GOVERNING CLIMATE RESILIENCE IN POWER DISTRIBUTION: A HYBRID METHODOLOGY USING AI AND THEORY OF MIND TO STRUCTURE COMPLEX PROBLEMS

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Abstract. *Increasing the resilience of electricity distribution networks in the face of extreme climate events is a complex issue, with technical, regulatory and social dimensions. To deal with this challenge, this article applies an innovative hybrid methodology, using the synergy between Artificial Intelligence (AI) and human cognitive processes in the structuring and evaluation of this complex problem. The analysis indicates that the main barriers to resilience stem from tensions and paradoxes arising from the interaction between different perspectives — all of which are legitimate, yet partial. We argue that innovation in the cognitive and methodological tools we use to understand reality is essential to face the challenges of climate change in an increasingly complex and uncertain world.*

Keywords: *Energy policy; Climate resilience; Complex systems; Extreme weather events; Systems thinking; Power systems governance; Problem structuring methods.*

Thematic Area: *Complex Systems, Systems Thinking, and Systems Theories*

1. Introduction

The intensification of global climate change has contributed to an increase in both the frequency and severity of extreme weather events, such as prolonged droughts, floods, storms, and heatwaves (IPCC, 2023). These events are characterized by the occurrence of climate or meteorological variables reaching values in the rare extremes — or "tails" — of their historical distributions, whether upper or lower (IPCC, 2012).

In the literature, climate events with highly disruptive potential are often classified as High Impact, Low Frequency (HILF) events. Although rare, such events have significant potential to cause severe damage to critical infrastructure and supply chains. Their unpredictability and low frequency pose challenges for incorporation into traditional sectoral planning and regulatory models.

With intensifying climate change, however, attention to such events has grown, demanding more robust approaches to electricity system planning and resilience (National Research Council, 2012; Panteli and Mancarella, 2015). This need has been further reinforced by recent studies aimed at consolidating key concepts and proposing new resilience frameworks (Kaloti and Chowdhury, 2023; Mishra *et al.*, 2024), developing methodologies for modeling extreme events (Wilson *et al.*, 2022), and advancing risk analysis approaches under deep uncertainty (Gambhir and Lempert, 2023).

In the case of Brazil, a country of continental dimensions, the extensive geographical coverage of the National Interconnected System (NIS) makes it particularly vulnerable to a wide range of climate-related events. In 2024 alone, the country experienced a series of unprecedented occurrences, including torrential rains in Rio Grande do Sul that left hundreds of thousands without electricity, a prolonged drought in the Amazon region, and record-breaking heatwaves in the Midwest (World Meteorological Organization, 2025).

Electricity distribution networks, positioned at the final link of the electricity supply chain, are particularly susceptible to the impacts of HILF-type events. Characterized by a high density of components, wide geographical dispersion, and predominantly overhead structures with radial topologies and low redundancy, these networks are highly exposed to localized failures that can propagate and lead to cascading outages (Carvallo *et al.*, 2022). Their vulnerabilities are intrinsically linked to interactions with the local environment, such as falling trees and urban flooding, making the analysis of their resilience a unique and multidimensional challenge (Jufri *et al.*, 2019).

Grounded predominantly in techno-economic analysis, traditional approaches to planning and regulation in the Brazilian electricity sector have proven limited in addressing the multifaceted nature of the resilience challenge. Sector planning has historically relied on computational optimization models designed to expand the system at the lowest possible cost to meet projected demand (Silva *et al.*, 2025). Technical and economic regulation, in turn, is based on an incentive framework centered on performance indicators, such as the duration (SAIDI) and frequency (SAIFI) of service interruptions, and on tariff review cycles that evaluate realized costs. While these tools are effective for optimizing efficiency in stable and predictable contexts, they are inherently inadequate for valuing proactive investments in new technologies and resilience, whose benefits tend to be diffuse and difficult to quantify (Bovera *et al.*, 2021).

