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Unravelling deep roots in drylands: A systems thinking participatory approach to the SDGs

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Non-technical summary

Achieving sustainability on the ground poses a challenge in decoding global defined goals, such as the Sustainable Development Goals (SDGs), 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 the 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 the UN 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 the results from six multi-stakeholder dialogues held across drylands in Brazil with a focus on desired futures aligned with the 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 reaching the SDGs in an integrated manner. The unique approach developed in this project 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 the SDGs. Understanding root causes of unsustainability is critical to move towards sustainable and just futures.

Keywords: 2030 Agenda, Transformative capacities, Systems thinking, Three Horizons, Brazilian semi-arid, multiscale participatory approach.

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, Peterson, Norström, Wong, & Downing, 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 towards *all* the SDGs through the transformation of social-ecological systems (Collste, 2021; IGS, 2023; TWI2050, 2018; Weitz, Carlsen, Bennich, Nilsson, & Persson, 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: Crossing Pathways to the SDGs in 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, Järnberg, Quinlan, & Ryan, 2021) to reach 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, Jameli, Bernard, & Melo, 2019; Peixoto, Soares, & Ribeiro, 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 multi-sectoral policies (Bennich, Weitz, & Carlsen, 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 behaviour and the leverage points, namely, the points to intervene in a system to effectively change its development towards a more desirable trajectory or future

(Meadows, 2008; Abson et al., 2017; Dorninger et al., 2020) Furthermore, we argue that the adoption of multi-scale 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 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 (Ana Paula D. 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; 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 multi-scale participatory dialogues in the context of the SDGs (Sharpe, Hodgson, Leicester, Lyon, & Fazey, 2016; Collste et al., 2023).

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 (Walker & Salt, 2012; Reynolds & Holwell, 2020; Ramage & Shipp, 2020).

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, Antunes, & Santos, 2017) by providing a common language and creating a space for incorporating diverse perspectives (Maani & Cavana, 2010; Elias, 2017).

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 (Senge, 1990; Maani & Cavana, 2010). It recognises four interconnected levels of thinking that provide insights into various aspects of a system: (1) events or symptoms, (2) behaviour 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 towards 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.

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

(Figure Box 1 here)

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); (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, while a '-' is used when the variables move in 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 behaviour 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 towards stability and buffer changes. In the example (Figure Box 1.a), if population grows, the number of births grows, increasing the population, in a reinforcing loop; on the other hand, 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).

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 1.c). 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 (Pereira, Hichert, Hamann, Preiser, & Biggs, 2018; Fazey et al., 2020; Falardeau, Raudsepp-Hearne, & Bennett, 2019; Ana Paula D. Aguiar et al., 2020; Harmáčková et al., 2022; Collste et al., 2023). 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 ten people) discuss sustainable futures for a given geographic area. The development of the approach was guided by the "indivisible nature" of the 2030 agenda, i.e., to enable the discussion of integrated pathways towards all the SDGs through the transformation of a social-ecological system. Therefore, 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 is structured as follows. In STEP 1 ("The desired future", focusing on the 3rd 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 existing "seeds" (Bennett et al., 2016) or initiatives in the present that capture some of the features of the desired future. Under the proper conditions, growing such seeds can guide the transformation. STEP 2 centres around the 1st 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 2nd Horizon, exploring "How to reach the desired future from the present," and identifying which actions are needed to overcome present problems and their root causes and nurture the seeds for transformative change.

Throughout the three steps, the results are captured in coloured 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 analysed, including their convergences and divergences (see Appendix A). Divergences, i.e., 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 analysing 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 (Causal Loop Diagrams), a Systems Thinking tool (Section 2.1), as central pieces in STEP 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 problems of the present, 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 1.b). They can include topics previously listed as problems or new ones. When possible, casual circular relationships which are also known as feedback loops are looked for. The exercise usually takes forty to fifty minutes in groups of ten to twelve 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 present 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 the CLDs to identify systemic structures and leverage points.

(Figure 1 here)

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 at present; (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); (g) Divergences noted during the workshop. A typical in person 3H-CLD workshop, with 20-25 participants, usually takes one day and a half, with a number of groups working in parallel (figure prepared by the authors).

