensures that the outcomes of social interaction materialize in shared ideas and guide the production of new knowledge. We argue that these concepts can aid scientists in navigating the construction of scenarios with a transdisciplinary approach, engaging other actors in the process in multiple ways, from an individual and/or collective perspective toward collaborative outcomes.

3. Material and methods

We draw upon the context of the SPSAS course that took place in the Municipality of São Pedro, in the state of São Paulo, Brazil, in 2019, which aimed at capacity building in scenario modeling of biodiversity and ES (for further details, see Rosa et al. 2020). The participants attended theoretical lectures and group work focused on case studies published in an issue of the *Biota Neotropica* journal (Joly et al. 2020). The SPSAS course was attended by 85 participants, representing 21 nationalities and five continents, with the majority being PhD students/candidates or early career researchers (Rosa et al. 2020). Although the main goal of the course was capacity building, the event provided a unique opportunity to further

explore the self-perceived role of participants in scenario building to pursue alternative and sustainable futures. Given the limited time during the course, the group of five participants (lead authors of this article) designed a questionnaire survey as the most effective instrument for obtaining qualitative data regarding the perceptions of participants. On the last day of this intensive two-week course, we sent an online survey ([Supplementary Material A](#)) to all participants to identify and evaluate the knowledge gained during the course and the perceived contributions of scenarios and modeling to sustainability. The initial analysis of the survey triggered the need for complementary information regarding scenario building and its social-ecological implications. Although the survey data collected reflect a wide range of opinions from early career researchers, more information on existing gaps and challenges in scenario building is needed. Thus, we complemented these results with a literature review of the use, challenges and limitations of scenario building and assessed the two IPBES reports (IPBES 2016, 2019; see [Section 3.2.1](#)).

3.1. Questionnaire survey on the SPSAS course

The questionnaire consisted of nine open-ended questions and five additional closed-ended questions. The open-ended questions were structured into two main themes: (1) co-production of knowledge in scenarios and modeling and (2) the contributions of scenarios and modeling to sustainability. The additional questions inquired about involvement in further research and about the general background and expertise of the participants. All potential respondents were informed that the data collected would be used for a joint article and were also invited to take part in it, with 27 participants eventually coauthoring it. They were also assured that all the responses would be anonymized. In the end, 75 of the 85 course participants completed the questionnaire.

To analyze the survey data, we applied a qualitative content (thematic) analysis via an inductive approach, which does not rely on any prior research or existing theory (Bryman 2016). Data from Question 1 about keywords were analyzed quantitatively for the purpose of the word cloud visual summary of the frequency of occurrences ([Figure 1](#) in [Supplementary Material A](#)). The word cloud was created via the qualitative data analysis software MAXQDA (maxqda.com). Data from other open-ended questions (numbers 2–9) were coded independently by four researchers. After the first round of initial coding, categories and themes were created based on groups of codes and their meaningful clusters (Hsieh and Shannon 2005). All codes were then cross-checked by at least one other researcher to ensure sufficient intercoder reliability

across the dataset (O'Connor and Joffe 2020). The results of the survey have been used to develop [Sections 4, 5](#) and [6](#), and the full results are presented in [Supplementary Material A](#).

3.2. Literature reviews

To supply the need for complementary information regarding scenario building and its social-ecological implications that emerged from the survey, we conducted a literature review in two steps to assess A) IPBES challenges and B) the general applications of scenario building for BES.

3.2.1. Assessing IPBES challenges

To identify the key challenges that need to be addressed to reverse the decline of life on Earth and support the transformative changes provided by the IPBES (i.e. IPBES challenges), we conducted a content analysis (Bryman 2016) of two global reports and their accompanying summary for policy-makers. Both reports were related to models and scenarios from a broader scale: the Methodological Assessment Report on Scenarios and Models of Biodiversity and Ecosystem Services (IPBES 2016) and the IPBES Global Assessment Report on Biodiversity and Ecosystem Services (Díaz et al. 2019; IPBES 2019). Although some regional reports are available, they were not included given the broader scale intended for this study. In the first step, we analyzed the reports individually and extracted information related to key findings, guidance points, recommendations and challenges related to models and scenario building for reaching sustainability. After that, all the data were merged and organized under challenges ([Table B1](#) in [Supplementary Material B](#)). This assessment was performed to understand the full set of challenges already raised in scenario building by the IPBES. The results of the IPBES challenges were used to develop [Section 5](#), and the full results are presented in [Supplementary Material B \(Table B1\)](#).

3.2.2. Scenario building for BES

We conducted a systematic literature review to provide insight into general applications of modeling and scenario building on BES, following the PRISMA checklist (PRISMA Group guidelines in Moher et al. 2015). We established an input – process – output protocol that clearly defined each step of the systematic review following Vačkář et al. (2018) and Slovák et al. (2023). This process consisted of four stages to ensure the selection of only relevant studies ([Figure B2](#), [Supplementary Material B](#)). We used the Web of Science platform (18 March 2020) and the following string of keywords: (ecosystem service*) AND (biodiversity) AND (scenario*) AND (model*), from which we obtained 806 papers. The asterisk (*) provided flexibility to incorporate alternative endings

(e.g. ‘modeling’ or ‘modelling’) and/or plurals (e.g. ‘scenario’ or ‘scenarios’). We chose ES instead of NCP because the former has been more consolidated in the scientific literature since its establishment as a framework in the late 1990s (Costanza et al. 1997; Daily et al. 1997; de Groot et al. 2002). The NCP was first proposed in 2018; therefore, only more recent studies have adopted this terminology. We assume that this gap has been filled by the assessment of IPBES reports (see Section 3.3.1. and [Supplementary Material B](#)). While the ES/NCP concepts were successfully used to highlight the concrete values that ecosystems provide to human well-being and promote their conservation (Díaz et al. 2019; IPBES 2019), they focused on the instrumental value of nature. Although many studies highlight the importance of considering nature’s reciprocal and intrinsic values, we acknowledge the risk of framing nature and its ecosystems as providers of goods and services for human use (Muradian and Gómez-Baggethun 2021). However, addressing the issues of modeling and scenarios in biodiversity and ecosystem services was the main theme of the course and has been the focus of major international agencies, aligned with efforts such as the IPBES (IPBES 2016, 2019; see section 2.3.1).