The inadequacy of these approaches reveals that the challenge of resilience goes beyond purely instrumental analysis. It is a multifaceted issue whose complexity arises from the interplay of technical, economic, political, social, and behavioral dimensions, characterizing what the literature refers to as "complex problems" or "wicked problems" (Rittel and Webber, 1973). Addressing this type of problem requires methods capable not only of capturing technical data but also of incorporating the perceptions, mental models, and biases of the actors involved in decision-making processes (Eden and Ackermann, 1998).

In this context, new methodological frontiers are emerging. This study explores the intersection of Artificial Intelligence (AI), Theory of Mind (ToM), and problem structuring methods, examining how the structured interaction between AI and human cognition can enhance the understanding of complex problems and uncover new dimensions of their nature.

The rationale for this study, therefore, lies in the integration of theoretical insights with practical outcomes. On a practical level, it aims to provide decision-makers with a more multifaceted understanding of the impacts of extreme weather events. From a theoretical perspective, the study contributes to the knowledge frontier by exploring the synergistic interaction between humans and AI in the structuring of complex problems. Accordingly, this research introduces a novel framework that employs an artificial intelligence tool to provide an initial systemic modeling of agents perspectives, extracting them under the principles of Theory of Mind within the CHAP2 structuring methodology.

The following sections describe the development of the study. Section 2 outlines the foundations of the hybrid methodology employed and its implementation, detailing the assumptions and steps involved in each phase, including the conduction of interviews and the construction of concept maps. Section 3, Results and Discussion, presents the resulting knowledge structure, analyzes its implications through the lens of complex systems theory, and proposes concrete pathways for intervention based on this analysis. Finally, Section 4 summarizes the main findings and suggests directions for future research.

2. Methodology

2.1. Problem Structuring Methods and Multimethodology

The complexity inherent in real-world problems introduces dynamic factors and uncertainties that are difficult to quantify and represent in formal models, thereby challenging the limits of computational rationality (Simon, 1979). Such problems often involve multiple actors with differing perspectives and objectives and are characterized by incomplete or conflicting data, factors that exceed the capabilities of purely quantitative models in traditional Operations Research (OR), also referred to as "Hard" OR (Checkland, 1981). The inability of these models to adequately address the social, political, and behavioral dimensions of real-world issues gave rise, from the 1970s onward, to the development of a new field of thought (Ackermann, 2012).

In response to this challenge, "Soft" OR emerged, an approach later consolidated under the term Problem Structuring Methods (PSMs) (Rosenhead, 1989). PSMs constitute a family of predominantly qualitative methods that aim, in the early stages of modeling, to formally structure problem situations where there is no consensus on goals, alternatives, or even on the nature of the problem itself. By employing visual tools and fostering the participation of multiple stakeholders, PSMs seek to make underlying issues explicit and to build a shared representation of reality (Mingers and Brocklesby, 1997; Midgley *et al.*, 2013).

The recognition that most complex problems encompass both "soft" (subjective and qualitative) and "hard" (objective and quantitative) dimensions has led to the natural evolution toward Multimethodology. This approach involves combining two or more methods — or components thereof — to address the various facets of a problem more effectively than the methods alone could achieve (Lins *et al.*, 2018). Although integrating methods from different philosophical paradigms (*e.g.*, interpretivist and positivist) poses theoretical and practical challenges (Mingers and Brocklesby, 1997), it is increasingly acknowledged as essential for effective intervention in real-world problem contexts.

The concept of Multimethodology is closely related to, and often used interchangeably with, the term "Hybrid Models" or "Hybrid Systems Modeling," particularly in the simulation and computational modeling literature (Mustafee *et al.*, 2018). While Multimethodology refers to the broader paradigm of combining different methods, Hybrid Models often describe the specific outcome of such an intervention — a single, integrated model that leverages techniques from different paradigms.

This study is situated within this context, adopting a multi-methodological and multi-paradigm framework (Mustafee *et al.*, 2018). Specifically, it integrates the Complex Holographic Assessment of Paradoxical Problems (CHAP2) method (Lins *et al.*, 2021) with a computational tool — Artificial Intelligence, employed through a structured inquiring process to model a range of stakeholder perspectives. This approach aligns with the classification of Hybrid Models in Operations Research, combining "Soft" OR techniques with computational tools to enhance the conceptual modeling phase (Mustafee *et al.*, 2022). One example of such hybridization in the Brazilian context is presented by Jahara and Lins (2021), who combined qualitative structuring methods with discrete event simulation to diagnose and intervene in a complex production problem.

