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Unraveling deep roots in drylands: a systems thinking participatory approach to SDGs

Ana Paula Dutra Aguiar[1,2], David Collste[2], Sofia Cortés-Calderón[2,3], Taís Sonetti-González[4], Minella Alves-Martins[1], Antonio J. Castro[3], Amadou Diallo[5], Karl Martin Eriksson[6], Deborah Goffner[7], Zuzana V. Harmáčková[8], Amanda Jiménez-Aceituno[2,9], María D. López-Rodríguez[3], María Mancilla-García[4], Veronica Olofsson[2], Aldrin Martin Pérez Marin[10], Francisco Gilney Silva-Bezerra[1], Hanna Sinare[2] and Claire Stragier[7]

[1]National Institute for Space Research (INPE), São José dos Campos, SP, Brazil; [2]Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden; [3]Andalusian Centre for Global Change – Hermelindo Castro, Department of Biology and Geology, University of Almeria, Almería, Spain; [4]Socio-Environmental Dynamics Research Group, Free University of Brussels (ULB), Brussels, Belgium; [5]International Research Laboratory (IRL 3189 ESS), Environnement santé et sociétés/CNRS/UCAD, Dakar, Senegal; [6]West Sweden Nexus for Sustainable Development (Wexsus), University of Gothenburg, Gothenburg, Sweden; [7]Centre national de la recherche scientifique (CNRS), Toulouse, France; [8]Global Change Research Institute of the Czech Academy of Sciences, Brno, Czech Republic; [9]Social–Ecological Systems Institute (SESI), Leuphana University of Lüneburg, Lüneburg, Germany and [10]Semiarid National Institute (INSA), Campina Grande, PB, Brazil

Research Article

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Corresponding author:
Ana Paula Dutra Aguiar;
Email: anapaula.aguiar@su.se

Abstract

Non-technical summary. Achieving sustainability on the ground poses a challenge in decoding globally defined goals, such as sustainable development goals, and aligning them with local perspectives and realities. This decoding necessitates the understanding of the multifaceted dimensions of the sustainability challenges in a given context, including their underlying causes. In case studies from Brazilian drylands, we illustrate how an enhanced multiscale participatory method, combined with systems thinking tools, can shed light on systemic structures that currently entrench unsustainable development trajectories. This method offers insights into co-designing potential pathways toward sustainable futures and unlocking transformative capacities of the local population.

Technical summary. Translating United Nations global sustainable development goals (SDGs) into actions that address local realities and aspirations is an urgent challenge. It requires new thinking and approaches that foster the discussion about the main challenges to implementing the SDGs at multiple levels. This paper presents a novel multiscale participatory approach that combines the popular Three Horizons diagram with the formalism of causal loop diagrams in systems thinking. We present results from six multi-stakeholder dialogues held across drylands in Brazil with a focus on desired futures aligned with SDGs. Focusing on identifying the root causes and systemic structures of unsustainability, participants identified lock-ins, leverage points, and interventions for how these could be changed. The core lock-ins are the discontinuity of public policies, and the historical land and power concentration reinforced by the current expansion of large-scale agricultural, mining, and energy projects. The proposed interventions are structural and – if implemented – would contribute to achieving SDGs in an integrated manner. The unique approach developed in this study can provide leverage as it bridges the inclusivity of participatory visioning with the change potential of systems thinking tools to tackle root causes and unleash societal transformations.

Social media summary. We are not achieving SDGs. Understanding root causes of unsustainability is critical to move toward sustainable and just futures.

1. Introduction

The 2030 Agenda emphasizes the importance of achieving all 17 sustainable development goals (SDGs) in a holistic way to ensure 'Leaving No One Behind' (UN, 2015). However, decoding these global goals into actionable measures that align with local realities remains a challenge (Biggeri, 2021). Tackling this challenge requires approaches and tools that integrate diverse perspectives, engaging actors across sectors and balancing bottom-up and top-down strategies (Biggeri, 2021; Caniglia et al., 2021; Jiménez-Aceituno et al., 2020; Moallemi et al., 2020; UCLG, 2017). Besides, the 2030 Agenda stresses the 'indivisible' nature of the 17 SDGs, calling for approaches that enable the discussion of integrated pathways toward

all the SDGs through the transformation of social–ecological systems (Collste, 2021; IGS, 2023; TWI2050, 2018; Weitz et al., 2023).

Adopting a systemic perspective is particularly helpful for dryland ecosystems which are home to approximately 2 billion people, covering over 47% of the Earth's land surface. These areas face interlinked sustainability challenges, including vulnerability to droughts, wildfires, water shortages, extreme temperature, and land degradation – challenges exacerbated by climate change, with severe impacts on food security, livelihoods, and human wellbeing (ECIU, 2023; UNCCD, 2017). Moreover, conflicting interests and unequal access to natural resources often result in disputes among different actors, in particular concerning the multiple uses of water. Unequal access to resources also leads to disagreements related to land use, environmental degradation, and community rights (Pousa et al., 2019; Woodhouse, 2012).

In this context, the project XPaths – 'Science in Action: Intersecting Pathways to the SDGs across Scales in the Drylands' – proposes a novel multiscale participatory approach, rooted in systems thinking. The project aims to discuss pathways and co-design strategic action plans (Enfors-Kautsky et al., 2021) to achieve the SDGs in drylands through case studies in Senegal, Brazil, and Spain. In this paper, we focus on the Brazilian semiarid case, a region facing multiple challenges in the context of water, energy, and food production (Martins et al., 2024; Neri et al., 2019; Peixoto et al., 2022; Pérez-Marin et al., 2017; Pousa et al., 2019). The project's premise is that achieving the SDGs in an integrated manner – respecting their 'indivisible' nature – requires more than addressing their interactions to design proper multisectoral policies (Bennich et al., 2020; Nilsson et al., 2018; van Soest et al., 2019). There is also a need to understand and overcome the core systemic structures locking a region in unsustainable paths. This requires identifying the root causes of such unsustainable systems behavior and the leverage points, namely, the points to intervene in a system to effectively change its development toward a more desirable trajectory or future (Abson et al., 2017; Dorninger et al., 2020; Meadows, 2008). Furthermore, we argue that the adoption of multiscale participatory processes to discuss sustainable futures is essential because, to successfully implement globally defined goals (such as the SDGs and Paris Agreement targets), it is necessary to discuss their relevance and make them actionable at the regional and local levels. To this end, it is important to capture the plurality of perspectives and tensions about desired futures at these multiple levels – including power asymmetries (Aguiar et al., 2020; Caniglia et al., 2021; Collste et al., 2023).

The goal of this paper is twofold: (1) to present this novel multiscale participatory approach to identify the key causes and systemic structures underlying current undesired and unsustainable development trajectories in a given context; and (2) to illustrate the operability of the approach, selecting the Brazilian semiarid case study as an example. The methodological approach lies in the combination of the formalism of systems thinking – as laid out by Nguyen and Bosch (2013) – and the Three Horizons approach to structure multiscale participatory dialogues in the context of SDGs (Collste et al., 2023; Sharpe et al., 2016).

2. Analytical framework

2.1 Systems thinking: concepts and tools

Systems thinking supports the understanding of how different system components are interconnected and affect each other (Maani & Cavana, 2010; Meadows, 2008). It provides a wide array of tools and perspectives to understand social–ecological interconnections as coupled systems, rather than focusing on isolated parts (Ramage & Shipp, 2020; Reynolds & Holwell, 2020; Walker & Salt, 2012).

A systems thinking approach involves building systems conceptualizations and maps that depict the overarching system, its main variables, and their interconnections. These models, often in the form of causal loop diagrams (CLDs) (Ford, 2010), help to assess and visualize how changes in one area might affect other parts of the system (see example in Box 1). This analytical tool has been widely used for facilitating communication, consensus-building, and collaboration in stakeholder settings (Van den Belt, 2004; Vennix, 1996; Videira et al., 2017) by providing a common language and creating a space for incorporating diverse perspectives (Elias, 2017; Maani & Cavana, 2010).

Another key tool is the iceberg metaphor or the 'Four Levels of Thinking model' which serves as a framework to guide the analysis of systems' dynamics and explore plausible entry points beyond typical symptoms-based responses (Maani & Cavana, 2010; Senge, 1990). It recognizes four interconnected levels of thinking that provide insights into various aspects of a system: (1) events or symptoms, (2) behavior patterns, (3) systemic structures, and (4) mental models (Box 1). In systems thinking, systemic structures are understood as the driving forces behind the production of events, demonstrating how different components and patterns within a system are interconnected and affect each other in causal chains giving rise to feedback. With this deeper understanding, we can identify 'leverage points', defined as points to intervene in the system to effectively change its development toward a more desirable trajectory (Meadows, 2008).

The seminal work of Nguyen and Bosch (2013) discusses the application of the 'Four Levels of Thinking model' to sustainability problems, exemplifying the use of CLDs for representing system structures that assist in the identification of leverage points and interventions. Our approach combines the formalism of systems thinking with the Three Horizons approach (Box 1) to facilitate collective thinking about pathways to desired futures.

2.2 Pathways to the SDGs: combining the Three Horizons and systems thinking

2.2.1 Three Horizons framework in the context of the SDGs

The Three Horizons (3H) framework was developed by Sharpe et al. (2016) to support group discussions about transformative change around a simple and intuitive diagram (Box 1c). The 3H diagram is a cognitive tool that guides collective thinking about pathways into the future and has become quite popular in the sustainability arena (Aguiar et al., 2020; Collste et al., 2023; Falardeau et al., 2019; Fazey et al., 2020; Harmáčková et al., 2022; Pereira et al., 2018). In this paper (Sections 2.2.3 and 2.2.4), we propose an adaptation of the method initially developed by Collste et al. (2023), which applied the Three Horizons tool to explore pathways to the SDGs at multiple scales. Their approach is referred to as 3H4SDG.

The multiscale process described in Collste et al. (2023) consists of conducting a knowledge co-production process through several workshops in which small groups (around 10 people) discuss sustainable futures for a given geographic area. The development of the approach was guided by the 'indivisible nature' of the 2030 Agenda, that is, to enable the discussion of integrated pathways toward all the SDGs through the transformation of a social–ecological system. Therefore,

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Box 1. Tools combined in the 3H-CLD approach