Literature from 2015 to 2020, representing 65.7% of all articles (530 studies), was analyzed to better understand the most recent use of models and scenarios and their social-ecological implications for proposing alternative sustainable futures. From these, we screened the title and abstract of all articles and retained for review studies published in English that directly connected scenarios and models with any aspect of BES (for all eligibility criteria, see [Figure B2 in Supplementary Material B](#)), encompassing a final list of 206 studies. From each article, we extracted the following information: country/region, spatial and temporal scale of application, type of ecosystem, main drivers of change, type of scenario (following IPBES’s classification: <https://ipbes.net/scenarios>), main analytical tools used and the ES/NCP categories considered (following Díaz et al. 2019). To unify the criteria, for each study, we recognized the NCP-equivalent category to which each ES pertained. We also identified the reported limitations and evaluated whether the NCP concept was explicitly used, whether the models or scenarios addressed any policy application, and whether studies considered social or economic aspects in model or scenario building. If studies included applications from more than one region or location, we recorded them as separate cases. We created a shared template spreadsheet to collect and organize data extracted from all relevant studies. The full reference list and the description for each category of information extracted from the papers can be found in the supplementary material

([Supplementary Material B and C](#)). The general trends that emerged from the literature review on scenario building for BES are presented in the results section.

3.3. Synthesizing limitations and challenges in scenario building and proposing recommendations for sustainable futures

In rethinking scenario building, we summarized key limitations and challenges emerging from the SPSAS course survey and the literature reviews. We clustered them into categories by expanding the dimensions of knowledge co-production following Armitage et al. (2011). The categories include knowledge gathering, knowledge sharing, knowledge integration, knowledge interpretation and knowledge application. This expansion was accomplished by acknowledging such dimensions and emphasizing the relevance of context in scenario building.

These results were synthesized to propose recommendations to rethink scenario building by proposing five key attitudes and approaches of scientists engaged in scenario building that can address the combination of limitations and challenges identified in each knowledge dimension.

4. Results

4.1. Literature review of scenarios and models for BES

A total of 206 articles were reviewed to explore how scenario building with ES/NCP and biodiversity has been applied in the scientific literature (for details on the review, see methods and [Supplementary Material B](#) for complete results). Most of the reviewed articles had a local study area, modeling one particular type of ecosystem, highlighting a strong bias toward forests, and Europe and most of the Americas were the most represented regions ([Figure 2](#)). We also found a strong bias toward regulating and material contributions (e.g. carbon storage and sequestration services to the regulation of climate contribution) (Díaz et al. 2019), whereas few studies considered non-material or relational ES/NCP ([Figure 3, Supplementary Material B](#)). The most frequent NCPs across studies were ‘Regulation of climate’, ‘Habitat creation and maintenance’, ‘Maintenance of options’ (mostly related to biodiversity conservation studies) and ‘Food and Feed’ (which is intimately associated with the main direct drivers identified across studies, i.e. land use and land cover change – LULC). Non-material contributions were scarce throughout the review, but we found studies that addressed diverse ways in which people use and value ecosystems in scenario building, such as valuing

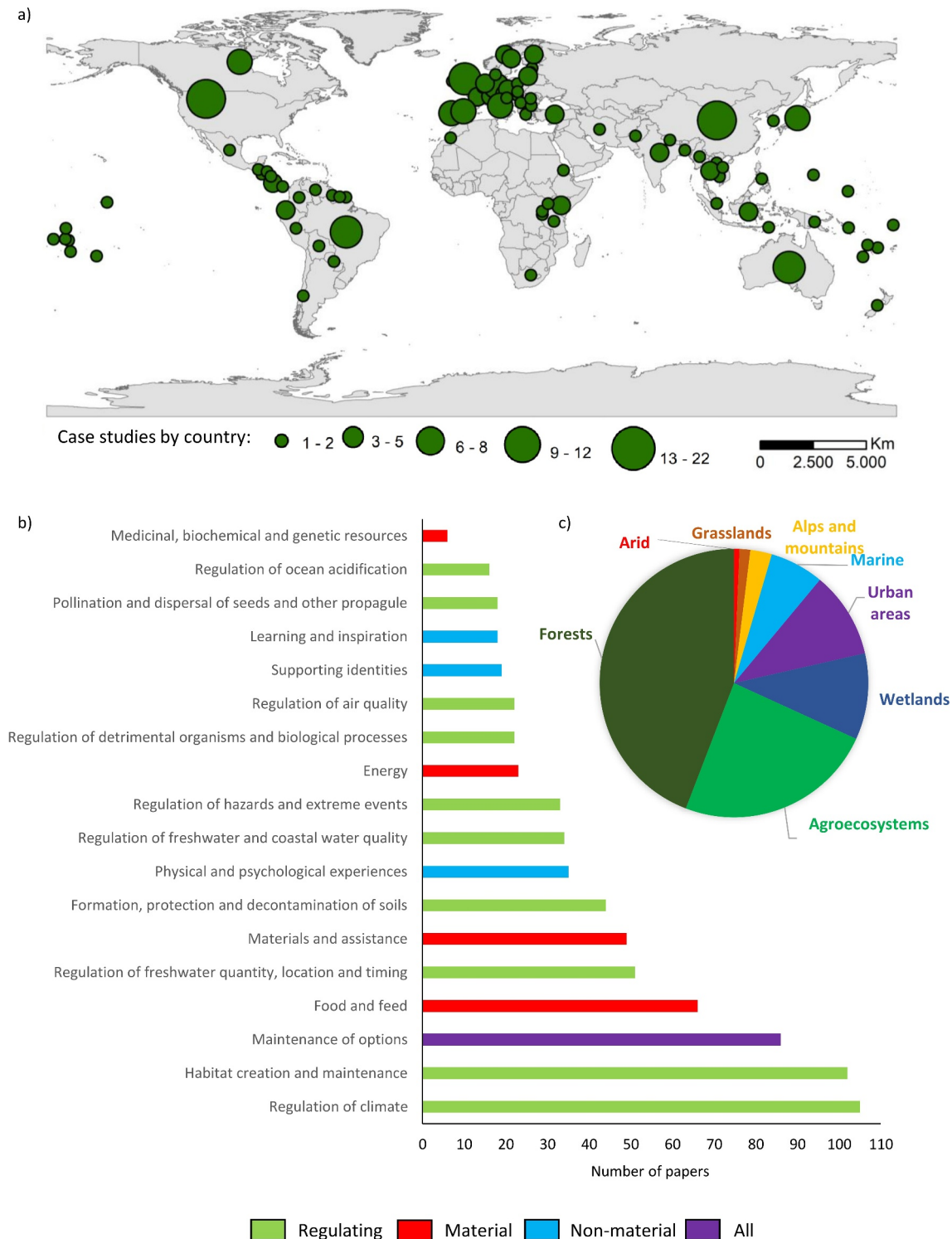


Figure 2. a) case studies by country involving scenarios and modeling of ES and biodiversity found in our review of the local and regional (more than one country) approach; b) number of studies referring to NCP categories (more details in [Supplementary Material B](#)); c) percentages (%) of the different ecosystems where the models and scenarios were performed: agroecosystems (including croplands, implanted pastures for livestock), alpine and mountain ecosystems, arid ecosystems, forests, grasslands, marine ecosystems (taking into account open waters and coastal areas), urban areas and wetlands (including freshwater systems such as lakes, rivers basins, etc.).

local knowledge and a cultural connection to the place, experiences related to wildlife watching, recreational activities and physical and mental well-being associated with different types of ecosystems (see [Supplementary Material B](#) for additional information).