The detailed application of the methodology adopted in this study is presented in the following sections.

2.2. CHAP2 Method: Fundamentals and Adaptation

The specific method selected for this study is CHAP2 (Lins *et al.*, 2021), a multi-methodological approach developed to structure complex problems based on theoretical foundations from Theory of Mind and metacognition. This method investigates how individuals assess the behavior of other agents and construct their own mental models of reality. CHAP2 includes an interface between qualitative and quantitative approaches, employing concept maps as core tools to support model validation, identify consistencies and conflicts, and manage paradoxes inherent in complex systems.

Concept maps are graphical tools for organizing and representing knowledge. Grounded in a constructivist theory of learning, they illustrate the relationships between concepts through a network of nodes and labeled links (Novak *et al.*, 1984). Their non-linear structure facilitates collaborative knowledge construction and shared understanding, making them particularly effective for externalizing and negotiating complex mental models. This visual representation allows multiple stakeholders to see not just the components of a problem, but the intricate web of relationships between them, enabling specific parts of the map to be deepened or challenged without losing sight of the whole. Thus, in the context of this study, the concept map is not merely a data visualization tool but a central artifact in the dialogical process of co-creating meaning.

The canonical CHAP2 process unfolds in six sequential phases: starting with the initial system characterization alongside privileged agents (Phase 1) and the training of the dialogue group (Phase 2), followed by the elicitation of individual knowledge from participants (Phase 3), the construction of conceptual and paradoxical models in workshops (Phase 4), formal quantitative modeling (Phase 5), and, finally, intervention monitored by performance indicators (Phase 6) (Lins *et al.*, 2021).

In this study, an innovative adaptation of the CHAP2 method was implemented to leverage the synergy between human and artificial cognition during the problem structuring phase. The primary modification was introduced in Phase 1 of the traditional process, which typically involves interviews with human managers; instead, knowledge was elicited from AI agents. This adaptation is justified by the potential of AI to synthesize large volumes of information and to represent a broader and more systematic spectrum of stakeholder perspectives than would be feasible through a limited number of human interviews. The AI agent was instructed to operate under the principles of Theory of Mind to generate a knowledge corpus, from which a pilot concept map was constructed by the authors.

In essence, the methodology adopted in this study aligns with what Donaldson (2021) refers to as an epistemology of “practical inference”, which seeks to understand the "reasons" and "justifications" for action in complex problem contexts, rather than focusing solely on causes and effects.

This research concentrates on the implementation and outcomes of the adapted Phase 1 and Phase 3 (with Phase 2 conducted concurrently with Phase 3). In the latter, the pilot concept map — constructed by the authors from the AI dialogue — is employed as a reference artifact to deepen and structure the knowledge of human participants. The remaining phases of the CHAP2 method (Phases 4, 5, and 6) lie beyond the scope of this article.

Finally, it is crucial to clarify the nature of this hybrid approach. It constitutes a structured process in which the researchers, guided by the theoretical frameworks of CHAP2 and Theory of Mind, employs the AI as a powerful engine for knowledge modeling and synthesis (Canas *et al.*, 2004). In this process, the AI-generated concept map functions as a “cognitive scaffold” (O’Donnell *et al.*, 2002): an external, structured artifact designed to support and enhance the subsequent cognitive work of the human agents. This approach aligns with broader research in information visualization and decision support, which explores how visual representations can bridge AI-driven reasoning with human cognition to improve complex planning (Katifori *et al.*, 2007).

2.3. Implementation of the Hybrid Methodology

Phase 1: Pilot Concept Map Generation Using AI Tools

The objective of this initial phase was to generate a comprehensive, multi-perspective pilot concept map to serve as a structured foundation for subsequent knowledge elicitation with human participants. To achieve this, we developed and applied the Systemic Inquiring Network (SIN), a structured questioning method designed to reveal tensions, incorporate multiple perspectives, and stimulate critical reflection.