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:

- *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 behaviour 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 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 towards 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 behavioural patterns, e.g., 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. While 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 other hand, 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, Colosi, & Lobdell, 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 in 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 km². It includes the entire Caatinga biome and portions of the Cerrado biome (Figure 2). 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, Silva, Santos E Silva, & De Carvalho, 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, 2022b, 2022a; Peixoto et al., 2022), spatially concentrated around large-scale irrigation projects (Figure 2.b).

The semiarid is also an area of socio-economic contrasts - which largely reproduces the multiple inequalities that characterize Brazilian society, including access to land (Guedes-Pinto, 2020) (Figure 2.c). 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 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.

(Figure 2 here)

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).

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 2.a). 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 twenty-six neighbouring municipalities, located in the driest region of the Brazilian semiarid and at the transposition area (Santos & Ioris, 2024; MDR, 2025); Petrolina/Juazeiro and another thirteen neighbour 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 nineteen neighbour 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, Bastos Lima, & Reis, 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 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).

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

(Table 1 here)

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 coloured 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).

Table 2 – 3H-CLD Dialogues: Number of participants by sector.

(Table 2 here)

The local workshops presented challenges arising from the context of conflict in the region (CPT, 2022b, 2022a). 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.

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 3.a 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 3.b presents a synthesis of the categories that emerged from the thematic clustering of the CLD variables. Appendix 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).

(Figure 3 here)

Figure 3 – Thematic clustering: (a) STEP 2 (Present Concerns): total number of post-its in each category considering all workshops (first ten categories). (b) STEP 2 (CLDs): total number of times a category was included in the CLDs (first ten categories). Please see Appendix B for complete results.

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 3.b. 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 (Figure 3.a and 3.b, 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 in the present 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 4.a 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 4.b, we observe that manufacturing has steadily lost relative importance in the Brazilian GDP since the 1990s. It is 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 4.c 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 4.d 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 4.e illustrates the temporal pattern of the land distribution Gini index – an indicator of inequality in the countryside. The closer this measure is to the number 1, the greater the concentration in the land structure. Brazil presents a high degree of concentration – one of the highest in the world (Bauluz, Govind, & Novokmet, 2020) – which remained stable between 1975 and 2006, and increased in the 2017 survey (IBGE, 2023; Wilkinson, Reydon, & Di Sabbato, 2012). Also related to inequal access to resources, Figure 4.f illustrates a notable increase in water usage in the São Francisco Basin, particularly in irrigation, while the amount for human use remains consistent (Figure 4.f). Moreover, the number of families affected by land and water conflicts has sharply increased, particularly since the 2010s (refer to Figures 4.f). This relates to the maps in Figure 1.b and 1.c which display how water usage and conflicts concentrate in areas of large-scale irrigation projects for commodities production.

(Figure 4 here)

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).

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:

- **iCLD 1 (Box 2)** illustrates in a simplified and schematic way how the *lack of execution and continuity of public policies* hinders the longstanding issue of access to basic services (education, health, sanitation, etc.) and social and power inequality in the country from being addressed.
- **iCLD 2 (Box 3)** links the root causes of environmental degradation (in of particular natural vegetation and water) and socio-ecological 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 Sustainable Development Goals (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, etc. 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).

Socio-environmental 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, etc. 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.

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

(Figure Box 2 here)

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, 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, Novais, & Ricupero, 2011; Ribeiro, Darcy, 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.

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Box 3 – Integrative CLD 2: Land concentration and dependence on commodities (iCLD2)

(Figure Box 3 here)

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 socio-ecological 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 2.c).

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.

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-Guara 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 other hand, 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 (Ana Paula D. Aguiar et al., 2020; von Randow, Aguiar, & 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 favour 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 deny the negative impacts of the dynamics expressed in iCLD2, i.e., the occurrence of socio-environmental 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 other hand, 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, Batistella, Silva, & Moran, 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 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).

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

(Table 3 here)

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 other hand, 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).