Regarding how models were developed, we found a great variety of tools. Mathematical or statistical and spatially explicit approaches (or a combination of both) were the most commonly used approaches (68%). In contrast, qualitative methods, such as interviews and questionnaires or integrating the participation of

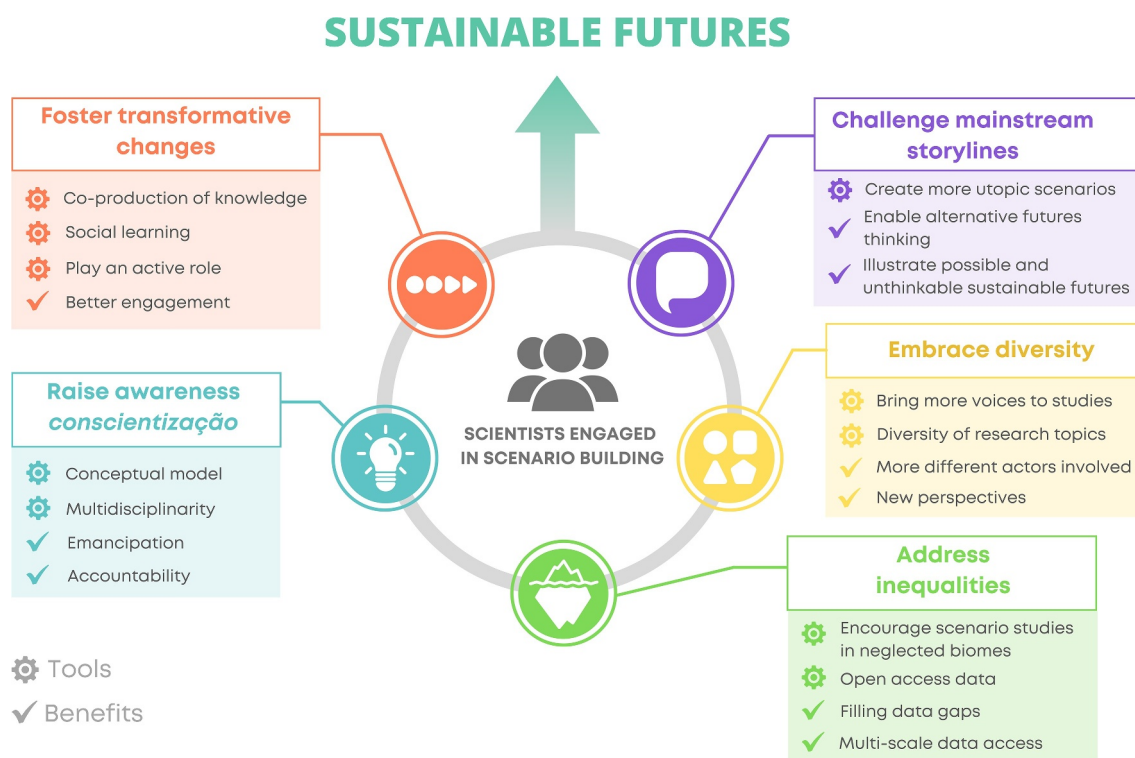


Figure 3. Conceptual scheme summarizing the suggested roles of scientists engaged with scenario building for sustainable futures. Specific tools can help pursue each role and provide certain benefits to reach sustainable futures. The roles are complementary and should be understood as independent elements.

stakeholders into modeling, are rarely used. Most studies represented exploratory scenarios (77%), whereas participatory approaches (2.4%) and intervention scenarios (target-seeking 6% and policy screening 9%) were scarce, and retrospective policy evaluation scenarios were found in only two studies. The main drivers of change considered in these scenarios were LULC (38%), climate change (22%) or both (8%).

Regarding social-ecological systems, 65% of the studies included social or economic aspects in their scenario building. Although most of the studies focused on Western science, some of them integrated diverse knowledge types. For example, Yazzie et al. (2019) presented different scenarios for future forest conditions under climate change and interpreted their findings from the perspective of Indigenous knowledge. In this case, the authors highlighted the potential effects on their livelihoods and well-being. Finally, concerning policy application, 72% of the studies geared their scenarios or models toward end-goal policy development or implementation. However, the literature review was unable to assess whether scenario outputs were included in this end goal of decision-making and policy implementation. Although policy application was a major end goal, 8% of the studies mentioned the lack of feedback from policy implementation as a limitation.

It is also important to acknowledge the limitations of our review. First, this review was performed using one database (Web of Science), and different outputs could

have been found with other sources. Second, we selected keywords and applied them in a way that would target a wide range of publications, as our aim was to assess the general trend in which scenarios and models were applied regarding BES. The use of more specific terms would result in different results. Other systematic reviews, such as Thorn et al. (2020) and Quintero-Urbe et al. (2022), have different findings that focus only on participatory scenarios and particular ecosystems or areas. The word ‘model’ could also be related to a more quantitative and mathematical approach rather than narrative and qualitative scenarios. Additionally, the ES/NCP concepts are usually associated with the instrumental value of nature; thus, the intrinsic value of nature is less represented. Third, our eligibility criteria included publications from five years (2015–2020, Figure B1, Supplementary Material B). Finally, we included only studies published in English. Although we excluded only 13 publications in other languages (from 530), we would like to highlight the importance of local studies in other languages. A general limitation when applying the ES framework among searched keywords is that we possibly missed studies that address ES or NCP but do not necessarily refer to them as such.

4.2. Course survey on advancing scenario building

Scenarios and models have become popular tools for demonstrating the possible outcomes of decisions,

including social and political changes, in the future. Our review highlighted some trends and limitations in their use. In this section, we analyze the SPSAS course survey findings and use the concepts of social learning, knowledge co-production and *conscientização* to build links with the identified limitations and challenges in scenario building for sustainable futures. The content of the SPSAS course included many interdisciplinary groups and thus provided space for discussions and mutual learning in a unique environment (for more information, see Rosa et al. 2020).