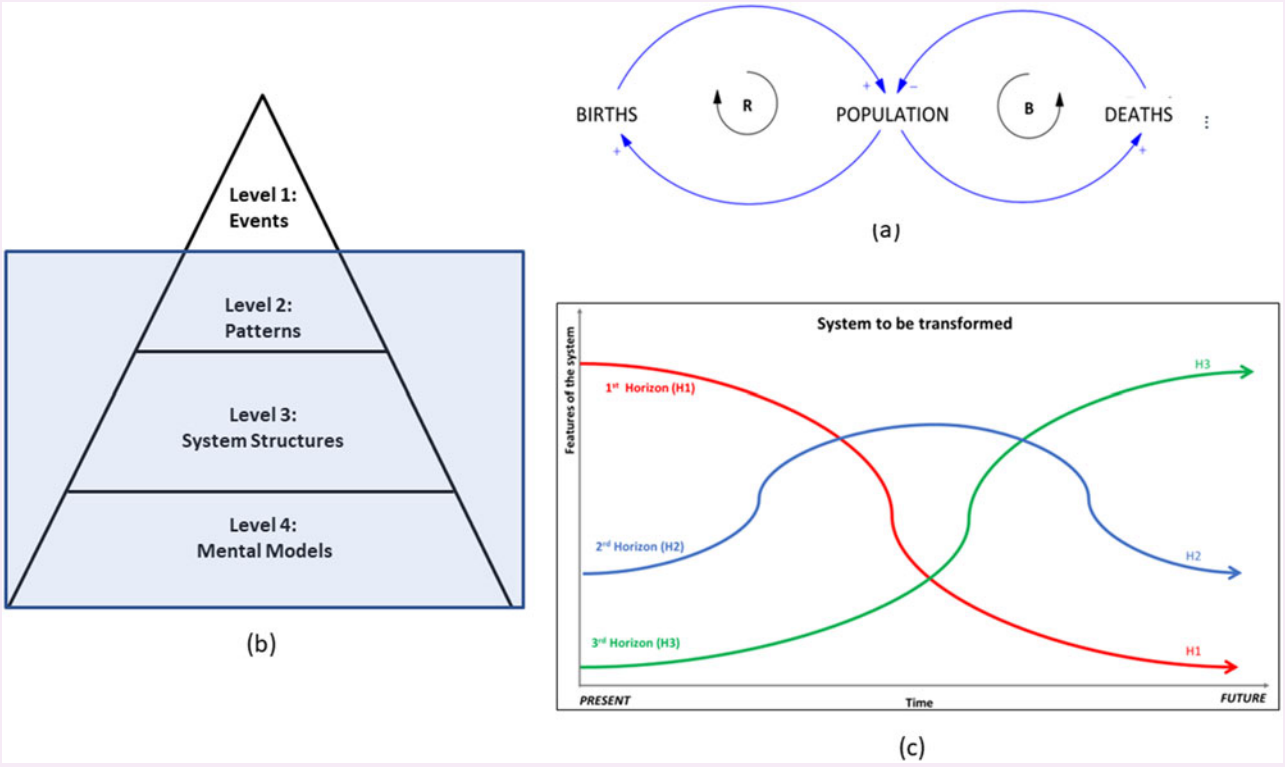

Figure Box 1. (a) Causal loop diagram example (prepared by the authors); (b) Four Levels of Thinking model (prepared by the authors based on Maani and Cavana 2010); and (c) The Three Horizons diagram (prepared by the authors, based on Sharpe et al. 2016).

(a) *Causal loop diagrams (CLD)*: In a CLD, an arrow represents a causal link between each pair of variables. The polarity sign (+ or –) depends on the type of cause–effect relationship. A '+' is used when both variables move in the same direction, whereas a '–' is used when the variables move in the opposite directions. When causal links are suspected to have an ambiguous polarity, this usually indicates the presence of multiple causal pathways that should be represented separately. Systems thinking emphasizes the interconnectedness of various components of a system, shifting away from linear causality (from a to b to c) to circular causality in a circular direction (from a to b to c and back to a). They are categorized as either reinforcing loops, which, when dominating the behavior of the system, typically drive the system to continue in the same direction – amplifying an ongoing change – and balancing loops, which often steer the system toward stability and buffer changes. In the example (Figure Box 1a), if population grows, the number of births grows, increasing the population, in a reinforcing loop; on the contrary, as population grows, the number of deaths also grows, controlling the growth of the population (balancing loop B).
(b) *Four Levels of Thinking model*: At the top level, events or symptoms, which in the iceberg metaphor constitute the 'tip of the iceberg', represent the most visible part of reality. Although underlying these events there are deeper problems, decisions, and interventions often focus on these events or symptoms. The second level of thinking, which in the iceberg metaphor constitutes ice beneath the water's surface, involves patterns and trends of the events, where a large set of events are linked together to reveal recurring patterns over time. Moving deeper beneath the water's surface, we reach the third level or the systemic structures. Systemic structures demonstrate how different components and patterns within a system are interconnected to produce the visible events. Finally, in the fourth level, we find the mental models. These include our cognitive understanding of reality and can be viewed as 'systemic structure generators' because they shape our reasons for approaching things the way we do and guide the creation or change of various structures. Mental models reflect our individual personal beliefs, values, and assumptions, as well as collective shared visions (Maani & Cavana, 2010; Nguyen & Bosch, 2013).
(c) *Three Horizons (3H) diagram*: In the 3H diagram, three lines are plotted against two axes. The first line represents the current system (H1), the second represents the transition process (H2), and the third represents potential future alternatives (H3). In groups, participants use the diagram to mediate a conversation about how to transform the system. The *x*-axis represents the time from the present into the future, and the *y*-axis represents the degree of dominance of certain elements, characteristics, initiatives, or events of the system. The method also includes a discussion about which actors influence the necessary actions, as well as the role of power relations in transforming the system (Curry, 2015; Sharpe et al., 2016).

all dimensions of sustainability (social, environmental, economic, and governance) are considered, without selecting a priori SDGs of interest. This allows the important issues in a given context to emerge from the process, not being imposed.

During the workshops, the activities in each group are structured as follows. In step 1 ('The desired future', focusing on the third horizon), participants discuss their aspirations regarding a sustainable and fair future for their region, considering multiple dimensions of sustainability. This step also includes the identification of the current existing 'seeds' (Bennett et al., 2016) or initiatives that capture some of the features of the desired future. Under the proper conditions, growing such seeds can guide the transformation. Step 2 centers around the first horizon, which identifies the 'Current challenges'. Facilitators also foster a discussion on the root causes of these problems without employing any specific tool to map causal relations. Step 3 concentrates on the second horizon, exploring 'How to reach the desired future from the present', and identifying which actions are needed to overcome the current problems and their root causes and nurture the seeds for transformative change.

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Throughout the three steps, the results are captured in colored post-it notes representing different dimensions of sustainability (environmental, social, economic, and governance). The post-it notes are synthesized in creative outputs (e.g. letters, drawings, plays) that aim to apprehend and internalize the collective results of the group. Each group follows the same structure and produces similar results, which are later integrated and analyzed, including their convergences and divergences (see Appendix A). Divergences, that is, differences in perspectives, views, or values, among participants in the same group or between groups are noted down. Such divergences are recognized as important and natural to the process – and may be key to revealing a better understanding of potential transformations. By analyzing the multiple perspectives that emerge, a broader space of options can be understood and further evaluated (Aguiar et al., 2020).

Collste et al. (2023) tested the original 3H4SDG approach in a Pan-African context and considered it very useful for understanding local aspirations, visualizing the desired future(s) and capturing multiple perspectives. However, it was less useful for exploring how transformative change may occur – as it does not explicitly deal with underlying system structures. Therefore, the current study incorporates CLD, a systems thinking tool (Section 2.1), as central pieces in steps 2 and 3.

2.2.2 The 3H-CLD approach

In the new version of the modified approach (named 3H-CLD), CLDs produced by each group are the main output of step 2 and are the basis for identifying entry points for transformative change (step 3). The process of building the CLDs with the participants in step 2 consists of:

- *Selection of core problems.* After completing the 3H diagram with the current problems, we briefly explain what a CLD is using a simple example such as the one in Box 1. We then ask the participants to collectively prioritize three of the problems, based on their importance for the region. The three selected problems are the initial variables included in the CLD (a sheet of paper or software like Vensim might be used).
- *Guided by the iceberg model metaphor*. The selected problems are typically seen as the tip of the iceberg. The exercise continues by prompting participants to reflect on the causes of the variables in the diagram, to examine deeper factors. New variables and causal relationships are then added to the CLDs as they are iteratively identified by participants (Figure Box 1b). They can include topics previously listed as problems or new ones. When possible, causal circular relationships which are also known as feedback loops are looked for. The exercise usually takes 40–50 min in groups of 10–12 participants.

In step 3, based on the CLDs collectively built in step 2, participants are invited to propose actions that could break the systemic problems identified. They are also asked to consider how to nurture the current good initiatives (step 1). Finally, they associate the actions with potential impacts on the SDGs. It is important to note that step 3 aims to avoid sectoral solutions or a focus on specific SDGs. Actions address core problems, their causes, and relationships.

At the end of multiscale 3H-CLD workshops, the process of integration, synthesis, and analysis of the information produced by all the groups/scales starts, involving researchers and stakeholders. Figure 1 illustrates the comparable information collected for each group (see example in Appendix A). There are several potential analyses that can be derived from the collected data. In this paper, we focus on the analysis and integration of CLDs to identify systemic structures and leverage points.

2.2.3 Systemic structures: integrating the CLDs

The CLDs elaborated during the workshops by the different groups aim to capture essential system elements and their connections, though not exhaustively – depending on the focus defined by the selected problems (see examples in Appendix C). Integrating and refining them to produce one or more integrative causal loop diagrams (iCLD) is key to our approach. An iCLD provides a concise yet comprehensive basis for understanding the causes of problems highlighted by workshop participants. They are built through the integration of recurring system components from various scales that are crucial to the core problems according to the participants. Therefore, the goal is to capture a synthesis of the main causal relationships and systemic structures acting as obstacles to sustainability in a given context. The iCLDs also aim to facilitate the understanding of individuals outside the workshops.

The process of building the iCLDs consists of the following:

- *Revision of CLDs:* Original CLDs are transcribed into digital form (e.g. using Vensim software). At this stage, the project team reviews the original CLDs to verify whether any significant causal factors or connections are missing and to ensure that the diagrams accurately reflect the participants' collective understanding of the system, as discussed during the workshops. When disagreements or uncertainties arise regarding potential causal relationships, these should be duly noted and discussed with the participants.
- *Thematic clustering* of post-it notes to integrate the results of the multiple workshops/groups. The thematic analysis enables the qualitative comparison of common themes that emerged in the different groups/workshops and their relative frequency (see example in Appendix B). In the case of integrating the CLDs, the most relevant thematic analysis relates to step 2 (present concerns post-it notes and the CLD variables themselves). The present concern's themes represent level 1 (events) of the 'Four Levels of Thinking model'.
- *Patterns:* The CLD themes are also subject to a comparative analysis to identify which ones came up repeatedly across locations and scales, pointing out possible systemic structures underlying the events. We explore the temporal and/or spatial patterns of the events and themes, using secondary data sources (preferably official if available), to capture common behavior across themes and events (level 2 – patterns).
- *Building new diagrams:* Focusing on the recurrent themes identified, the initial versions of the original CLDs are broken down into smaller, more manageable parts. These simplified versions lay the groundwork for building the iCLDs. The iCLDs are built gradually incorporating relationships that were consistently repeated across scales and the insights from previous analyses. Feedback loops are identified, and external drivers are highlighted. iCLDs need to be regularly reviewed with the participants to ensure they accurately represent perceived dynamics.