Two generative AI tools were employed in this phase: ChatGPT (GPT-4o model) and Gemini (2.5 Pro model). The decision to use two distinct models was a methodological strategy to avoid being constrained by the specific architectural biases of a single model. By triangulating the outputs from both, the aim was to enhance the diversity and robustness of the concepts produced, creating a richer and more balanced initial knowledge base.

The knowledge elicitation process was conducted through a structured dialogue, guided by a script of ten sequential questions. Prior to the first question, the AI was provided with a contextualizing text on the impacts of extreme weather events on electricity distribution services, establishing a preliminary scenario of the problem situation.

The logical structure of the questions, illustrated in Figure 1 and detailed in the supplementary material, followed an investigative sequence comprising the following stages:

- It began with an exploration of the plurality of perceptions (Question 1);
- It moved on to systemic effects and barriers to change (Questions 2 and 3);
- It moved on to the search for innovation and integrative solutions (Questions 4, 5, and 6);
- Finally, it confronted AI with paradoxes and tensions specific to the Brazilian electricity sector (Questions 7 to 10).

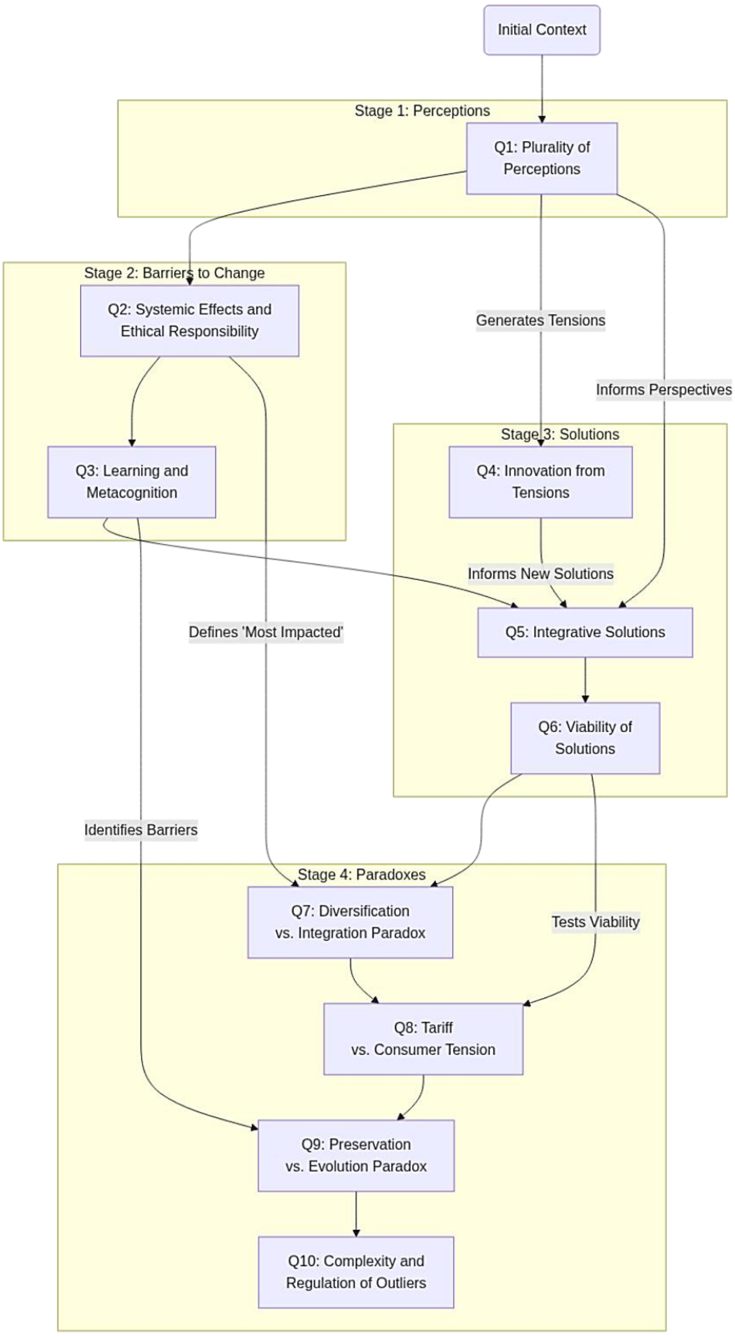

Figure 1. Systemic Inquiring Network applied during the AI-based knowledge elicitation.