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 (Wexus, 2019), a free, online learning tool for the self-assessment of how an activity, organisation, 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 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 towards 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, Jiménez-Aceituno, & Castro Martínez, 2024; López-Rodríguez, Jiménez-Aceituno, Quintas-Soriano, et al., 2024), 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 reach 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 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 towards 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, amidst the multitude of sustainability challenges our planet faces.

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Author Contributions

AA, DC, SC conceived and designed the study, performed the analysis and wrote the initial draft of the article. AA, TSG, MA, FB, AP, VO conducted data gathering and organization. AA, DG, AJ, HS, ZH, MM applied for funds and coordinated the project. All authors contributed to the development of the project methodology and reviewed the manuscript.

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Conflicts of Interest

All authors declare 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.

Transparency and Reproducibility

The most relevant results of the participatory process in Brazil are directly available as Supplementary Material. The complete results are available at:

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Supplementary Material

Appendix A - Workshop Results

Appendix B - Thematic Clusters

Appendix C - Original CLDs

Appendix D – Strategic Action 4 – national and international level actions

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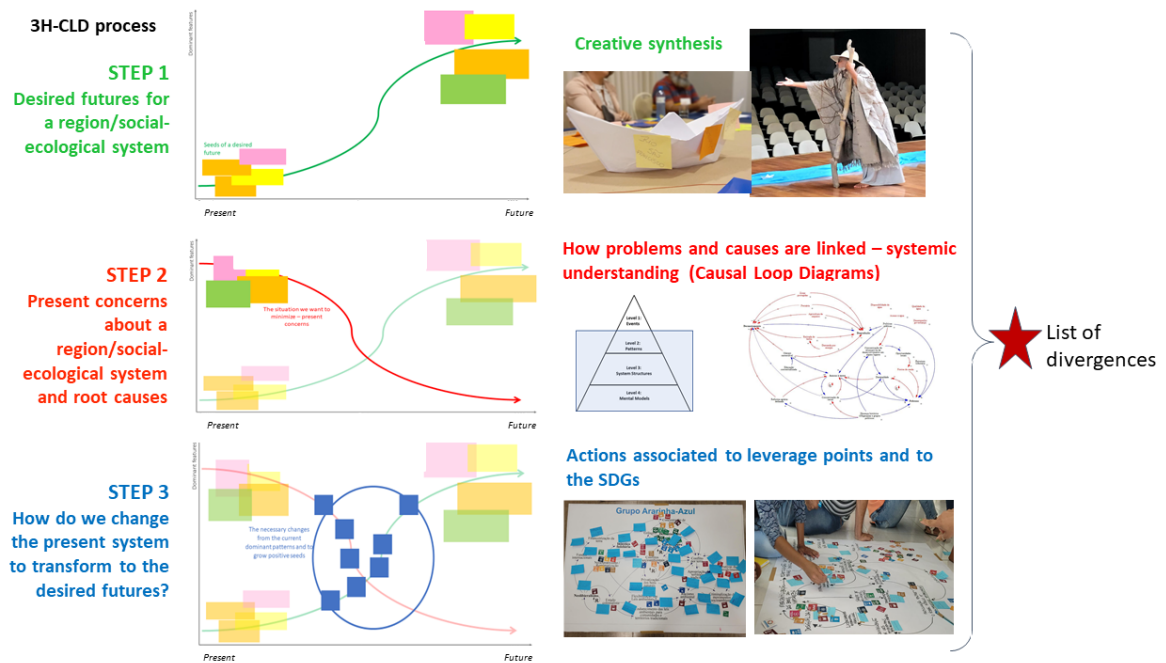


Figure 1: 3H-CLD outcomes in each step (for each group): (a) Desired Futures (post-it notes counted and grouped on similar themes); (b) Creative processes illustrating/illuminating and synthesizing desired futures; (c) “Good seeds” (initiatives) of the future already existing at present; (d) Problems 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); (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 (figure prepared by the authors).