4.2.1. The course as a social learning experience

The survey findings demonstrated the potential of social learning in scenario building. For example, with different levels of engagement and interaction, interdisciplinary and participatory approaches rely on collective behavior to balance power and define negotiation strategies. In the context of the SPSAS course, 68% of the participants perceived changes in their individual beliefs or assumptions concerning modeling and social-ecological systems. These responses may indicate that the group discussions and case studies developed during the course challenged participants to engage with different perspectives and rethink their own views, for example, *‘I learned that the basis for making good future projections is the respect for diversity and the different forms of values.’* The course allowed them to engage in negotiations and realize their biases, for example, *‘I learned to see in a human perspective because my work is always focusing on conservation by itself, intrinsic values, without thinking [from] the point of view of human uses of nature.’*

The majority of respondents highlighted the importance of incorporating a social-ecological approach in the development of scenarios and models. Interestingly, most of them have a natural science background (96% of respondents reported an environmental, biological or geographical science background). By examining the social-ecological system prior to the proposition of scenarios, different perceptions, values and knowledge emerged within working groups, challenging participants’ previous conceptions and beliefs. By sharing their perspectives with the group, people realized a variety of experiences and views, for example, *‘mainly, I learned from the experiences with different people to address and solve problems in ways that are different from my usual way.’*

4.2.2. Co-producing scenarios

The experience of collaboratively developing case studies during the SPSAS course enabled participants to understand the limitations of not involving other actors, which triggered their awareness (consciousness) that co-production could enhance the

practical application of the knowledge being produced. The results revealed that the complexity underpinning social-ecological models was a key factor in participants’ understanding of a model’s usefulness and applicability at the interface of science and policy. The respondents also acknowledged the importance of stakeholder involvement in general, followed by knowledge on how to develop scenarios with stakeholders. Highlighting inclusivity, the respondents affirmed that they had learned to acknowledge multiple perspectives and emphasized the importance of interdisciplinarity and the need to find a common solution with the participation of interested parties.

Another essential aspect of co-production indicated by the survey concerns the roles each societal actor can perform and the types of knowledge included in scenario building. Unbalanced power relations were perceived by 45% of the respondents, who expressed that certain types of knowledge and opinions were privileged against others. In their responses, they indicated that the environmental or ecological perspective prevailed over the social or economic perspective within the course context (probably due to the majority’s background in the natural sciences, including lecturers). The discussions carried out during the course usually focused on environmental sustainability, setting aside discussions regarding economic and social sustainability. This imbalance may be reproduced in several other contexts where scenarios are developed. Additionally, Western approaches, along with scientific or academic knowledge, were mentioned as privileged, disregarding traditional knowledge and Indigenous and other cultures.

4.2.3. Promoting *conscientização* through scenario building

Raising awareness and having an impact were the two most prominent overarching themes related to the potential contributions of scenario building to a sustainable future. Acknowledging the need to raise awareness of the political and social forces that affect social-ecological systems, we propose the concept of *conscientização* as a vehicle to increase awareness in scenario building. In the context of the SPSAS course, respondents addressed the role played by scientists in producing inclusive knowledge to raise awareness; for example, *‘getting directly in contact with communities is the first and main step to contribute to a sustainable future. To spread my research in a palatable way to society, to bring science inside schools and the different worlds are my contributions to reach a sustainable future.’* Furthermore, emphasizing the need for *‘using participatory approaches to mobilize people’* underlines the transformational

importance of scenario-building exercises for capacity building.

In the context of scenario building, mobilizing the concept of *conscientização* can become instrumental in shedding light on underlying assumptions and power relations that influence environmental change. In other words, knowledge co-produced through scenario building should go beyond understanding the drivers of environmental change. For example, participants recognized their ability to communicate and expand the potential of scenarios as a tool to illustrate possible and unthinkable sustainable futures, combining societal aspirations with scientific knowledge, for example: *‘Mainly, I learned from the experiences with different people to address and solve problems in ways that are different from my usual way. This I intend to apply in my life and work, in order to produce higher-level science and to work more connected to other researchers. I also intend to share these different perspectives with those around me as much as possible.’*

4.3. Limitations and challenges in scenario building

The summary of key limitations and challenges included the categories of knowledge gathering, knowledge sharing, knowledge integration, knowledge interpretation and knowledge application (Table 1).

4.3.1. Knowledge gathering

In general, since most biodiversity hotspot areas are associated with large knowledge gaps, the key limitations and challenges here are data access and quality, which are spatially and temporally biased (Rodrigues et al. 2004; Chaplin-Kramer et al. 2019). These knowledge gaps can be used to highlight the diverse data required for scenario building, including not only environmental information but also social, cultural and economic data. From the literature review, we identified a series of limitations that were identified in many studies. Most studies mentioned some type of limitation for model development (75%), of

which model complexity and uncertainty associated with scenario projections were most frequently mentioned (35%). Furthermore, most studies recognized that they did not include all relevant drivers of change.

Scenario building often relies on social, economic and institutional sets of metrics and practices, and this approach allows scenario builders to find the interlinks between the drivers of environmental change and their consequences, which can identify options to achieve a desired outcome. However, by exploring a limited set of options that may be biased toward existing strategies and further avoiding options that may impact the status quo, such an approach may replicate existing power asymmetries and privilege certain ways of knowing over others, e.g. underrepresented local knowledge (Adam 2007; Milkoreit 2017; Ossewaarde 2017). Moreover, this can even prevent asymmetries from being noticed or detected and can further prevent the inclusion of knowledge diversity in scenario building and decision-making (e.g. a scenario for threatened species built only on scientific-academic knowledge ignores traditional/ethnobiological knowledge and interactions with biodiversity) (Andersen et al. 2021).

4.3.2. Knowledge sharing and integration

Scenarios have the potential to facilitate the combination of cutting-edge scientific knowledge with Indigenous and local knowledge in assessments and decision-making (Pereira et al. 2020). However, scenario building has advanced through asymmetries built on power inequalities over the production of knowledge (Knappe et al. 2019). Privileging one’s knowledge over another’s may reproduce social-ecological conflicts and prevent knowledge co-production and mobilization (Norström et al. 2020). Importantly, scenario-building exercises that struggle to include multiple knowledge systems, even though methods are available, might produce pathways in which less represented people have little to no agency or ownership to decide upon their futures (Granjou

Table 1. Suggested links between knowledge dimensions and existing limitations and challenges in the process of scenario building. Categories of the dimensions of knowledge co-production were adapted from (*) Armitage et al. (2011). Limitations and challenges in scenario building were based mainly on the survey results and complemented with findings from the literature review (including IPBES reports).