The role of the researchers in this phase is to structure the input from participants and contribute with the knowledge and skills of systems thinking to the exercise, and not to provide nor impose the researchers' values on the diagrams. It is therefore critical that the process includes rounds of feedback from

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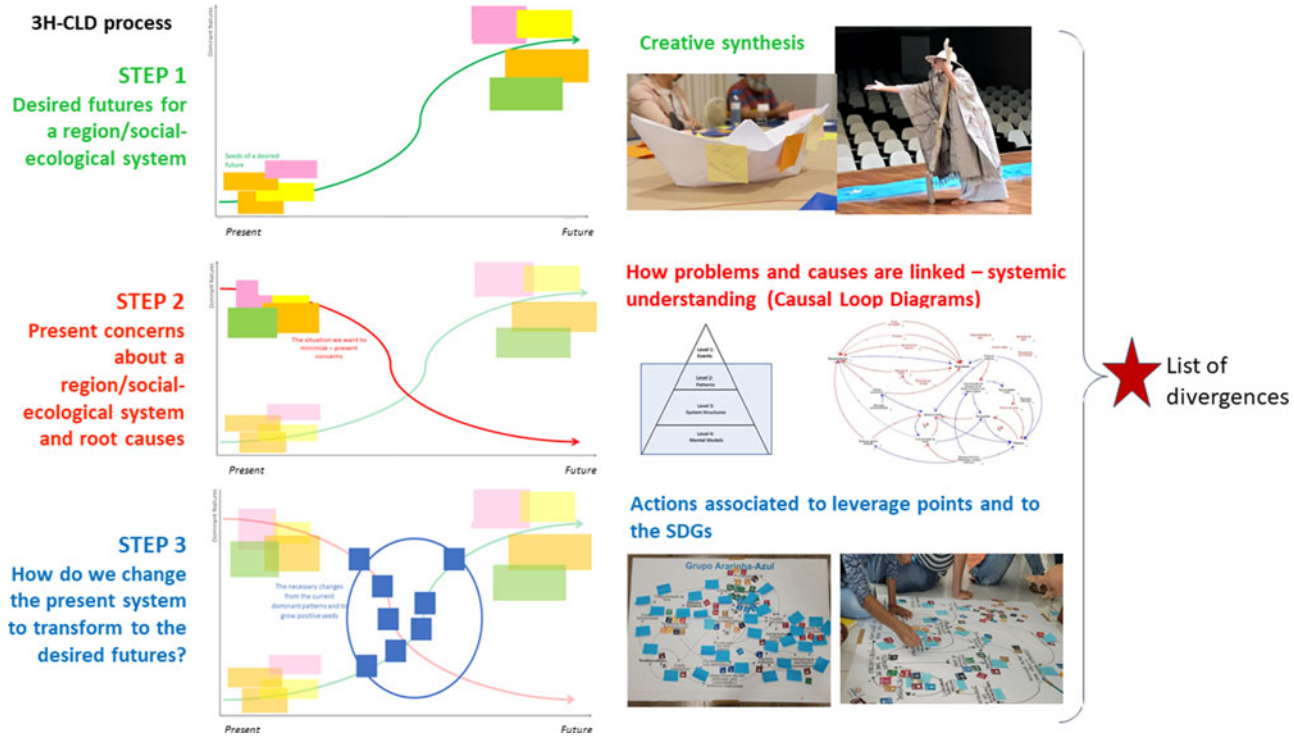

Figure 1. 3H-CLD outcomes in each step (for each group): (a) desired futures (post-it notes counted and grouped on similar themes); (b) creative processes illustrating/illuminating and synthesizing desired futures; (c) 'good seeds' (initiatives) of the future already existing currently; (d) problems of the present (post-it notes counted and grouped on similar themes); (e) systemic understanding of the roots of the problems and actors involved (CLD); (f) actions to achieve sustainable futures and grow seeds (post-it notes counted and grouped on similar themes); and (g) divergences noted during the workshop. A typical in person 3H-CLD workshop usually takes one day and a half, with a number of groups working in parallel (*source*: figure prepared by the authors).

participants, and that disagreements are brought to the surface and not downplayed. Interaction with participants during the construction of the iCLDs should occur through additional workshops, smaller meetings, or report reviews.

2.2.4 Identifying leverage points and interventions to change the system

The last phase of the process consists of a new participatory workshop where we collectively identify leverage points and interventions (actions) to change the system toward sustainable futures:

- *Together with participants, the first step is to discuss the dynamics of the system represented by the iCLDs, by identifying* 'Central variables', dominant loops, and external variables. Central variables often contribute to major behavioral patterns, for example, sustaining undesired development trajectories. Those are not necessarily the problems identified in the initial versions of CLDs, as some of them might represent symptoms rather than root causes. The dominant structures existing in the system in the form of feedback loops need to be identified. This analysis can lead to a set of informed hypotheses about what has kept the system in its current state, and what options are available and shed light on where the system might be heading in the future.
- *The second step consists of an analysis of the elements that can potentially be modified and act as leverage points in the new iCLD, and collectively defining interventions at these points.* Initial insights can be gleaned through associating the variables and loops in the iCLDs to the step 3 thematic clusters (actions). See an example in Appendix B.

2.3 Applying the approach

We conceived the 3H-CLD approach (Section 2.2) to be easily applicable through workshops in multiple contexts, from local to global scales. However, it requires careful preparation and training of the research team and facilitators. Although the Three Horizons framework is quite intuitive, building CLDs and identifying leverage points require an understanding of the underlying systems thinking concepts (Section 2.1). On the contrary, both tools are becoming quite popular in several fields, as they address the need to collectively change the way we understand and act upon the world (Cabrera et al., 2008). Training is also particularly important to generate comparable results across multiple sites and scales, as in the case of the XPaths project discussed in the next section.

3. Case study: XPaths multiscale participatory process

In the XPaths project (https://www.xpathsfutures.org/), the 3H-CLD approach was applied to the drylands of Brazil, Senegal, and Spain – with slight adaptations due to each case study specificities on the ground. In this paper, we illustrate the 3H-CLD approach with the Brazilian case study.

3.1 Study area: the Brazilian semiarid

The Brazilian semiarid has more than 31 million inhabitants, corresponding to 15% of the country's population (IBGE, 2022) and occupies an area of over 1 million km^2. It includes the entire Caatinga biome and portions of the Cerrado biome (Figure 2).

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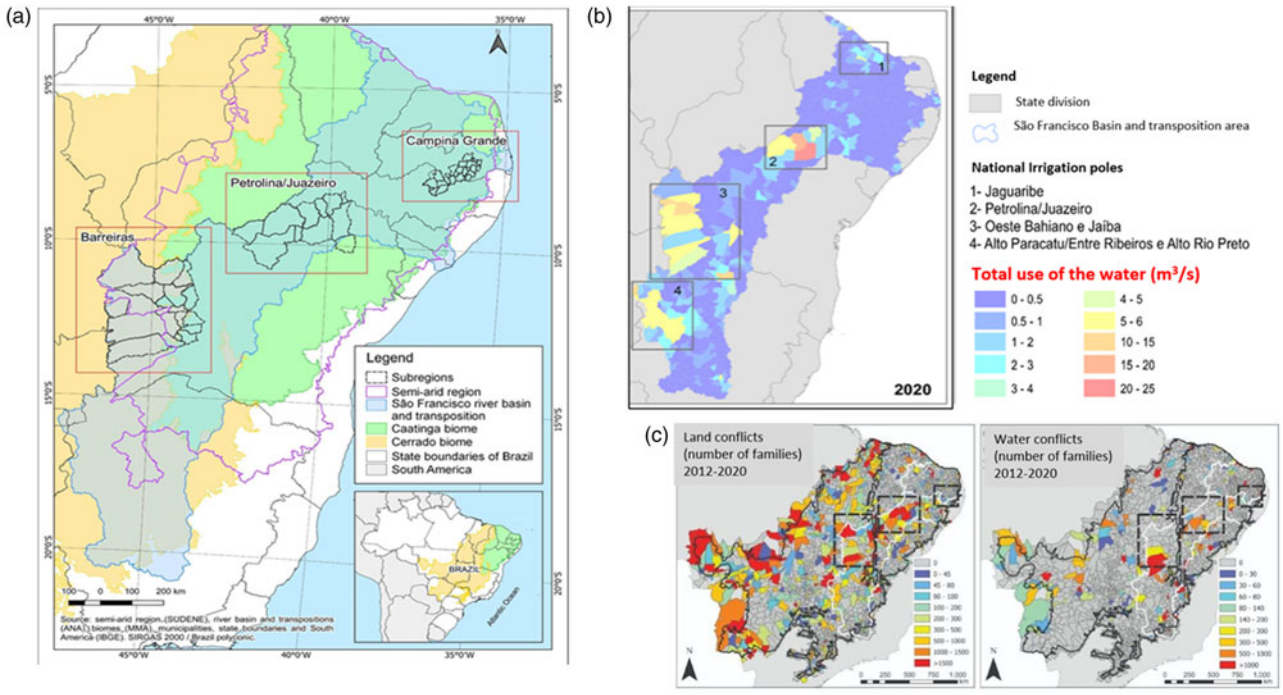

Figure 2. (a) Location of the semiarid and SFRB in Brazil and their location within the Cerrado and Caatinga biomes (prepared by the authors). (b) Map illustrating how the municipalities in irrigation poles (the four black rectangles) consume most of the water in the SFRB. *Source*: Prepared by the authors using data from the Brazilian Water Agency (ANA, 2023). (c) Maps illustrating the concentration of conflicts in the same irrigated areas within the Sao Francisco Basin. Note that a high level of land conflicts is also located on the border of the Cerrado and Amazon biome. *Source*: Prepared by the authors using data from the Land Pastoral Commission (CPT) (CPT, 2022a, 2022b).

Running through both biomes, the São Francisco River Basin (SFRB) is of crucial economic, ecological, and cultural importance to the region. The river is also fundamental for the supply of water, food, and energy to the region and the world through the production of irrigated agricultural commodities (Bezerra et al., 2019). The region also has enormous potential for the expansion of renewable energies – in particular, wind and solar plants (Neri et al., 2019; Olofsson, 2023; Sales & Sales, 2023). The expansion of large-scale projects for food and energy production has reshaped the region, presenting both opportunities and risks. For example, 72% of the water is withdrawn for irrigation (ANA, 2023) leading to conflicts over water use (CPT, 2022a, 2022b; Peixoto et al., 2022), spatially concentrated around large-scale irrigation projects (Figure 2b).

The semiarid is also an area of socioeconomic contrasts – which largely reproduces the multiple inequalities that characterize Brazilian society, including access to land (Guedes-Pinto, 2020) (Figure 2c). However, although historically stigmatized as an impoverished region ravaged by drought (Alvalá et al., 2019), the semiarid has a strong network of social movements that, in the last few decades, have outlined new perspectives for the future, notably through the paradigm of 'coexistence with the semiarid' (Pérez-Marin et al., 2017). This new paradigm coexists – not without conflicts – with the expansion of mega-enterprises for food and renewable energy production.

In this context, the 3H-CLD process took place at multiple scales and geographic contexts. Given the characteristics of the region, we chose their water–energy–food production characteristics as entry points to select the study sites. Our regional focus was the SFRB and the transposition area – the dry area receiving water from the river through large channels. We also organized workshops to discuss the Cerrado and Caatinga, where the basin is located (Figure 2a). At the local scale, we selected three regions located inside the SFRB and transposition area, which present distinct challenges concerning the water–agriculture–energy nexus. The local scale areas were the municipality of Campina Grande and 26 neighboring municipalities, located in the driest region of the Brazilian semiarid and at the transposition area (MDR, 2025; Santos & Ioris, 2024); Petrolina/Juazeiro and another 13 neighbor municipalities, corresponding to the irrigated fruit production hub for exportation on the banks of the São Francisco River – also where large hydroelectric plants are located (Cavalcanti, 1997; Irineu De França, 2020); and Barreiras and 19 neighbor municipalities, in Western Bahia/MATOPIBA, the intersection of the semiarid region with the Cerrado, a critical area in the context of the production of agricultural commodities and large-scale irrigation (Martins et al., 2024; Russo Lopes et al., 2021). The selection of local municipalities was made through a cluster analysis of similar regions according to socioeconomic and biophysical indicators (Arcoverde et al., 2023) and consultation with partners and experts in the region.

3.2 Workshops' design and implementation

The first phase of the 3H-CLD participatory process in Brazil consisted of a series of workshops between October 2021 and August 2022. Throughout the process, a total of 100 individuals participated in the process directly (Table 1). When selecting the participants, we aimed at having a plurality of perspectives from different sectors of society (private sector, civil society, academia, government, international bodies) and geographic contexts. Different approaches at the regional and local scales were employed, due to the limitations imposed by the COVID

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Table 1. 3H-CLD dialogue process in Brazil: date, scale, and scope of the workshops

Date	Type of workshop	Scale	Geographic focus	Number of participants
October 26, 2021	Phase 1 (online)	Regional	Caatinga biome	10
October 28, 2021	Phase 1 (online)	Regional	Cerrado Biome	10
February 2, 2022	Phase 1 (online)	Regional	SFRB and transposition area	9
March 7–11, 2022	Phase 1 (CLDs review and step 3) (online)	Regional	All regional (CLDs review and stage 3)	20
April 27–28, 2022	Phase 1 (in-person)	Local	Campina Grande and neighbor municipalities	25
June 28–29, 2022	Phase 1 (in-person)	Local	Barriers and neighbor municipalities	22
August 17–18, 2022	Phase 1 (in-person)	Local	Petrolina/Juazeiro and neighbor municipalities	24
November 7–11, 2022	Phase 2 – Review of first cross-scale analyses (online)	All	All	38
May 1–5, 2023	Phase 2 – Discussion about leverage points and interventions	All	All	18

pandemic. At the regional scale, workshops were online and participants were selected through a broad mapping of institutional actors participating in the public debate on the sustainability of the Caatinga and Cerrado (Silvino, 2019).