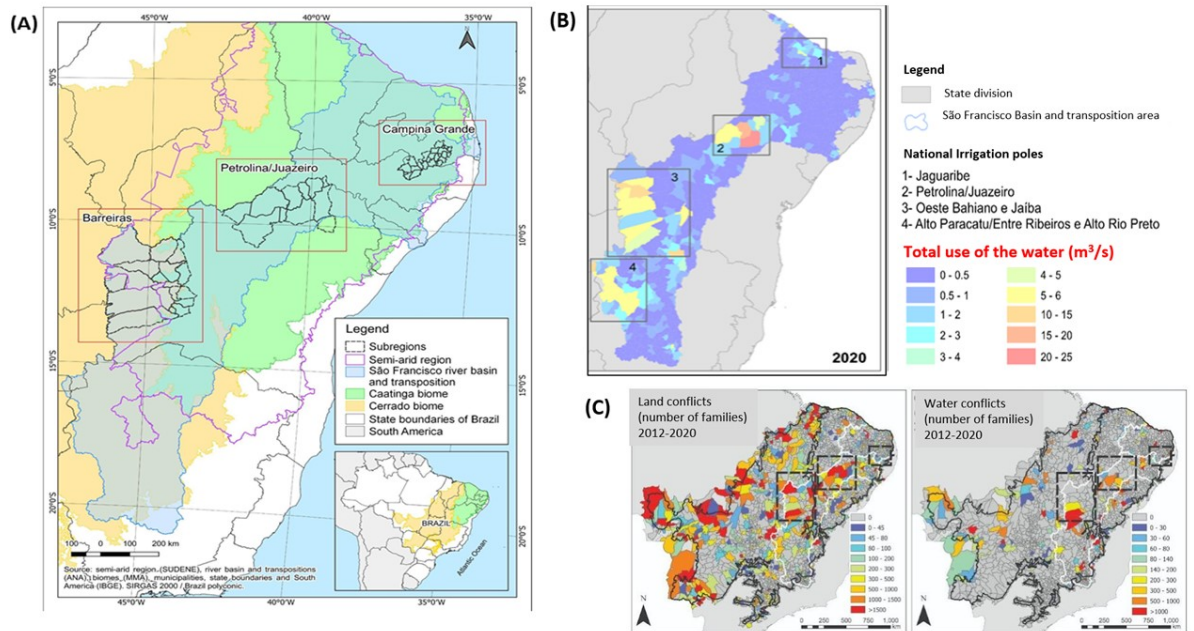


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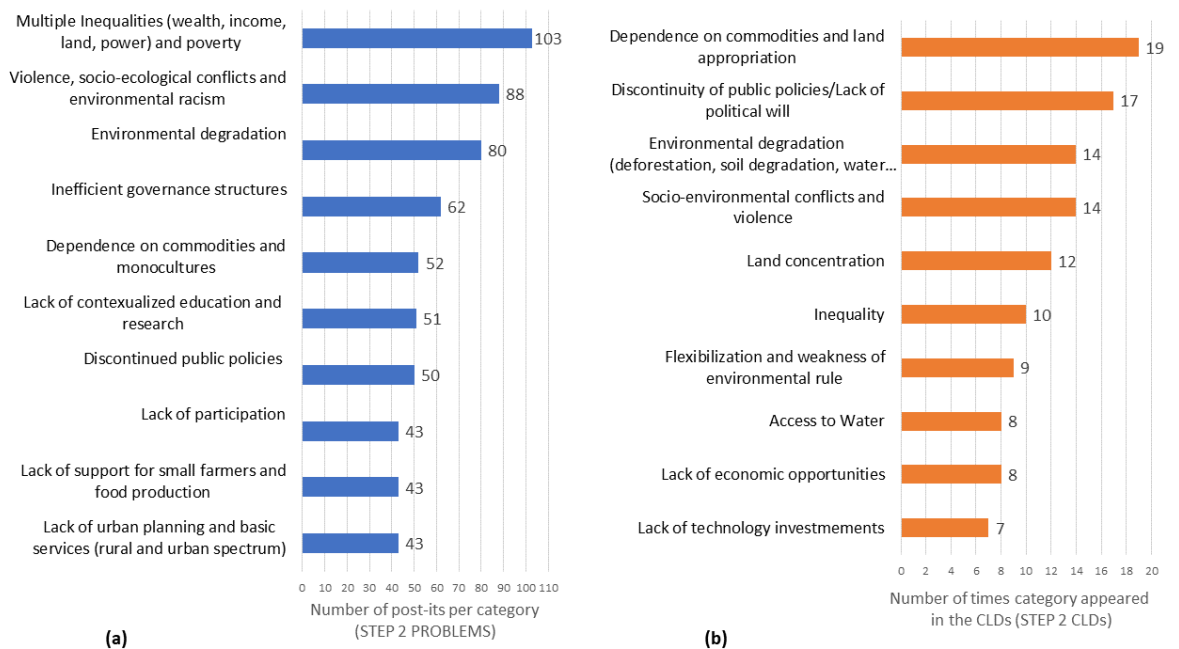
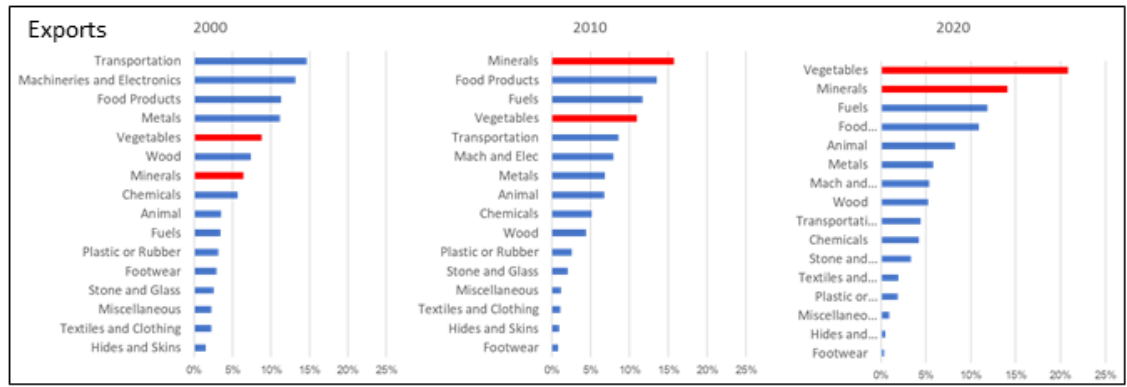