Knowledge dimension*	Examples of limitations and challenges in scenario building
Knowledge gathering	Applying participatory methods in an inclusive and multidisciplinary fashion Collecting and accessing data due to methodological or financial constraints; understudied sites
Knowledge sharing	Inability to communicate results to various audiences Difficulties integrating the natural and social sciences
Knowledge integration	Finding common ground (building consensus) to deliberate and draw up solutions Privileging quantitative over qualitative methods Fostering interdisciplinarity and multidisciplinary
Knowledge interpretation	Reporting results for stakeholders of different cultural and technical backgrounds Model calibration and validation can lead to the wrong interpretation of outputs
Knowledge application	Limited application of scenarios Lacking the opportunity to raise awareness through scenario-building exercises Weak engagement between researchers and policymakers

et al. 2017; Kelz 2019; Knappe et al. 2019). In our review, studies that used tools involving consultation or interviews (e.g. to include values, knowledge and stakeholders' participation) were scarce. As a result, stakeholders may miss the opportunity to engage in collective and individual reflections on the links between humans and nature and thus are unlikely to identify innovative solutions to current social-ecological challenges, limiting the possibilities of scenarios built.

The path toward more just and ecologically sustainable futures requires new behavior that moves us away from the colonized perspective (i.e. where only the Eurocentric worldview is superior) to produce decolonized perspectives (which permits looking into the future while encompassing a deep understanding of the past) (Terry et al. 2024; Turnhout 2024) and promotes connectedness across all sectors and peoples, which can help to avoid further deterioration in biodiversity (Moldavanova and Goerdel 2018; Kok et al. 2018; Dragicevic 2020; Goymann and Küblbeck 2020). Colonial practices impose their culture, time and space understandings at the expense of local beliefs, which has led to decreased mental health and increased detachment from nature in some peoples, but has also led to the development of a double perspective (i.e. the individual connects with both the dominant perspective and his own traditional one) by more resilient peoples (Svalastog et al. 2022). One way forward is through the understanding and incorporation of local traditional knowledge (e.g. the Entangled Time Tree concept from Terry et al. 2024) while supporting the application of existing policy instruments to enlist individual and collective actions for transformative change (Díaz et al. 2019; Pascual et al. 2023). Among the challenges pointed out by participants in the SPSAS course, the lack of experience in *'working directly with society and culture'* was indicated as a hindrance to their ability to identify *'social drivers, to propose policies'* and to relate *'nature as culture'*.

Another insight by participants in the SPSAS course that can be linked to how scenarios are developed refers to the *'difficulty [...] to get out of [their] ecology perspective and look for new ways of thinking outside the biolog[ical] and conservati[onist] [perspective]'*. Additionally, the challenge of including perceptions was noted as a major methodological limitation for developing scenarios to *'include different types of knowledge, perception[s] and interests in the models'*. Nonetheless, the majority of respondents understood the need to include perceptions from traditional, local, rural and Indigenous communities; from stakeholders; and from multidisciplinary scientific approaches, which can be incorporated through the application of participatory scenarios that are currently underused (Lundquist et al. 2021).

4.3.3. Knowledge interpretation and application

One conspicuous challenge that hinders the use of scenarios and models for policy development and implementation relies on scientists' inability to communicate effectively the uncertainty associated with scenario projections and its consequences for the decision-making process (IPBES 2016; Rieb et al. 2017; Rosa et al. 2020). Furthermore, reporting results for stakeholders with different technical and cultural backgrounds must explicitly acknowledge assumptions and evaluate the consequences of different outcomes.

The need to increase the applicability of scenario knowledge has been recognized in the literature but is also highlighted by participants of the SPSAS course, for example: *'[during the school], I could feel how distant my research and I are from society and how technical my mind and proposals are, which does not reflect reality. I have realized that I really need to produce science to reach society and not only to produce science to gain knowledge.'* If they could draw on the potential of *conscientização*, we suggest that the scientific community might gain an opportunity to raise awareness through scenario-building exercises.

The predominant technical use of scenarios tends to limit their capacity to integrate diverse knowledge types and address power dynamics inherent to human-nature dynamics, including decision-making and management. The science-policy gap may reflect why most commonly used scenarios *'have limitations in their ability to incorporate shared values, norms and policy objectives related to nature conservation and good quality of life'* (Lundquist et al. 2021, 1773). As an alternative, capacity building at the science-policy interface has the potential to improve scientists' ability to better understand decision-makers' needs, embrace other perspectives and translate scenario outcomes and assumptions to non-academics. In the following section, we address some of the limitations and challenges in scenario building by proposing attitudes and approaches that can build capacities for scenario-building research and exercises.

5. Discussion

Several attitudes can be addressed to improve scientists' capacity to engage context-specific knowledge and stakeholders in the process of scenario building. In light of our results, we discuss the application of innovative methods for the construction of transformative scenarios by mobilizing social learning to foster transformative change, relying on the concept of *conscientização* to raise awareness; addressing knowledge inequalities across scales, biomes and geographies; and challenging mainstream storylines. We then highlight the contribution of our approach in concluding remarks. Here, we present a broader scale study to capture trends across

biomes and regions. We reveal common challenges as a starting point for developing scalable solutions that can be adapted to specific contexts.

5.1. Innovative approaches to build scenarios in the pursuit of sustainability

Not only early-career researchers but also experienced researchers engaged in scenario building have the potential to help create sustainable futures. Plato noted that thinking about the future influences what we do in the present (Ruse 2013). In the scientific use of scenarios, those known as transforming normative scenarios (Börjeson et al. 2006), or visions (i.e. target scenarios), already play a substantial role in shaping new possible futures. On the other hand, explorative scenarios rely on possible developments intended to bring external ‘forces’ to local and specific contexts and enable decisions to be made despite their consequences. Walsh (2013) argues that in contemporary science, the ‘cultural authority of scientists’ (p. viii), backed up by scientifically testable projections, gives them the opportunity to act as ‘scientific advisors’ regarding what may happen in the future, assisting society’s adaptation and resilience. Walsh (2013) also uses the IPCC as an example of how scientific projections have shifted the status of climate change from ‘a scientific dilemma to a political one’ (p.164), making room for science-based actions. The Nature Futures Framework (NFF), led by the IPBES task force on scenarios and models, is another example of an innovative approach to create sustainable futures that integrate different values of nature and brings together stakeholders and the scientific community (Lundquist et al. 2017; Pereira et al. 2020). Based on this framework, different applications have been developed, such as participatory building of scenarios to identify desirable futures, pathways toward them and the varying values for nature that different stakeholders have in relation to a national park (Kuiper et al. 2022) and to evaluate how different restoration scenarios in Europe consider different values (Quintero-Urbe et al. 2022).