At the local scale, an in-person qualitative social network creation tool, NetMap (Schiffer & Peakes, 2009), was used to identify the most influential and connected individuals in each group. In each location, we held about four to five NetMap meetings in small groups (two to five people) or individually of actors of the same sector, selected through a snowball approach. We used simple materials such as cardboard or any other paper and thick colored pens for participants to write the names of the main actors operating in the region, identify their connections, and their degree of influence. Based on the exercises, names of organizations and key people in each context emerged. Some names were repeated in different NetMap meetings. Our goal was to identify about 20–25 actors to participate in the 3H-CLD dialogue per location. The selection logic was based on the concept of centrality (Borgatti, 2005). The degree of centrality is a simple measure by which we can measure power within a network or even a social structure. Table 2 presents the distribution of sectors at regional and local scales. The first phase methods, including the process for selection of actors, are detailed in an online report (Aguiar et al., 2023).

The local workshops presented challenges arising from the context of conflict in the region (CPT, 2022a, 2022b). The division of participants into groups acknowledged the local power asymmetries and aimed at providing a more comfortable environment for the participants – particularly in cases where specific groupings were requested by the participants due to serious conflicts.

The second phase took place from August 2022 to May 2023, through the (co)production of a series of derived products, including the iCLD and leverage points. Early versions of iCLDs were presented in an online workshop in November 2022, helping articulate assumptions participants might have about the system and how these are depicted in the diagrams. After the iterative construction process, the final version was discussed during an in-person workshop, held in May 2023, with representatives from all scales to confirm the legitimacy and quality of the iCLD and co-produce an analysis of leverage points. This paper focuses on the second phase of the process, integrating the results of the workshops through iCLD, using the 'Four Levels of Thinking model' to identify leverage points.

Table 2. 3H-CLD dialogues: number of participants by sector

	Regional: *Caatinga biome, Cerrado biome, SFRB, and transposition area*	**Local:** *Campina Grande and neighbor municipalities*	**Local:** *Barriers and neighbor municipalities*	**Local:** *Petrolina/ Juazeiro and neighbor municipalities*
Private sector (companies, consultancies, associations representing the private sector)	2	6	4	7
Government (executive, legislative, or judiciary)	5	7	5	4
Civil society (NGOs, social movements, associations, etc.)	12	7	8	7
Academia (public/private research institutes and universities)	7	5	5	6
International bodies	3	0	0	0
Total	**29**	**25**	**22**	**24**

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4. Results and discussion

In this section, results and discussion about how we identified leverage points and interventions to transform the Brazilian semiarid are structured according to the 'Four Levels of Thinking model' (events, patterns, systemic structures as represented by the iCLDs, and mental models).

4.1 Level 1: events and symptoms in the Brazilian semiarid system

Figure 3a presents a synthesis of the most frequent categories of problems identified by the participants during the workshops' 3H-CLD step 2 (present concerns), ordered by their recurrence in the workshops. These categories are considered the 'events' of the iceberg metaphor. Among them, the most mentioned present concerns across scales were the multiple inequalities (income, wealth, land access, power, etc.) and poverty; violence, social–ecological conflicts, and environmental racism; and environmental degradation (deforestation, soil degradation, salinization, water pollution). Figure 3b presents a synthesis of the categories that emerged from the thematic clustering of the CLD variables. Appendixes A and B trace the categories to the results of the workshops at different scales. Full workshops results are available in Aguiar et al. (2023).

When building the CLDs, the identified problems start to be connected through causal relations. Two categories stand out in the thematic analysis of the CLD variables illustrated in Figure 3b. The discontinuity or non-execution of public plans/policies appropriate to different contexts was a recurring problem and also central to the CLDs prepared by participants during the workshops (Figures 3a and 3b, respectively). This problem was highlighted by participants as the root of several other social and environmental problems in rural and urban areas, and one of the main obstacles to be overcome currently to achieve sustainable futures. Participants highlighted that, in many cases, plans and policies exist, but they: (a) are either discontinued with each change of government; (b) or implemented in a way that does not consider the specificities of each region; (c) do not serve the interests of the general population but rather of dominant economic groups. Furthermore, Brazil's dependence on commodity exports, monocultures, and historical patterns of land ownership concentration were frequently cited as root causes of environmental degradation and social issues, including conflicts and inequalities, as further discussed below.

4.2 Level 2: patterns

In this section, we explore temporal patterns of selected themes identified above, using indicators derived from official databases for the SFRB. Constrained by easily accessible data about the continuation of public policies at different levels in official databases, we focused the analysis on exploring some patterns of environmental degradation, inequalities, social–ecological conflicts, and the role of the commodities in the national economy using data from governmental/inter-governmental databases (ANA, 2023; IBGE, 2022; IPEA, 2023; MAPA, 2023; WITS/World Bank, 2023) or from other reliable sources (CPT, 2022a; Oliveira & Gabriel, 2023).

Figure 4a illustrates those Brazilian exports in 2020 were predominantly commodities such as vegetables, minerals, and fuel. In contrast, in 2000, the main products exported by Brazil were manufactured goods, including transport and electronics. Moving to Figure 4b, we observe that manufacturing has steadily lost relative importance in the Brazilian GDP since the 1990s. It is

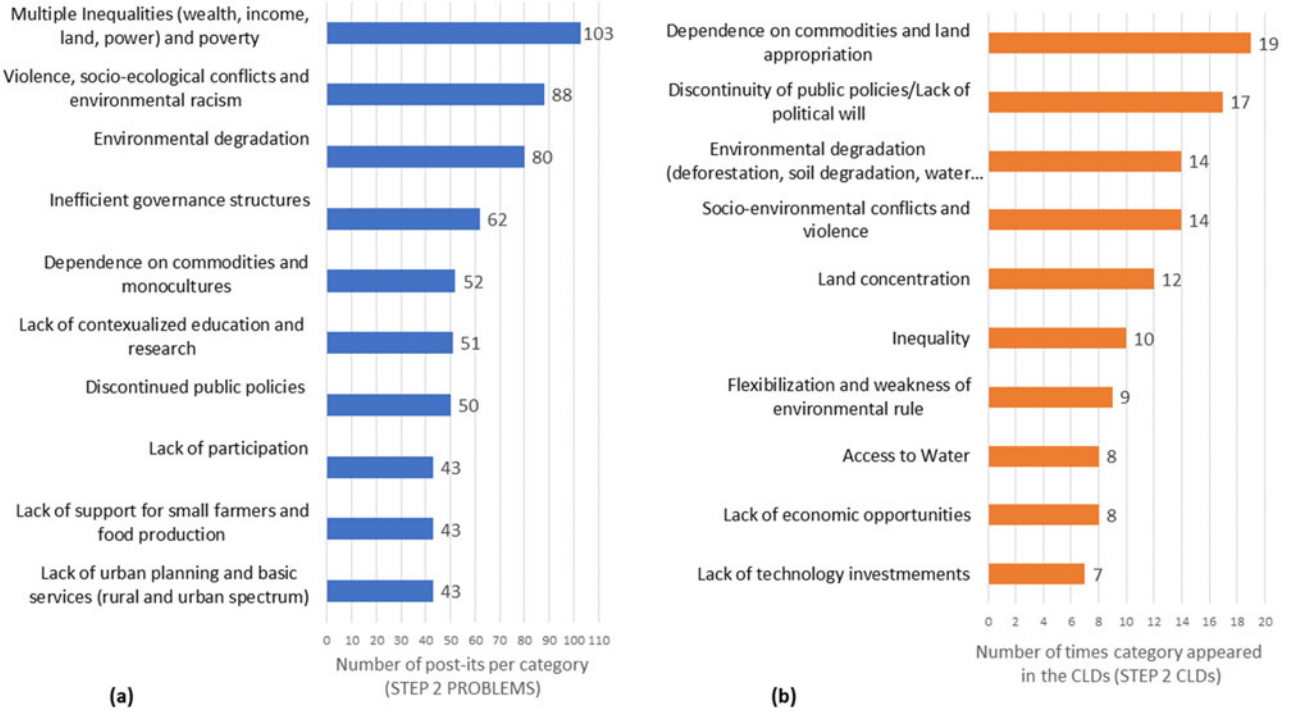

Figure 3. Thematic clustering: (a) step 2 (present concerns): total number of post-its in each category considering all workshops (first 10 categories). (b) step 2 (CLDs): total number of times a category was included in the CLDs (first 10 categories). See Appendix B for complete results.

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important to note that these graphs are not intended to establish causal relations between the growth of the agribusiness sector and the deindustrialization of the country; such a discussion is beyond the scope of this paper. Instead, they serve as a foundation for exploring how the growing importance of the primary sector relates to environmental degradation.

Figure 4c delves into the relative macroeconomic importance of commodities, with a specific focus on soybeans, underscoring how it has contributed to increasing the political power of a historically dominant sector in Brazil (Faoro, 1958). Political power is represented by the number of agribusiness-related senators and deputies in the National Congress, serving as a proxy for the sector's influence. Figure 4d illustrates an example of the flexibilization of environmental rules during this period, specifically highlighting the number of new agrochemicals allowed in the country.

Additionally, Figure 4e illustrates the temporal pattern of the land distribution Gini index – an indicator of inequality in the countryside. The closer this measure is to the value 1, the greater the concentration in the land structure. Brazil presents a high degree of concentration – one of the highest in the world (Bauluz et al., 2020) – which remained stable between 1975 and 2006, and increased in the 2017 survey (IBGE, 2023; Wilkinson et al., 2012). Also related to unequal access to resources, Figure 4f illustrates a notable increase in water usage in the São Francisco Basin, particularly in irrigation, while the amount for human use remains consistent (Figure 4f). Moreover, the number of families affected by land and water conflicts has sharply increased, particularly since the 2010s (refer to Figure 4f). This relates to the maps in Figures 1b and 1c which display how water usage and conflicts concentrate in areas of large-scale irrigation projects for commodities production.

4.3 Level 3: building iCLDs

Based on the content of the original CLDs (Appendix C) and the previous analyses (levels 1 and 2) we built two interconnected iCLDs. They were built by iteratively combining the causal relations from the original CLDs, peer-reviewed evidence and official data sources. The iCLDs were discussed, improved, and validated by participants in two workshops. The first workshop was held online in November 2022 and the second in person in May 2023. Therefore, the iCLDs represent the participants' understanding of the main causal relationships and systemic structures acting as obstacles to sustainability in the region, backed up by scientific references or official data sources. The resulting iCLDs are:

- **iCLD1 (Box 2)** illustrates in a simplified and schematic way how the *lack of execution and continuity of public policies* hinders the long-standing issue of access to basic services (education, health, sanitation, etc.) and social and power inequality in the country from being addressed.
- **iCLD2 (Box 3)** links the root causes of environmental degradation (in particular natural vegetation and water) and socioecological conflicts to *the land concentration and dependence on commodities*. iCLD2 dynamics connect to iCLD1 via the concentration of political power and multiple inequalities, in particular the inequality in access to land.

The systemic structures depicted in both iCLD1 and iCLD2 act as impediments to the attainment of several SDGs. For example, the *weakening of environmental legal frameworks* (iCLD2) contributes to the degradation of *natural resources* in several ways, including, for example, making it easier to obtain licenses to suppress vegetation, excessive release of pesticides, ineffective law enforcement and monitoring, and so on. The occupation of large areas for the installation or expansion of large primary sector projects also impacts the water availability, quality, and access (quantity and quality).