Notably, the script functions not only sequentially but also as a network, incorporating feedback loops where later questions explicitly revisit and deepen earlier themes. For instance, the exploration of tensions (Q4) arises from initial perceptions (Q1), while the analysis of paradoxes (Q9) reflects barriers to change (Q3).

These feedback loops reflect principles of first-order cybernetics, which concern the regulation of an observed system — in this case, guiding and structuring the dialogue with AI as the system under observation. At a deeper level, by instructing the AI to simulate perceptions and engaging in a process of co-constructing knowledge, the study adopts a second-order cybernetic perspective, wherein the researcher becomes an integral part of the system under investigation, and cognition itself becomes the object of analysis (Foerster, 2003).

In addition, the methodological approach of applying a sequential and investigative question network directly aligns with — and extends — the chain-of-thought (CoT) prompting techniques found in the literature on Large Language Models (LLMs) (Wei *et al.*, 2022). CoT prompting is based on the principle of instructing the model not merely to provide a final answer, but to explicitly articulate its reasoning step by step — a strategy shown to significantly enhance performance on tasks that require multi-step inference.

The innovation of this study lies in transposing the chain-of-thought logic from the realm of purely deductive problems to that of a complex socio-technical issue, whose defining feature is the plurality of human perceptions. In this context, the “chain of thought” does not refer to a sequence of mathematical deduction steps, but rather to a progression of simulated stakeholder perspectives, aimed at elucidating multiple dimensions of the problem.

The design of the script was intentionally grounded in two main foundations: (i) the theoretical framework of paradoxes in complex systems and Theory of Mind, as systematized by Lins (2018); and (ii) the authors’ practical experience in analyzing recurring challenges in the regulation and planning of the Brazilian electricity sector.

The multiplicity of perspectives was formally introduced in the first question, which instructed the AI to articulate the problem from the standpoint of 15 key stakeholders. This selection, detailed in Table 1, was designed to represent the problem's ecosystem while balancing the principles of completeness and parsimony. To ensure completeness, stakeholders were drawn from across the entire value and impact chain; to ensure parsimony, they were grouped into three functional categories: (i) those directly involved in the sector’s production processes; (ii) those affected by the impacts of extreme events; and (iii) those who influence, regulate, or finance the system.

It is important to note the dual role of consumers within this ecosystem. Although primarily classified as “affected” — as they are the ultimate recipients of the service’s impacts — they are also the principal financial agents in the entire chain, ultimately bearing the costs that shape interactions among all other actors.

The textual responses generated by the AIs during the dialog were consolidated to form the analytical corpus for this phase. A subsequent process of content analysis and coding was conducted to extract key concepts and perceived causal relationships. The specific methodological approach used for this content analysis was Thematic Analysis (Braun and Clarke, 2006), which will be detailed below. These elements were then synthesized and organized by the authors into a pilot concept map. To enhance interpretability, the concepts in this map were grouped into three core thematic clusters: Problematic Situation, Actors Involved, and Challenges to Change. This map served as the primary reference artifact for Phase 3 of the methodology.

Thematic Analysis is a foundational method for identifying, analyzing, and reporting patterns of meaning within qualitative data (Braun and Clarke, 2006). The process applied in this research involved an iterative cycle of familiarization with the textual corpus, followed by the systematic coding of key arguments, concepts, and perceived causal relationships. These codes were then organized into broader, more interpretive themes that formed the conceptual basis for constructing the concept maps.