The use of scenarios in ecological research more commonly relies on predictive scenarios (i.e. what-if scenarios) that are intended to enable planning and adaptation to probable (expected) futures (Börjeson et al. 2006). In general, researchers engaged in scenario building can make projections that can encourage new political discourses, which, in turn, can bring about societal transformations. Most of the reviewed studies mentioned end-goal policy development or implementation (72%); however, whether their recommendations were considered and applied remains to be seen. Therefore, we suggest that scientists require capacity building to leverage concepts such as social learning, knowledge co-production and *conscientização*, as discussed in Section 3.2, to

advance scenario building for sustainable futures. The survey results suggest that involving all interested groups of actors in the development of scenarios brings broader perspectives to foresee and anticipate problems, propose innovative solutions and communicate them to all the actors involved. A collaborative construction facilitates the use of appropriate language and channels to create awareness among actors, apportion responsibility to them, and mobilizes them to take action. Based on the results presented above, we suggest further capacity building for scientists who work with scenario approaches to actively pursue the following attitudes (Figure 3).

5.1.1. Fostering transformative change

Social learning is key to producing new understandings and finding solutions through the constant interaction between stakeholders in learning spaces (Lumosi et al. 2019). New capacities could enable scenario builders to deploy their talent and knowledge in a humble, perseverant and open-minded fashion to produce and facilitate such interactions and spaces. In an attempt to foster social learning, scientists should recognize, respect and defend the diversity of knowledge, backgrounds and cultures involved in any system, including scientists and researchers as part of the whole. There is a need to further develop the ability to enhance the role that scenarios play in the science-policy interface by, for example, including practical and local knowledge in the building stages (e.g. the NFF, Pereira et al. 2020), with relevant context-specific options and not just broad societal drivers that are difficult to link to management options that are solution oriented (Andersen et al. 2021). Creating inclusive settings can enhance agency and balance the role of diverse actors, who ultimately produce change (de Haan and Rotmans 2018). In an example of an innovative and transformative scenario approach (the Seeds of Good Anthropocene project), the authors suggest that providing a safe space for creativity and imagination for a diverse mix of participants and stimulating transformative thinking are key aspects in generating useful lessons for participants that can further catalyze innovative action in the real world (Pereira et al. 2018).

There is room for scientists and researchers to play active roles in the pursuit of sustainable futures (IPBES 2016). They can, as individuals, act as role models, engage in activism (Woolston 2016), promote scientific communication to a broader public (Scheufele and Krause 2019) and call attention to urgent issues (e.g. scientistswarning.org). The SPSAS course participants highlighted their individual contributions toward performing the multiple roles they might play. Responses referred to influencing other people by improving communication skills for

dealing with the public but also taking direct action to promote changes on the ground. Drawing on the survey results, we find that the societal relevance of scenarios increases by adding emphasis on social aspects and connecting the consequences of environmental changes to human well-being. Several approaches have emerged in the literature to assist in engagement and participation in research and practice (Chambers et al. 2022); for example, scientists can use knowledge as a bridge to society and engage with stakeholders, policy-makers and decision-makers to promote change.

One of the most challenging aspects in pursuing sustainable futures is fostering societal behavioral change. Current consumption and production behavior trends and nature management paradigms are aggravating the current environmental crisis (Clark 2007; Geels et al. 2015). As such, if we want to motivate people to change their behavior in favor of more sustainable practices, we must use not only the results of scenarios but also the development process itself as an engagement and communication tool (Lumosi et al. 2019; Sitas et al. 2019). When society's representatives participate as stakeholders in the research process and become agents in the co-production of knowledge, as in scenario building, outcomes are more likely to be appropriated by society and gain impact (increased legitimacy, credibility and saliency, according to Cash et al. 2003; Safford et al. 2017). However, another bridge lies between scientific development and practical actions to improve people's lives (Page et al. 2016; Fazey et al. 2018). Ultimately, it is not just about achieving better knowledge but also how to ensure that the knowledge is helpful for achieving better things (Turnhout 2024). Based on the limitations and challenges presented above, we propose that engaging in interactions with stakeholders confers legitimacy to the process of scenario building and promotes the appropriation of its outputs (Cash et al. 2003; Safford et al. 2017), enabling its materialization in policy-making and changes in societal behavior (Caniglia et al. 2021).

5.1.2. Raising awareness through *conscientização*

Scenario-building exercises have demonstrated great potential for making interrelations between humans and nature visible (Joly et al. 2020). For example, building a conceptual model, which is a key input for scenario building, represents a major opportunity for relevant stakeholders (e.g. local resource users, Indigenous peoples and scientists) to co-produce knowledge and promote social learning. A conceptual model not only depicts what elements influence environmental change but also shows how these elements affect each other and therefore the whole system (Lundquist et al. 2017). However, we

argue that the potential of these exercises has not been fully exploited.

A scenario-building endeavor should also represent a space to reflect on the political forces that influence the system. As we presented earlier and in light of Freire's concept of *conscientização* (see Section 4.3.) and our findings, we propose that new capacities guide the use of research approaches to facilitate the understanding of political forces influencing social-ecological systems. In other words, scenarios can be used as tools of emancipation by democratizing the process of building scenarios, which can then democratize decision-making and increase accountability. Although these conclusions are not completely new (see Pereira et al. 2020; Rose et al. 2020; Quintero-Urbe et al. 2022), there is a constant need to raise awareness of this issue to operationalize its implementation (e.g. the NFF). We recognize the importance but do not consider context-dependent variables that influence participation and local engagement (e.g. culture of participation) and focus on scientists' ability to consider such attitudes in scenario building, beginning with how they delineate the process and embed it in reality. As such, researchers can pair conceptual model building with qualitative methods (e.g. focus groups or interviews) to grasp sociopolitical issues (Weiskopf et al. 2022). Thus, this proposal emphasizes the need for multidisciplinary approaches and researchers trained in various disciplines to enable the inclusion of concepts such as *conscientização* in scenario building.

The literature review results highlighted a strong bias toward exploratory scenarios, which is partially explained by our choice of search terms, as mentioned in Section 4.1. We acknowledge that including other search terms, such as 'visions' and 'pathways', could have revealed different insights into the use of other types of scenarios. Although exploratory scenarios are very valuable in analyzing possible sustainable futures, other types are crucial to policy design and implementation through evaluating the outcomes achieved by implementing them. Therefore, scenario building could be improved if more is known about policy implementation outcomes (feedback) and with increased stakeholder involvement (Weiskopf et al. 2022).