Socioenvironmental conflicts are, in this case, driven by the expansion of large enterprises in territories occupied by rural communities, particularly traditional populations (CPT, 2022a, 2022b). The expansion of wind farms, agribusiness, and small hydroelectric plants makes it difficult for communities to survive due to the lack of access to land and water, as well as contamination.

Another negative aspect of the widely discussed land concentration process would be *unplanned urbanization*, and without economic alternatives or appropriate services being offered to urban populations. This has numerous negative consequences, including an increase in *rural and urban violence*, health issues due to lack of sanitation, and so on. In turn, these issues are deemed as directly linked to the problems of implementing adequate *public policies* (including urban planning and access to basic services), represented in iCLD1.

4.4 Level 4: mental models

In the first phase of the participatory workshops, we brought together people from multiple sectors and geographic contexts, aiming to capture the plurality of perspectives on sustainable and just futures in the region and across scales (see Section 3.2). The main divergences that arose from the process were related to the diverse impacts of the current economic development model (see the Divergences Table in Appendix A). One group of actors sees the expansion of large enterprises, land ownership concentration, and urbanization as a natural outcome of the development process (in line with the dominant development narrative). They propose solutions for social–ecological problems based on efficiency gains to decrease the pressure on natural resources and the creation of urban jobs (see the Lobo-Guará CLD in Appendix C). They also value agribusiness as a driver of growth for the country and local economies, as we observed in the regions where the cities of Barreiras and Petrolina are located. On the contrary, actors aligned with the social and environmental movements bring concerns related to the reproduction of traditional modes of life in rural areas when faced with the negative impacts of the expansion of large-scale agricultural and energy projects. Based on an analysis of the divergences (Appendix A), another subproduct of the 3H-CLD process – out of the scope of this paper – was the co-design of alternative scenarios representing these perspectives (Aguiar et al., 2020; von Randow et al., 2024).

For building the iCLDs we took a different approach, focusing on commonalities rather than divergences. We attempted to be as exhaustive as possible in capturing the causal relationships expressed in the original CLDs. Moreover, we made a conscientious effort to adhere to comments and suggestions received throughout this process after the workshops. But there is a caveat. Although we tried to be impartial when integrating both perspectives in the iCLDs, we are conscious that there might be a slight bias in favor of the perspectives of the social and environmental movements – due to our values as researchers (i.e. the importance of giving voice to non-dominant narratives), but also due to scientific evidence and official data. For example, some actors might

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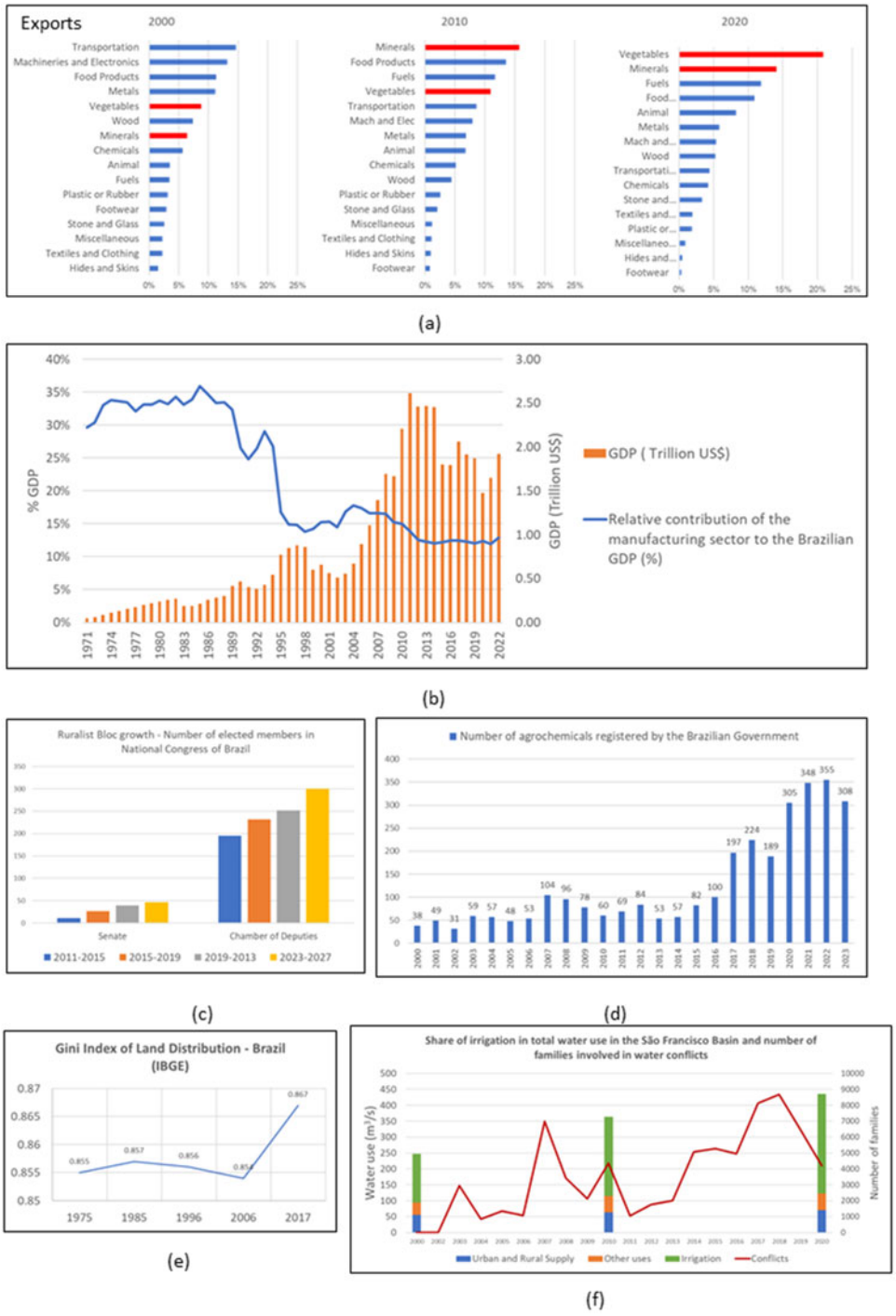

Figure 4. Temporal patterns of selected indicators representing some of the core themes identified in step 2: (a) changes in the Brazilian exports per type of product. *Source*: WITS/World Bank (2023). (b) Decrease of the relative contribution of the manufacturing sector as a percentage of the total Brazilian GDP. *Source*: IPEA (2023). (c) Growth of the agribusiness bloc in the National Congress. *Source*: Oliveira and Gabriel (2023). (d) Number of agrochemicals allowed by the Brazilian Government. *Source*: MAPA (2023). (e) Land distribution Gini index. *Source*: IBGE (2023). (f) Share of irrigation water use in the in the São Francisco Basin and number of families affected by water conflicts. *Sources*: ANA (2023), CPT (2022a).

deny the negative impacts of the dynamics expressed in iCLD2, that is, the occurrence of socioenvironmental conflicts, deforestation, or limits to exploring natural resources (Figure Box 3), but existing data sources elucidate such events and their patterns (Figure 4). On the contrary, the prevailing development narrative to which these actors align focuses on the macroeconomic advantages of the *Investment Loop* in iCLD2, highlighting the potential reinvestment of revenues in social development and the – contested – local development of commodities' production areas (Martinelli et al., 2017; Russo Lopes et al., 2021). In this sense, the iCLDs integrate both perspectives while also capturing the tensions between them.

During the last workshop in May 2023 (Table 1), there was no disagreement about the systemic structures represented by the

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Box 2. Integrative CLD 1: execution and continuity of public policies (iCLD1)

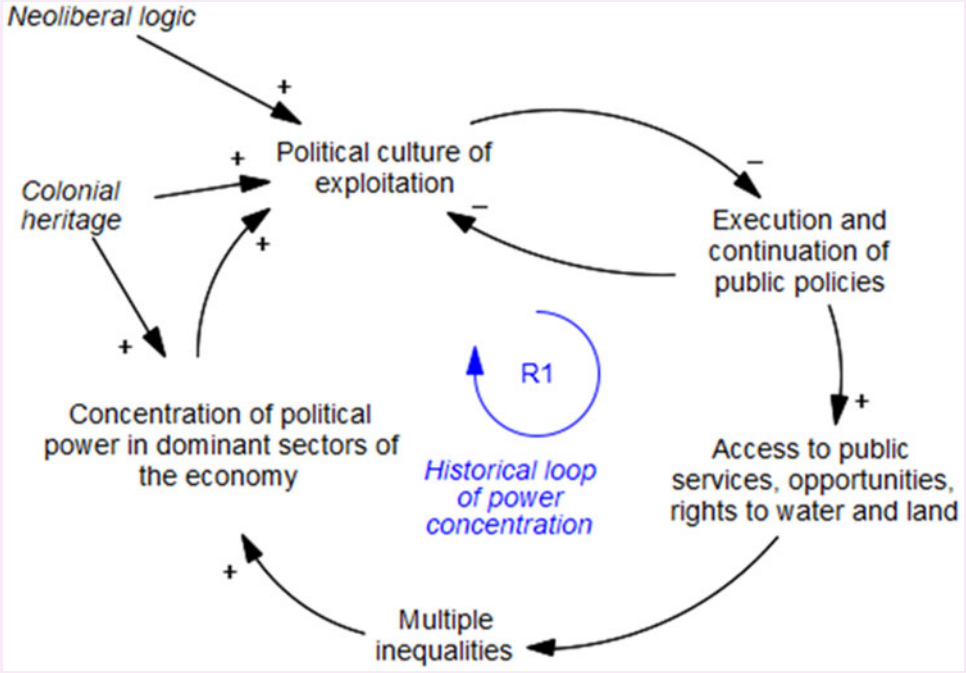

Figure Box 2. iCLD1 diagram: the systemic structures cause the lack of *execution and continuity of public plans and policies*, leading to the lack of *public services* and maintenance of multiple inequalities. The external factors that enhance this dynamic are highlighted in italics.

The diagram presents a reinforcement loop (R1 – *Historical Loop of Power Concentration*), which links the historical process of political capture by dominant economic groups to *multiple inequalities* (IBGE, 2023). The *colonial process* and the *capture of political power* by economic groups/activities (in particular, the primary sector focused on commodity production) are seen as the historical cause of an *exploitative and exclusionary political culture*, dominant in the region (Faoro, 1958). This historical process and political culture also influence the closed way in which the electoral system works, which hinders the emergence of new leadership.

These dominant groups work to ensure that the system remains closed and do not take action to give the population *access to basic public services*, such as quality education, healthcare, and basic sanitation, in addition to access to land and water. In turn, without the implementation of adequate policies, *multiple inequalities* remain or are intensified – in turn, this process, which reinforces itself, makes it difficult to reduce the social gap and the power imbalances. There is a vast literature about the process described in this loop, citing the classics (Faoro, 1958; Prado Júnior et al., 2011; Ribeiro, 1995). Participants also indicated factors contributing to *the non-execution and discontinuity of public policies and plans:* the lack of training of government bodies, particularly at municipal levels; the corruption; and the lack of political will to change this situation.

iCLDs. However, it was clear that people with different perspectives chose to work with leverage points and solutions better aligned with their 'mental models'.

4.5 Leverage points and interventions

Table 3 provides a summary of the leverage points and prioritized interventions identified by participants, considering the systemic structures represented in the iCLDs and the synthesis of the workshops (Appendix B).

Strategic actions 1 and 3 focus on improving transformative capacities to address the structural problems represented in iCLD1 and iCLD2 through environmental education and political training, respectively. They seek to strengthen popular participation to break the political and economic power concentration structures that are at the root of the region's environmental and social problems. Strategic actions 2 and 4, on the contrary, have a direct policy intervention character as they aim to modify, directly, through a set of actions at different levels, two central problems of the region and the country: the legacy of land ownership concentration and the dependence on commodities (Appendix D).