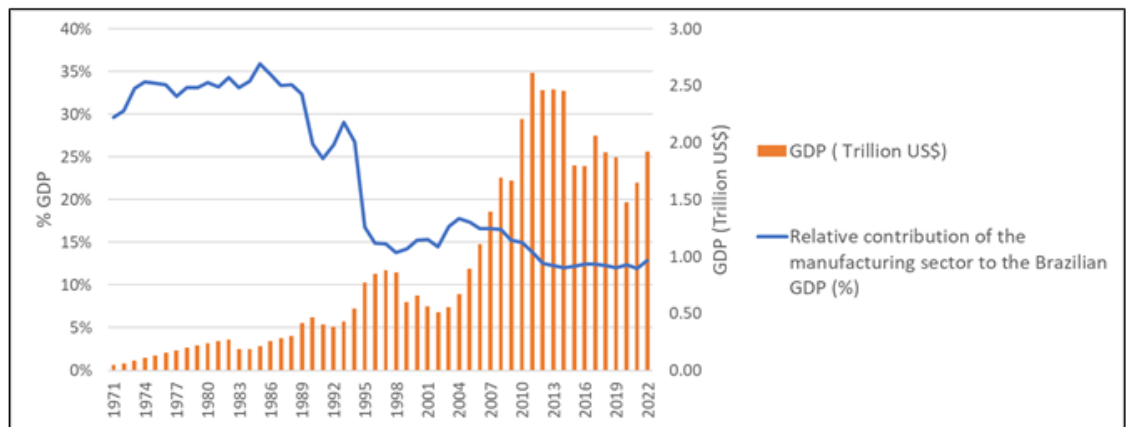


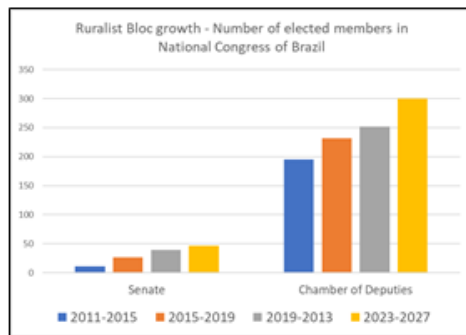
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(a)