5.1.3. Addressing knowledge inequalities across scales, biomes and geographies

The current global biodiversity crisis has triggered the development of global targets aimed at reducing biodiversity loss, maintaining ES/NCP and developing sustainable futures (e.g. CBD, SDGs and Aichi targets). Recognizing the main limitations found in our review (across scales, biomes, methods), the applicability of models and scenarios to promote human well-being depends, to a certain extent, on addressing

some of these knowledge gaps and providing the data needed to strengthen the science-policy interface. Therefore, there is a need to encourage new scenario studies, especially in neglected biomes, such as grasslands and arid ecosystems (Isbell et al. 2022).

Regarding the science-policy interface, focusing on biomes that present LULC change and climate change as major threats, such as those mentioned above (O'Mara 2012; Huang et al. 2016), could lead to new ways of addressing sustainable practices and conflicting mitigation measures. These approaches could help scientists engaged in scenario building to achieve a more complete and comprehensive overview of ecosystems worldwide. For example, in one of the case studies on the SPSAS course, participants suggested a conservation policy proposal for supporting sustainable development in the region by integrating scientific publications, current policy-based conservation laws and conservation efforts in the Río de La Plata grasslands (Gorosábel et al. 2020). In another, participants identified the drivers of forest loss in Pará state (eastern Amazon) and proposed policies to address the drivers and support positive future scenarios for the Amazon forest (Siqueira-Gay et al. 2020). Additionally, by developing a conceptual framework, building scenarios and modeling BESs, participants were able to illustrate complex social-ecological systems in protected areas in Brazil (Dib et al. 2020) and the Mexican Caribbean (Sánchez-Quinto et al. 2020). Filling data availability gaps across scales, biomes and geographies can help to i) reduce inequalities in data access among people (and research communities) worldwide, ii) support scientific development at local scales, and iii) foster diversity in types of knowledge and worldviews (Nagaraj et al. 2020). Thus, multiscale data access is required to encourage new ways of protecting both nature and culture and to increase the capacity to build scenarios that are commensurate with major threats and activities across scales.

5.1.4. *Embracing diversity*

The prevalence of science-policy knowledge gaps, including difficulties in producing transdisciplinary research to support the integration of the natural and social sciences with stakeholders, local communities and Indigenous peoples, is a major reason for the failure to achieve global sustainable targets (Xu et al. 2021; Weiskopf et al. 2022). In addition, other reasons include inadequate policies, a lack of financial resources and the imperfection of monitoring systems (Xu et al. 2021). The inclusion of differing perspectives (including stakeholder involvement) and real-life complexity was indicated as a methodological gap to be filled (Weiskopf et al. 2022). Additionally, including stakeholders in the scenario design in local areas could also fill sectoral and thematic gaps

while meeting the needs of a broader range of users across communities (Harmáčková et al. 2022). Thus, closing these gaps is strongly necessary to support and embrace diversity and inclusion into different contexts (Pereira et al. 2020). Moreover, new capacities could be developed to focus on representing different voices and knowledge when new scenarios are being built. In particular, during the SPSAS course, the participants' diverse backgrounds were relatively homogeneous, with a prevalence of academics involved in natural and environmental research (only 10% of the respondents reported a social science background). As a consequence of having very few other actors participating – 5 out of 85 participants were practitioners, policy-makers, decision-makers or representatives of societal organizations – the general ability of groups to add diverse knowledge or perspectives in their case construction was limited (Joly et al. 2020; Rosa et al. 2020). However, most of the participants realized the importance of including different perspectives to learn from and with each other. We understand that scenarios will be more inclusive of different perspectives (worldviews) if different actors are involved in the building process.

A diversity of perspectives, as well as a diversity of research topics, need to be embraced. Drawing from the literature review, most scenario studies have focused on the material and regulation NCP. Non-material contributions are overlooked, even though they are very important in highlighting the connection between nature and people and can help identify what people value the most (Müller et al. 2019). Promoting an integrative perspective (from holistic and transdisciplinary training) – bridging the gaps between the social and environmental sciences and between science and society – is imperative for building scenarios that aim to catalyze the required transformative change, to safeguard society, nature, NCP, and to support sustainable futures (e.g. the NFF approach) (Díaz et al. 2019; Leclère et al. 2020; Pereira et al. 2020). However, addressing the global environmental crisis might need re-framing human-nature relationships beyond NCP and their utilitarian conception to strongly include a morality of care and justice to non-human entities (Muradian and Gómez-Baggethun 2021), e.g. by operationalizing more-than-human participatory approaches (O'Connor and Kenter 2019).

5.1.5. *Questioning and challenging mainstream storylines*

Human communities, from global to local, have shown signs of resilience and innovation in the face of stochastic and unpredicted events (e.g. tsunamis, droughts, social movements and pandemics) (Rivera-Collazo 2022). For example, the COVID-19

pandemic has shown remarkable adaptability to some major life changes, such as increases in working-from-home (i.e. reduction in commuting, use of petrol), increases in virtual meetings (reduction in domestic and international travel) and increases in home and community gardening, which at a national or global scale could all be significant transformative changes that could be included in models to show their contributions to sustainable futures. At the same time, scenarios with incremental or small changes could be used to identify the magnitude of changes required and, over what time scale, to achieve climate and environmental goals. Therefore, scenarios may enable the incorporation of novel elements and interventions, including individual and institutional responses to disruptive shifts toward sustainable futures. Indeed, Bai et al. (2016) argue that sustainability debates should focus less on the continuity of present pathways and be more inclusive of new possibilities. If this is so, then scenario building could be more inclusive of these new visions and opportunities, positive futures or utopias (c.f. Pereira et al. 2018), to prevent the present from colonizing the future (Scarano 2024).