4.5.1 Linking actions to the implementation of the SDGs

After identifying the leverage points, we asked participants to reflect in groups about the potential impacts of these strategic actions on achieving the SDGs. They used the SDG Impact Assessment Tool (Wexsus, 2019), a free, online learning tool for the self-assessment of how an activity, organization, or innovation affects the SDGs. Table 2 illustrates the results of this self-assessment. They concluded that the proposed actions would positively impact (directly or indirectly) most of the SDGs. This positive assessment highlights the usefulness of the 3H-CLD approach in fostering the discussion about integrative pathways to all the SDGs – respecting the integrative and universal spirit of the 2030 Agenda.

It was clear to participants, however, that such integrative actions can only be implemented through the collective commitment and engagement of diverse actors across various levels. Participants discussed strategies to engage with existing networks

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Box 3. Integrative CLD2: land concentration and dependence on commodities (iCLD2)

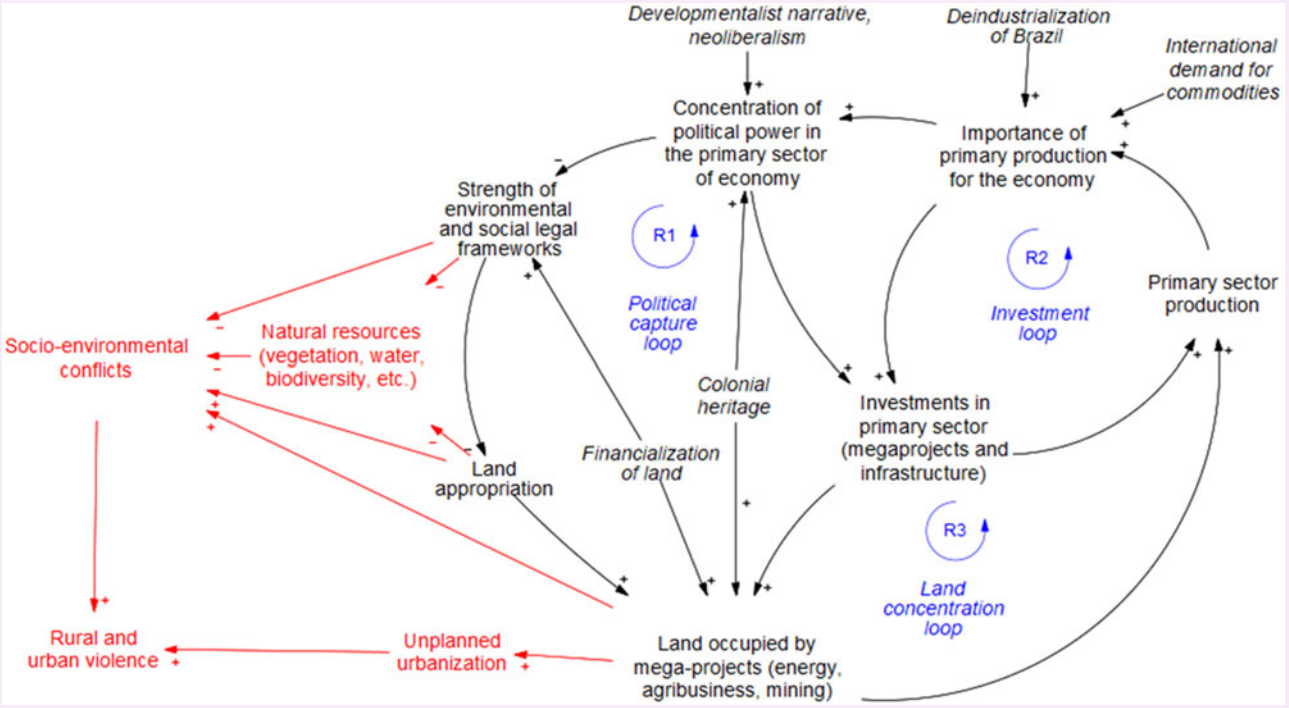

Figure Box 3. iCLD2b diagram: causal links between dependence of commodities and land concentration (black) to environmental degradation (in particular natural vegetation and water) and socioecological conflicts (red). The external factors that enhance this dynamic are highlighted in italics.

The diagram is made up of three aligned reinforcement loops, illustrating how these dynamics feedback on each other:

Investment loop (R2): The increasing importance of commodities for the Brazilian macroeconomy fosters public and private investments in infrastructure (e.g. faster transport to take the production to ports, energy for megaprojects, etc.) and technology to further increase the economic benefits. These investments in infrastructure and technology, reduce costs and promote investments in new projects, increasing the *production of commodities* (creating a positive reinforcement loop). Deindustrialization further increases the country's reliance on primary production.

Land concentration loop (R3): Encompassing R2, the greater the investments, the greater the production and territorial occupation of mega-enterprises focused on *primary production*. This means a greater share of *land occupied by large landowners/companies* since the dominant economic model is based on economies of scale, excluding small producers. This contributes to the increase in the already historically high land concentration in the country (Figure 2c).

Political capture loop (R1): Encompassing the R2 and R3 loops, the greater the strength and political power of large companies and producers in the primary sector, the tendency is for the strength of *environmental and social legal frameworks* to decrease. Together with the *financialization of land*, it has major impacts on *land appropriation* and land grabbing – increasing *land occupied by large enterprises* (R3), and a weakening of measures that protect small producers and traditional communities.

at multiple levels to present the plan. They also acknowledge that there are enormous challenges exactly due to the power structures represented in the iCLDs. Achieving sustainable and just futures in an area such as the Brazilian semiarid will not happen in the short term, but shedding light to such structural problems is critical to trigger the processes to move toward an inclusive sustainable development. We argue that these co-produced results are not a simple roadmap to implement the SDGs but an instrument of political negotiation. Indeed, the plan is being presented by the participants in several forums, from local to global (Appendix E).

A full description of the co-produced strategic actions and SDG impact assessment for the Brazilian semiarid XPaths case study can be found in the Brazilian case Strategic Action Plan report (Sonetti González et al., 2024). Similar processes were conducted for the Senegalese and Spanish cases (Goffner & Diallo, 2024; López-Rodríguez et al., 2024a, 2024b), with some methodological variations given their very diverse socioeconomic, political, and cultural backgrounds. Despite these differences, we found overarching similarities in visions and challenges across the three dryland countries – although in detail the challenges, systemic structures and proposed strategic actions are very context-dependent (XPaths-Project-Team, 2024).

5. Conclusion

Halfway to 2030, the prospects of achieving the SDGs are quite low (IGS, 2023; Malekpour et al., 2023; Nature, 2023). Several explanations for the lack of success in their implementation have been recently presented, including the adoption of siloed approaches that does not take into consideration the interactions and integration among the goals to define proper policies (Nature, 2023; Weitz et al., 2023). We argue that a deeper and contextualized understanding of the systemic structures underlying unsustainable trajectories is crucial. The 3H-CLD approach, an evolution of the 3H4SDG approach proposed by Collste et al. (2023), provides an integrated and localized approach to the discussion of transformative change to achieve sustainable and just futures. The approach focuses on integrative solutions to address the core systemic problems of each region rather than addressing the 'tip of the iceberg'. It fosters actors to reflect on the structures

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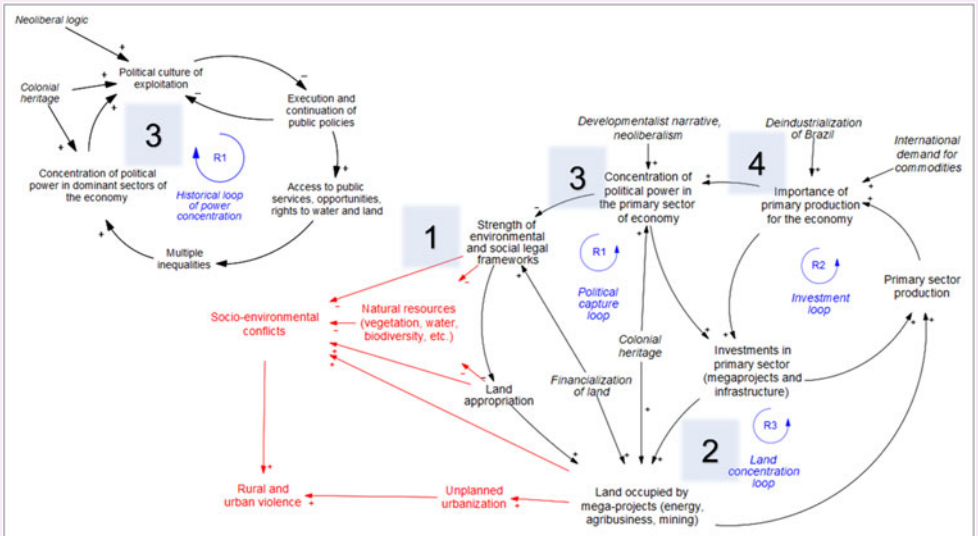
Table 3. Points of intervention in the iCLD (leverage points) and proposed solutions



	Points of intervention in the iCLD (leverage points)	STRATEGIC ACTION (prioritized interventions)
1	Impacts of large projects on the quality and quantity of water in the rivers of the SFRB (iCLD2b).	An **Environmental Education, Communication and Social Mobilization program** for the SFRB, involving all sectors.
	SDG impact: Positive Direct 1 2 4 6 8 12 15; Positive Indirect 3 5 7 9 10 11 13 14 16	
2	Land concentration, causing unequal access to land and consequently water (iCLD2).	An **agrarian reform** compatible with the traditional practices of the biomes and demarcation of territories of traditional peoples and communities.
	SDG impact: Positive Direct 1 2 3 4 6 7 8 9 10 11 12 13 15 16 17; Positive Indirect 5 14	
3	Concentration of political power/discontinuity of public policies (iCLD1).	A project for **political capacitation** to increase social awareness and political participation, leading to the formation of new leaderships and changes in the political system.
	SDG impact: Positive Direct 4 5 6 10 13 15 16; Positive Indirect 1 2 3 8 9 11 12 17	
4	Brazilian economy dependence on commodity deindustrialization, leading to several socio-environmental problems (iCLD2a/b).	A set of actions at national and international levels (Appendix D) to **foster new development models and re-industrialization** based on the local socio-environmental diversity allied to actions to impose limits and conditions to the commodities-related activities.
	SDG impact: Positive Direct 1 2 3 4 5 6 7 8 9 10 11 12 13 15 16 17; Positive Indirect 14	

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behind inequality (SDG 10) and poverty (SDG 1), or the lack of basic sanitation (SDG 6), for example. This means that instead of encouraging discussion about 'how to expand basic sanitation to the entire population?', our approach encourages discussion about: 'What are the causes of the lack of basic sanitation in cities like Petrolina? And considering these systemic causes, what should we do to change these structures?'. Common causes for several problems emerged in this process, culminating in the creation of the iCLDs. Achieving sustainable and just futures in an area such as the Brazilian semiarid will not happen in the short term, but changing such structural problems is critical to trigger the processes to move toward sustainable development.

Finally, the collaborative crafting of CLDs enhances our comprehension of the systemic underpinnings that perpetuate undesired developmental trajectories in a given area. The 3H-CLD approach is context-based, pluralistic, interactive, and goal-oriented, aligned to the four principles for knowledge co-production in sustainability research (Norström et al., 2020). Knowledge co-production combined with systems thinking can empower participants, strengthen ongoing collaborative efforts, and cultivate transformative capacities. We also argue that the approach also has the potential for global applicability, amid the multitude of sustainability challenges our planet faces.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/sus.2025.6.