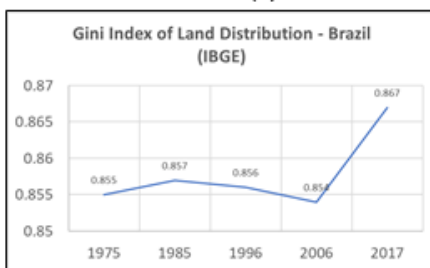
(b)



(c)



(d)



(e)



(f)

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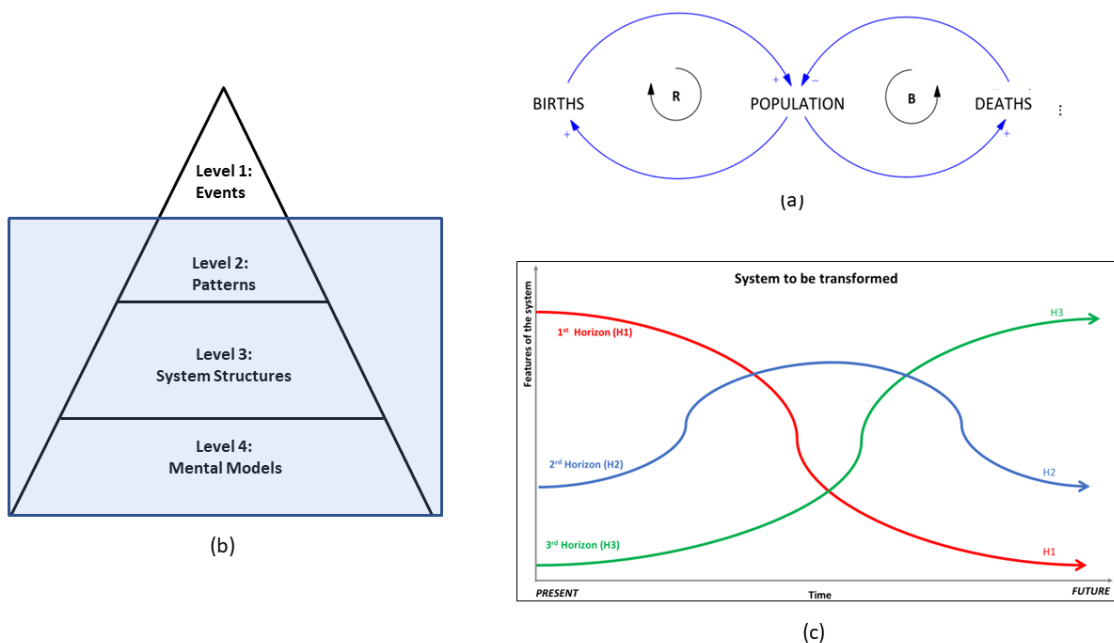


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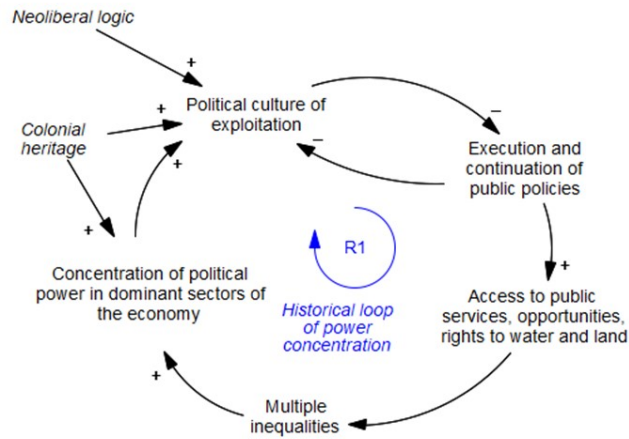


Figure Box 2 - iCLD1 diagram: the systemic structures cause the lack of execution and continuity of public plans and policies, leading to the lack of public services and maintenance of multiple inequalities. The external factors that enhance this dynamic are highlighted in italics.