Many storylines support plausible scenarios based on current global and regional trends (such as the IPCC and Shared Socioeconomic Pathways – SSP). Such storylines, which describe trends and alternative changes in societal aspects (i.e. demography, economy, technology, social, governance and environment), are used by the research and assessment communities and are usually aimed at being policy relevant (O'Neill et al. 2017). All pathways illustrate possible outcomes that depend on actions adopted in the present and/or setting targets to be met in the future. The SSP framework in particular was not developed to identify pathways for nature futures but rather for investigating climate change and land use impacts. While undesirable projections are understandably abundant, desirable ones are rarer and often limited in their discourses, producing restricted lines of thinking that are not open to the development of a transformational future. For example, four (out of five) SSP scenarios range from medium mitigation and adaptation challenges (SSP2) to fossil-fuel development (SSP5), and none of these four scenarios are likely to result in global society achieving sustainability by 2030. Only one SSP scenario (SSP1) promotes sustainable options and follows the global storyline proposed by the Sustainable Development Goals (SDGs; O'Neill et al. 2017). However, the careful use of words such as 'gradually', 'slowly' and 'increasing' in the SSP1 scenario narrative suggests that change will be incremental and may also struggle to achieve sustainability and climate goals by 2030. Essentially, SSP1 still falls within the range of 'plausible' rather than 'transformative'

scenarios, so that none of the SSPs truly go beyond 'plausible' changes. With these noted limitations of the SSP scenario framework, the NFF fills a significant gap as a tool to catalyze nature-centric scenarios that identify and model transformative changes to explore which options result in desirable nature futures. However, these SSPs can be used as a starting point to envision more nature-centric and nature-positive interventions, in parallel with other scenario approaches that explore different ways of managing nature, such as the Seeds of Good Anthropocene and the Manoa mashup, Half-Earth and Whole Earth, 'bending the biodiversity curve' and the 'Entangled Time Tree' (Büscher et al. 2017; Pereira et al. 2018; Leclère et al. 2020; Terry et al. 2024). A key difference from nature-centric NFF is in moving beyond business-as-usual to incorporate transformative changes; this may require modeling different drivers or interventions than are typically included in SSP scenarios or developing new indicators that are able to assess the success of interventions at reversing declines in nature across a range of human-nature values (IPBES 2016; Palacios-Abrantes et al. 2022; Haga et al. 2023).

6. Conclusion

We recognize the urgency of generating new proposals to address current environmental, social and economic challenges such as those generated by the COVID-19 pandemic and other extreme environmental events (e.g. devastating wildfires and floods). Innovative approaches and power balance are important for addressing environmental problems and filling gaps in scenario development to assess potential transformative changes that may be required to achieve sustainable futures for nature and people. Courses such as the SPSAS provide support for capacity building for scientists engaged in scenario building. We argue that capacity building could enable those scientists to be more inclusive of different knowledge systems and embrace participatory approaches to scenario development to identify regional and global behavior that could lead to sustainable futures. Here, we deployed the concepts of social learning, knowledge co-production and *conscientização* to reflect on how scientists can generate innovative scenarios to address unforeseen challenges. Our results indicate that increasing engagement with stakeholders (i.e. opportunities for social learning) and the inclusion of context specific knowledge can widen the possibilities not only for the development of legitimate normative scenarios but also for promoting *conscientização* while building those more grounded in observed trends (i.e. predictive scenarios). Now more than ever, society needs researchers committed to building sustainable futures through collaboration, *conscientização* and communication.

The abilities and attitudes described here cannot be under-emphasized, as they will address these more complex scenarios that bring together societal and natural systems and integrate social-ecological complexities, feedback and cross-scale interactions, among others. Our study illustrates the benefits of training researchers who specialize in complex scenarios and models through holistic approaches while promoting interdisciplinary collaboration and, ultimately, knowledge co-production. Capacity building opportunities such as this help develop a critical awareness of power structures, taking into account the actors involved in the final decision, the assumptions that drive decisions and solutions, the benefits and burdens of this process, etc. Opportunities such as the one provided by the SPSAS course provide insight into how the co-production of knowledge through the recognition of different world views is crucial for building new holistic and complex scenarios needed to achieve sustainable futures.

Disclosure statement

No potential conflict of interest was reported by the author(s).

CRediT authorship contribution statement

Danilo Borja, Jan Daněk, Julia C. Assis, Antonella Gorosábel and Rafael Borges contributed equally for the development of the manuscript and, therefore, shared first authorship.

Danilo Borja, Jan Daněk, Julia C. Assis, Antonella Gorosábel and Rafael Borges: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization, Supervision, Project Administration. Additionally, **Jan Daněk and Julia C. Assis:** Funding Acquisition. **Isabel Rosa, Carolyn Lundquist and Fabio Scarano:** Conceptualization, Writing – Review & Editing. **Silas C. Principe:** Formal analysis, Investigation, Writing – Review & Editing, Visualization. **Alice Ramos de Moraes, Edberto Moura Lima, Fábio H. C. Sanches, Juan Andrés Martínez-Lanfranco, Julia Niemeyer, Juliana Siqueira-Gay, Lara Cornejo-Denman, Matheus Camargo Silva Mancini, Nino Tavares Amazonas, Rafael Lembi, Raísa Romênia Silva Vieira, Tássia Rayane Ferreira Chagas and Wladimir Moya:** Formal analysis, Investigation, Writing – Review & Editing. **Viviane Dib:** Formal analysis, Writing – Review & Editing, Visualization. **Carla Rivera Rebella, Catalina Zuluaga Rodríguez and Sandra Benavides-Gordillo:** Formal analysis, Writing – Review & Editing. **Adnan Arshad, Diana Isabel Clavijo Rojas, Luis Filipe Lopes, Mercy Funke Salami and Priyanka Sarkar:** Formal analysis, Investigation. **Rob Alkemade, Unai Pascual, Simon Ferrier and Carlos Alfredo Joly:** Writing – Review & Editing.

Funding

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001. DB doctoral research is

supported in part by funding from the Social Sciences and Humanities Research Council of Canada and the Killam Trusts. JD acknowledges support from the Specific Academic Research project “Research on social and environmental innovations” [grant number VS260471] and from the Technology Agency of the Czech Republic [grant number TL02000520]. This work was supported by FAPESP [grant number 2017/17337-9 (FHCS)]. JN received a doctoral fellowship from The Brazilian Council for Scientific and Technological Development (CNPq) [grant number 142215/2019-8]. UP is supported by the Spanish Government through María de Maeztu Excellence Accreditation 2018–2022 [Ref. MDM-2017-0714]. LFL is a PhD fellow funded by the FCT [PT/BD/142963/2018], under the SUSFOR – Sustainable Forests and Products Doctoral Program [PD.00157.2012]. CRR acknowledges the Agencia Nacional de Investigación y Desarrollo [ANID PIA/BASAL FB0002]. RCB was funded by the Brazilian National Council for Scientific and Technological Development (CNPq) [grant numbers 373408/2019-6, 373092/2020-2] and received a travel grant from Vale Institute of Technology. JAML is funded by the National Agency for Research and Innovation (ANII-Uruguay) and the Computational Biodiversity Science and Services Program (Bios²-Canada). AA acknowledges the support from the China Scholarship Council (CSC) and PODA-Pakistan.

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