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Author contributions. A. A., D. C., and S. C. conceived and designed the study, performed the analysis, and wrote the initial draft of the article. A. A., T. S. G., M. A., F. B., A. P., and V. O. conducted data gathering and organization. A. A., D. G., A. J., H. S., Z. H., and M. M. acquired funds and coordinated the project. All authors contributed to the development of the project methodology and reviewed the manuscript.

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Competing interests. None.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

Research transparency and reproducibility. The most relevant results of the participatory process in Brazil are directly available as Supplementary materials. The complete results are available at: https://doi.org/10.5281/zenodo.10154264, https://doi.org/10.5281/zenodo.10678916.

References

Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., von Wehrden, H., Abernethy, P., Ives, C. D., Jager, N. W., & Lang, D. J. (2017). Leverage points for sustainability transformation. *Ambio*, *46*(1), 30–39. https://doi.org/10.1007/s13280-016-0800-y

Aguiar, A. P. D., Collste, D., Harmáčková, Z. V., Pereira, L., Selomane, O., Galafassi, D., Van Vuuren, D., & Van Der Leeuw, S. (2020). Co-designing global target-seeking scenarios: A cross-scale participatory process for capturing multiple perspectives on pathways to sustainability. *Global Environmental Change*, *65*, 102198. https://doi.org/10.1016/j.gloenvcha.2020.102198

Aguiar, A. P. D., Perez-Marin, A. M., Silvino, A. S., von Randow, C., de Melo, D. M. A., Bezerra, F. G. S., Arcoverde, G. F. B., Barros, J. D., Alves, L., Miranda, M. A. C. N., Buzzatto, M., Martins, M. A., Pinheiro, R. C., & Sonetti-González, T. (2023). *Relatório dos Diálogos Multiescala 3H-CLD dos Projetos NEXUS e XPATHS*. Zenodo. https://doi.org/10.5281/zenodo.10154264

Alvalá, R. C. S., Cunha, A. P. M. A., Brito, S. S. B., Seluchi, M. E., Marengo, J. A., Moraes, O. L. L., & Carvalho, M. A. (2019). Drought monitoring in the Brazilian semiarid region. *Anais da Academia Brasileira de Ciências*, *91*(suppl 1), e20170209. https://doi.org/10.1590/0001-3765201720170209

ANA. (2023). *Water Usage by Municipality – National Water Agency* [Data set]. Retrieved from https://dadosabertos.ana.gov.br/datasets/cd6baae8f24846778c6ddd5503b0ebbd_18/explore

Arcoverde, G. F. B., Menezes, J. A., Paz, M. G. A., Barros, J. D., Guidolini, J. F., Branco, E. A., De Andrade, P. R., Pulice, S. M. P., & Ometto, J. P. H. B. (2023). Sustainability assessment of Cerrado and Caatinga biomes in Brazil: A proposal for collaborative index construction in the context of the 2030 Agenda and the water–energy–food nexus. *Frontiers in Physics*, *10*, 1060182. https://doi.org/10.3389/fphy.2022.1060182

Bauluz, L., Govind, Y., & Novokmet, F. (2020). *Global land inequality*. International Land Coalition.

Bennett, E. M., Solan, M., Biggs, R., McPhearson, T., Norström, A. V., Olsson, P., Pereira, L., Peterson, G. D., Raudsepp-Hearne, C., Biermann, F., Carpenter, S. R., Ellis, E. C., Hichert, T., Galaz, V., Lahsen, M., Milkoreit, M., Martin López, B., Nicholas, K. A., Preiser, R., … Xu, J. (2016). Bright spots: Seeds of a good Anthropocene. *Frontiers in Ecology and the Environment*, *14*(8), 441–448. https://doi.org/10.1002/fee.1309

Bennich, T., Weitz, N., & Carlsen, H. (2020). Deciphering the scientific literature on SDG interactions: A review and reading guide. *Science of the Total Environment*, *728*, 138405. https://doi.org/10.1016/j.scitotenv.2020.138405

Bezerra, B. G., Silva, L. L., Santos E Silva, C. M., & De Carvalho, G. G. (2019). Changes of precipitation extremes indices in São Francisco River Basin, Brazil from 1947 to 2012. *Theoretical and Applied Climatology*, *135*(1–2), 565–576. https://doi.org/10.1007/s00704-018-2396-6

Biggeri, M. (2021). Editorial: A 'decade for action' on SDG localisation. *Journal of Human Development and Capabilities*, *22*(4), 706–712. https://doi.org/10.1080/19452829.2021.1986809

Borgatti, S. (2005). Centrality and network flow. *Social Networks*, *27*(1), 55–71. https://doi.org/10.1016/j.socnet.2004.11.008

Cabrera, D., Colosi, L., & Lobdell, C. (2008). Systems thinking. *Evaluation and Program Planning*, *31*(3), 299–310. https://doi.org/10.1016/j.evalprogplan.2007.12.001

Caniglia, G., Luederitz, C., von Wirth, T., Fazey, I., Martín-López, B., Hondrila, K., König, A., von Wehrden, H., Schäpke, N. A., Laubichler, M. D., & Lang, D. J. (2021). A pluralistic and integrated approach to action-oriented knowledge for sustainability. *Nature Sustainability*, *4*(2), 93–100. https://doi.org/10.1038/s41893-020-00616-z

Cavalcanti, J. S. B. (1997). Frutas para o mercado global. *Estudos Avançados*, *11*(29), 79–93. https://doi.org/10.1590/S0103-40141997000100005

Collste, D. (2021). *The indivisible 2030 Agenda: Systems analysis for sustainability* [Doctorate Dissertation]. Stockholm University. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-192266

Collste, D., Aguiar, A. P. D., Harmáčková, Z. V., Galafassi, D., Pereira, L. M., Selomane, O., & Leeuw, S. V. D. (2023). Participatory pathways to the sustainable development goals: Inviting divergent perspectives through a cross-scale systems approach. *Environmental Research Communications*, *5*(5), 055014. https://doi.org/10.1088/2515-7620/acce25

CPT. (2022a). *Áreas em Conflito* [Data set]. Retrieved from https://www.cptnacional.org.br/downlods/category/4-areas-em-conflito

CPT. (2022b). *Conflitos, massacres e memórias: Das lutadoras e lutadores do Cerrado* (p. 160). Goiânia: Comissão Pastoral da Terra. Retrieved from Comissão Pastoral da Terra website: https://www.cptnacional.org.br/publicacao/summary/75-publicacoes-cerrado/14272-conflitosmassacresmemorias

Curry, A. (2015). Searching for systems: Understanding three horizons. *APF Compass*, *27*(1), 11–13.
Dorninger, C., Abson, D. J., Apetrei, C. I., Derwort, P., Ives, C. D., Klaniecki, K., … von Wehrden, H. (2020). Leverage points for sustainability transformation: A review on interventions in food and energy systems. *Ecological Economics*, *171*, 106570. https://doi.org/10.1016/j.ecolecon.2019.106570
ECIU. (2023). *Climate, fossil fuels and UK food prices*. Climate Intelligence Unit.
Elias, A. A. (2017). Systems thinking and modelling for stakeholder management. *IIM Kozhikode Society & Management Review*, *6*(2), 123–131. https://doi.org/10.1177/2277975216681105
Enfors-Kautsky, E., Järnberg, L., Quinlan, A., & Ryan, P. (2021). Wayfinder: A new generation of resilience practice. *Ecology and Society*, *26*(2), 39. https://doi.org/10.5751/ES-12176-260239
Falardeau, M., Raudsepp-Hearne, C., & Bennett, E. M. (2019). A novel approach for co-producing positive scenarios that explore agency: Case study from the Canadian Arctic. *Sustainability Science*, *14*(1), 205–220. https://doi.org/10.1007/s11625-018-0620-z
Faoro, R. (1958). *Os donos do poder: Formação do patronato político brasileiro*. Editora Globo.
Fazey, I., Schäpke, N., Caniglia, G., Hodgson, A., Kendrick, I., Lyon, C., Page, G., Patterson, J., Riedy, C., Strasser, T., Verveen, S., Adams, D., Goldstein, B., Klaes, M., Leicester, G., Linyard, A., McCurdy, A., Ryan, P., Sharpe, B., … Young, H. R. (2020). Transforming knowledge systems for life on Earth: Visions of future systems and how to get there. *Energy Research & Social Science*, *70*, 101724. https://doi.org/10.1016/j.erss.2020.101724
Ford, A. (2010). *Modeling the environment* (2nd ed.). Island Press.
Goffner, D., & Diallo, A. (2024). *Final reports of the national workshops held during the XPaths project in Senegal*. Zenodo. https://doi.org/10.5281/zenodo.10635866
Guedes-Pinto, L. F. G. (2020). *Os donos das terras agrícolas no Brasil*. Marina Jordão.
Harmáčková, Z. V., Blättler, L., Aguiar, A. P. D., Daněk, J., Krpec, P., & Vačkářová, D. (2022). Linking multiple values of nature with future impacts: Value-based participatory scenario development for sustainable landscape governance. *Sustainability Science*, *17*(3), 849–864. https://doi.org/10.1007/s11625-021-00953-8
IBGE. (2022). *Censo Demográfico 2022* [Data set]. Retrieved from https://censo2022.ibge.gov.br/
IBGE. (2023). *Agricultural Census* [Data set]. Retrieved from https://www.ibge.gov.br/en/statistics/economic/agriculture-forestry-and-fishing/21929-2017-2017-censo-agropecuario-en.html
IGS. (2023). *Global sustainable development report 2023: Times of crisis, times of change: Science for accelerating transformations to sustainable development – Independent group of scientists appointed by the secretary-general GSDR*. United Nations.
IPEA. (2023). *IPEADATA* [Data set]. Instituto de Pesquisa Econômica Aplicada. Retrieved from http://www.ipeadata.gov.br
Irineu De França, D. P. (2020). A financeirização da natureza e a precarização do trabalho em Petrolina – PE – Vale do Rio São Francisco. *PEGADA – A Revista da Geografia do Trabalho*, *21*(2), 66–84. https://doi.org/10.33026/peg.v21i2.7333
Jiménez-Aceituno, A., Peterson, G. D., Norström, A. V., Wong, G. Y., & Downing, A. S. (2020). Local lens for SDG implementation: Lessons from bottom-up approaches in Africa. *Sustainability Science*, *15*(3), 729–743. https://doi.org/10.1007/s11625-019-00746-0
López-Rodríguez, M. D., Jiménez-Aceituno, A., & Castro Martínez, A. J. (2024a). *Co-creando estrategias de futuro para avanzar en los Objetivos de Desarrollo Sostenible en el semiárido español*. Zenodo. https://doi.org/10.5281/zenodo.10784384
López-Rodríguez, M. D., Jiménez-Aceituno, A., Quintas-Soriano, C., Miguel Requena-Mullor, J., Garau, E., Alba-Patiño, D., Otamendi-Urroz, I., Aguiar, A. P. D., Cortés-Calderón, S., & Castro, A. J. (2024b). Applying the Three Horizons approach in local and regional scenarios to support policy coherence in SDG implementation: Insights from arid Spain. *Global Environmental Change*, *89*, 102922. https://doi.org/10.1016/j.gloenvcha.2024.102922
Maani, K. E., & Cavana, R. Y. (2010). *Systems thinking, system dynamics: Managing change and complexity* (2nd ed., repr). Pearson Prentice Hall.
Malekpour, S., Allen, C., Sagar, A., Scholz, I., Persson, Å., Miranda, J. J., Bennich, T., Dube, O. P., Kanie, N., Madise, N., Shackell, N., Montoya, J. C., Pan, J., Hathie, I., Bobylev, S. N., Agard, J., & Al-Ghanim, K. (2023). What scientists need to do to accelerate progress on the SDGs. *Nature*, *621*(7978), 250–254. https://doi.org/10.1038/d41586-023-02808-x
MAPA. (2023). *Istema de Agrotóxico e Fitossanitário (Agrofit)* [Data set]. Retrieved from https://indicadores.agricultura.gov.br/agrofit/index.htm
Martinelli, L. A., Batistella, M., Silva, R. F. B. D., & Moran, E. (2017). Soy expansion and socioeconomic development in municipalities of Brazil. *Land*, *6*(3), 62. https://doi.org/10.3390/land6030062
Martins, M. A., Collste, D., Bezerra, F. G. S., Miranda, M. A. C. N., Gonçalves, A. R., Barros, J. D., Cardoso, M. F., Silvino, A. S., Sonetti-González, T., Ometto, J. P. H. B., von Randow, C., Tomasella, J., & de Aguiar, A. P. D. (2024). Long-term sustainability of the water–agriculture–energy nexus in Brazil's MATOPIBA region: A case study using system dynamics. *Ambio*, *53*(12), 1722–1736. https://doi.org/10.1007/s13280-024-02058-9
MDR. (2025). *Projeto de Integração do Rio São Francisco – Ministry of Integration and Regional Development* [Data set]. Retrieved from https://www.gov.br/mdr/pt-br/assuntos/seguranca-hidrica/projeto-sao-francisco
Meadows, D. (2008). *Thinking in systems: A primer*. Chelsea Green Publishing.
Moallemi, E. A., Malekpour, S., Hadjikakou, M., Raven, R., Szetey, K., Ningrum, D., Dhiaulhaq, A., & Bryan, B. A. (2020). Achieving the sustainable development goals requires transdisciplinary innovation at the local scale. *One Earth*, *3*(3), 300–313. https://doi.org/10.1016/j.oneear.2020.08.006
Nature (2023). The world's goals to save humanity are hugely ambitious – But they are still the best option. *Nature*, *621*(7978), 227–229. https://doi.org/10.1038/d41586-023-02844-7
Neri, M., Jameli, D., Bernard, E., & Melo, F. P. L. (2019). Green versus green? Adverting potential conflicts between wind power generation and biodiversity conservation in Brazil. *Perspectives in Ecology and Conservation*, *17*(3), 131–135. https://doi.org/10.1016/j.pecon.2019.08.004
Nguyen, N. C., & Bosch, O. J. H. (2013). A systems thinking approach to identify leverage points for sustainability: A case study in the Cat Ba Biosphere Reserve, Vietnam. *Systems Research and Behavioral Science*, *30*(2), 104–115. https://doi.org/10.1002/sres.2145
Nilsson, M., Chisholm, E., Griggs, D., Howden-Chapman, P., McCollum, D., Messerli, P., Neumann, B., Stevance, A.-S., Visbeck, M., & Stafford-Smith, M. (2018). Mapping interactions between the sustainable development goals: Lessons learned and ways forward. *Sustainability Science*, *13*(6), 1489–1503. https://doi.org/10.1007/s11625-018-0604-z
Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., Bednarek, A. T., Bennett, E. M., Biggs, R., de Bremond, A., Campbell, B. M., Canadell, J. G., Carpenter, S. R., Folke, C., Fulton, E. A., Gaffney, O., Gelcich, S., Jouffray, J.-B., Leach, M., … Österblom, H. (2020). Principles for knowledge co-production in sustainability research. *Nature Sustainability*, *3*(3), 182–190. https://doi.org/10.1038/s41893-019-0448-2
Oliveira, T., & Gabriel, J. (2023, June 7). Bancada ruralista cresce no Senado e tenta aprovar PL dos agrotóxicos e marco temporal. *Folha de São Paulo*. Retrieved from https://www..folha.uol.com.br/ambiente/2023/06/bancada-ruralista-cresce-no-senado-e-tenta-aprovar-pl-dos-agrotoxicos-e-marco-temporal.shtml
Olofsson, V. (2023). Energy justice and territory: Present and futures of wind energy in Brazil. *International Journal of Engineering, Social Justice, and Peace*, *10*(1), 27–49. https://doi.org/10.24908/ijesjp.v10i1.16050
Peixoto, F. D. S., Soares, J. A., & Ribeiro, V. S. (2022). Conflicts over water in Brazil. *Sociedade & Natureza*, *34*, e59410. https://doi.org/10.14393/SN-v34-2022-59410
Pereira, L., Hichert, T., Hamann, M., Preiser, R., & Biggs, R. (2018). Using futures methods to create transformative spaces: Visions of a good Anthropocene in Southern Africa. *Ecology and Society*, *23*(1), 19. https://doi.org/10.5751/ES-09907-230119
Pérez-Marin, A. M., Rogé, P., Altieri, M. A., Forer, L. F. U., Silveira, L., Oliveira, V. M., & Domingues-Leiva, B. E. (2017). Agroecological and social transformations for coexistence with semi-aridity in Brazil. *Sustainability*, *9*(6), 990. https://doi.org/10.3390/su9060990
Pousa, R., Costa, M. H., Pimenta, F. M., Fontes, V. C., Brito, V. F. A. D., & Castro, M. (2019). Climate change and intense irrigation growth in western