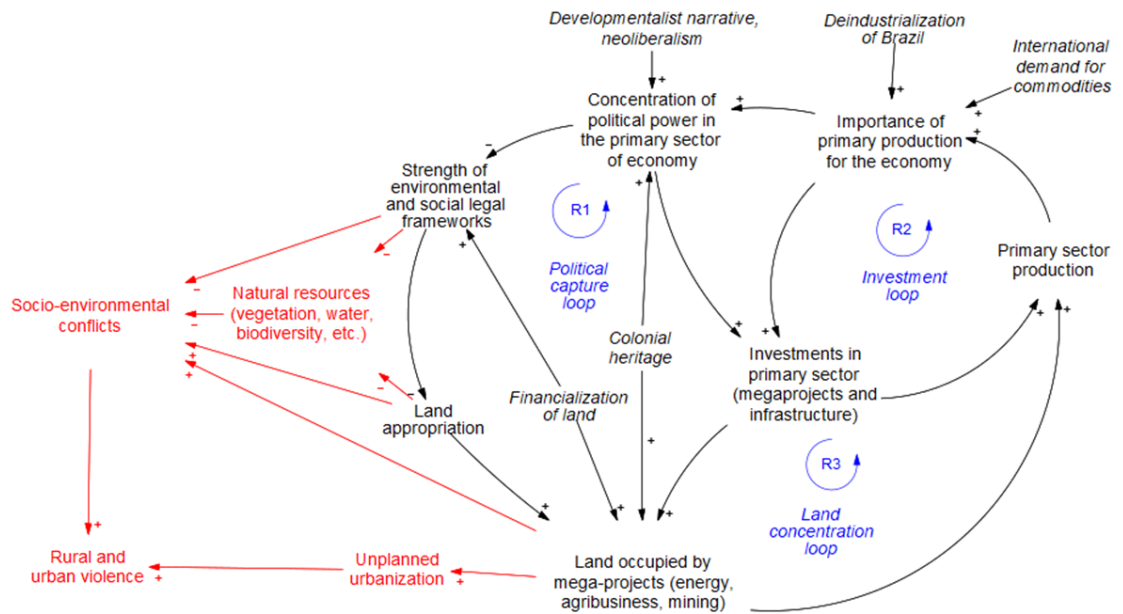


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Table 1 - 3H-CLD dialogue process in Brazil: Date, scale and scope of the workshops

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 neighbour municipalities	25
June 28-29, 2022	Phase 1 (in-person)	Local	Barriers and neighbour municipalities	22
August, 17-18, 2022	Phase 1 (in-person)	Local	Petrolina/Juazeiro and neighbour 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

Table 2 – 3H-CLD Dialogues: Number of participants by sector.

	Regional: <i>Caatinga biome, Cerrado biome, SFRB and transposition area</i>	Local: <i>Campina Grande and neighbour municipalities</i>	Local: <i>Barriers and neighbour municipalities</i>	Local: <i>Petrolina/Juazeiro and neighbour municipalities</i>
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

	to several socio-environmental problems (iCLD2a/b).	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 <input checked="" type="checkbox"/> 1 <input checked="" type="checkbox"/> 2 <input checked="" type="checkbox"/> 3 <input checked="" type="checkbox"/> 4 <input checked="" type="checkbox"/> 5 <input checked="" type="checkbox"/> 6 <input checked="" type="checkbox"/> 7 <input checked="" type="checkbox"/> 8 <input checked="" type="checkbox"/> 9 <input checked="" type="checkbox"/> 10 <input checked="" type="checkbox"/> 11 <input checked="" type="checkbox"/> 12 <input checked="" type="checkbox"/> 13 <input type="checkbox"/> 14 <input checked="" type="checkbox"/> 15 <input checked="" type="checkbox"/> 16 <input checked="" type="checkbox"/> 17 Positive Indirect <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6 <input type="checkbox"/> 7 <input type="checkbox"/> 8 <input type="checkbox"/> 9 <input type="checkbox"/> 10 <input type="checkbox"/> 11 <input type="checkbox"/> 12 <input type="checkbox"/> 13 <input checked="" type="checkbox"/> 14 <input type="checkbox"/> 15 <input type="checkbox"/> 16 <input type="checkbox"/> 17		

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