https://doi.org/10.1017/sus.2025.6 Published online by Cambridge University Press

Bahia, Brazil: The urgent need for hydroclimatic monitoring. *Water*, *11*(5), 933. https://doi.org/10.3390/w11050933

Prado Júnior, C., Novais, F. A., & Ricupero, B. (2011). *Formação do Brasil contemporâneo: Colônia* (New ed.). Companhia das Letras.

Ramage, M., & Shipp, K. (2020). *Systems thinkers*. Springer London. https://doi.org/10.1007/978-1-4471-7475-2

Reynolds, M., & Holwell, S. (Eds.). (2020). *Systems approaches to managing change: A practical guide* (2nd ed.). Springer.

Ribeiro, D. (1995). *O povo brasileiro: A formação e o sentido do Brasil*. Global Editora.

Russo Lopes, G., Bastos Lima, M. G., & Reis, T. N. P. D. (2021). Maldevelopment revisited: Inclusiveness and social impacts of soy expansion over Brazil's Cerrado in MATOPIBA. *World Development*, *139*, 105316. https://doi.org/10.1016/j.worlddev.2020.105316

Sales, R. M. M., & Sales, L. G. D. L. (2023). *Energia Renovável Centralizada e Minerais de Transição Energética – Paradoxos entre os negócios de energia e os direitos humanos de povos e comunidades tradicionais do Brasil*. Zenodo. https://doi.org/10.5281/ZENODO.7970721

Santos, J. G., & Ioris, A. A. R. (2024). Water conflicts and socioterritorial dynamics: The hydrosocial cycle after the São Francisco River transposition project in the northeast of Brazil. *Land*, *13*(12), 2032. https://doi.org/10.3390/land13122032

Schiffer, E., & Peakes, J. (2009). An innovative approach to building stronger coalitions: The Net-Map toolbox. *Development in Practice*, *19*(1), 103–105. https://doi.org/10.1080/09614520802576500

Senge, P. M. (1990). *The fifth discipline: The art and practice of the learning organization* (Currency paperback ed). Currency Doubleday.

Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., & Fazey, I. (2016). Three Horizons: A pathways practice for transformation. *Ecology and Society*, *21*(2), 47. https://doi.org/10.5751/ES-08388-210247

Silvino, A. S. (2019). *A conservação da caatinga entre arenas políticas do semiárido brasileiro* (Universidade Estadual de Campinas). Universidade Estadual de Campinas. Retrieved from https://repositorio.unicamp.br/acervo/detalhe/1092720

Sonetti González, T., Aguiar, A. P., Silva Bezerra, F. G., Alves Martins, M., Perez-Marin, A. M., Silva, A., Lima Peres, B., Cruz Cardoso, D., C. Henn Souza de Oliveira, F., de Aquino, F. I., de Souza Corte, I., Santos, J. C., Gnadlinger, J., da Silva Neto, J. P., Ferreira da Silva, L., Ayres da Motta Benevides Gadelha, M., Sales, R. M. M., da Silva Andrade, S. M., Rodrigues de Moraes, S., & Martins de Oliveira, V. (2024). *Plano de Ações Estratégicas no Semiárido Brasileiro – Com foco na Bacia do Rio São Francisco e Área de Transposição: Ações estratégicas no Semiárido Brasileiro – Com foco na Bacia do Rio São Francisco e Área de Transposição resultantes do Processo Participativo Multiescala 3H-ODS*. Zenodo. https://doi.org/10.5281/ZENODO.10678916

TWI2050. (2018). *Transformations to achieve the sustainable development goals. Report prepared by e world in 2050 initiative*. International Institute for Applied Systems Analysis (IIASA). Retrieved from International Institute for Applied Systems Analysis (IIASA) website: 10.22022/TNT/07-2018.15347.

UCLG (2017). *National and sub-national governments on the way towards the localization of the SDGs*. United Cities and Local Governments.

UN (2015). *Transforming our world: The 2030 agenda for sustainable development*. United Nations.

UNCCD (2017). *Global land outlook* (1st ed.). UNCCD.

Van den Belt, M. (2004). *Mediated modeling: A system dynamics approach to environmental consensus building*. Island Press.

van Soest, H. L., van Vuuren, D. P., Hilaire, J., Minx, J. C., Harmsen, M. J. H. M., Krey, V., Popp, A., Riahi, K., & Luderer, G. (2019). Analysing interactions among sustainable development goals with integrated assessment models. *Global Transitions*, *1*, 210–225. https://doi.org/10.1016/j.glt.2019.10.004

Vennix, J. A. M. (1996). *Group model building: Facilitating team learning using system dynamics*. J. Wiley.

Videira, N., Antunes, P., & Santos, R. (2017). Participatory modelling in ecological economics: Lessons from practice. In C. L. Spash (Ed.), *Routledge handbook of ecological economics: Nature and society* (pp. 362–371). Routledge.

von Randow, C., Aguiar, A. P. D., Bezerra, F. G. S., Martins, M. A., Miranda, M., Silvino, A. S., Sonetti-González, T., Alves, L. M., Neto, P. R. A., Arcoverde, G. F. B., Barros, J. D., Branco, E. A., Campos, E. F., Cardoso, M. F., Castro, A. A., Costa, R., Gonçalves, A. R., Perez-Marin, A. M., Pacheco, F., … Ometto, J. P. H. B. (2024). *Caminhos para a sustentabilidade no Cerrado e Caatinga brasileiros – Relatório técnico do projeto Nexus*. Retrieved from https://nexus.ccst.inpe.br/wp-content/uploads/2024/10/Nexus-Relatorio-Tecnico.pdf

Walker, B. H., & Salt, D. (2012). *Resilience practice: Building capacity to absorb disturbance and maintain function*. Island Press.

Weitz, N., Carlsen, H., Bennich, T., Nilsson, M., & Persson, Å (2023). Returning to core principles to advance the 2030 Agenda. *Nature Sustainability*, *6*(10), 1145–1148. https://doi.org/10.1038/s41893-023-01212-7

Wexsus. (2019). *SDG Impact Assessment Tool*. West Sweden Nexus for Sustainable Development. Retrieved from https://sdgimpactassessmenttool.org/en-gb

Wilkinson, J., Reydon, B., & Di Sabbato, A. (2012). Concentration and foreign ownership of land in Brazil in the context of global land grabbing. *Canadian Journal of Development Studies/Revue Canadienne d'études du Développement*, *33*(4), 417–438. https://doi.org/10.1080/02255189.2012.746651

WITS/World Bank. (2023). *World Integrated Trade Solution (WITS)* [Data set]. Retrieved from https://wits.worldbank.org/

Woodhouse, P. (2012). Reforming land and water rights in South Africa. *Development and Change*, *43*(4), 847–868. https://doi.org/10.1111/j.1467-7660.2012.01784.x

XPaths-Project-Team. (2024). *The XPaths Project – Challenges and solutions to implement the SDGs in the drylands*. Zenodo. https://doi.org/10.5281/zenodo.10807744

https://doi.org/10.1017/sus.2025.6 Published online by Cambridge University Press