Table 1: Perspectives considered in knowledge elicitation with AI

Category	**Agent / Stakeholder**
Directly Involved in Production Processes	Electricity Distributors
	Energy Transmission Companies
	National System Operator
	Suppliers of Critical Equipment and Services
Affected by Impacts	Consumers (different sizes, associations)
	Civil Defense / Municipalities
	Other Public Services (sanitation, telecommunications, gas, etc.)
Influencers, Regulators and Financiers	Regulator (ANEEL)
	Granting Authority (MME)
	Investors
	Insurers and Reinsurers
	Research Institutions and Academia
	Meteorology Companies
	NGOs and Local Community Groups
	Media and Public Communication

Phase 3 (A): Selection of Human Agents and Interview Process

The selection of participants for the Phase 3 interviews was purposively designed to explore the core tensions revealed in the multi-stakeholder map from Phase 1. While the selected human agents can be situated within the broader stakeholder landscape shown in Table 1 (*e.g.*, as consultants and academics who inform the 'Influencers, Regulators and Financiers' category), the goal of this phase was not to replicate the 15 perspectives individually. Instead, the selection sought to compose a cognitively diverse panel capable of analyzing the problem from three complementary analytical vertices, each designed to unpack a fundamental dimension of the problem's complexity that emerged from the initial map:

- Vertex 1: Operational challenges faced by electricity distributors and the need for intersectoral coordination;
- Vertex 2: Trade-offs in the tariff model and economic regulation, and their intersection with the socio-political dimensions of the problem — assessing the justice, feasibility, and legitimacy of resilience strategies from a public policy and conflict mediation standpoint;

- Vertex 3: A systemic view of the problem, emphasizing transdisciplinary integration and the analysis of complex causalities.

Three human agents were selected to represent the three analytical vertices. The combination of their profiles was intentionally designed to foster a rich analytical dynamic: the operational perspective (HA1) is contextualized by a socio-political and feasibility-oriented analysis (HA2), and both are integrated through a systemic and transdisciplinary viewpoint (HA3). Table 2 outlines the specific contributions of each agent to the overall analysis.

Table 2: Profiles of the Selected Human Agents

Identifier	Profile	Sector	Analytical Contribution
HA1	Regulatory Technical Analyst	Consultancy	Focus on the operational impacts of climate events, challenges in meeting service quality targets, and intersectoral governance among system actors.
HA2	Regulation and Public Policy Analyst	Consultancy	Bridging the gap between economic-regulatory analysis and socio-political realities, integrating philosophical, conflict mediation, and public policy lenses.
HA3	Systems Scientist	Academia	Providing a transdisciplinary and systemic perspective, combining qualitative and quantitative methods and applying Theory of Mind and Metacognition concepts.

Preparing for the interviews constituted a methodological stage in its own right. Semi-structured interview guides were tailored to each participant's profile, complemented by a careful analysis of the facilitator’s role in fostering critical reflection and managing paradoxes. Prior to each session, the research objectives and methodological foundations were presented to the interviewee to ensure their engagement and to promote metacognitive awareness, as recommended in Phase 2 of the CHAP2 method. During the individual interviews, the concept map generated in Phase 1 was used as a reference artifact to guide and deepen the discussion.

Phase 3 (B): Construction and Aggregation of Human Concept Maps

The process of structuring the knowledge of human agents based on the interview data followed three main methodological stages: content analysis and coding through the Thematic Analysis method previously outlined, construction of individual maps, and validation of the resulting outputs. First, the recorded interviews were carefully reviewed and analyzed in detail.

For each interview, the arguments, key concepts, and causal relationships articulated by the participant were systematically recorded, forming the data corpus for analysis. Based on the coded elements, an individual concept map was developed for each of the three agents

(HA1, HA2, and HA3), visually representing their respective mental models.

To ensure the reliability of the representations and minimize researcher interpretation bias, a participant validation stage (member checking) was conducted — an essential practice for establishing credibility in qualitative research (Lincoln and Guba, 1985). Each individual concept map was presented back to the respective participant for review, refinement, and final validation. This feedback loop ensured that the visual artifacts accurately reflected the interviewee's reasoning and perspective. The outcome of this phase was a set of three individual, validated concept maps.

3. Results and Discussion

The application of the hybrid methodology enabled the progressive structuring of the complex problem under investigation. This section presents and discusses the results obtained. It begins with the knowledge structure generated by the AI agents in Phase 1, followed by the analysis of knowledge elicitation with the human participants interviewed in Phase 3. Finally, it synthesizes these findings to propose a set of systemic interventions aimed at enhancing resilience.

3.1. Pilot Concept Map

The implementation of Phase 1, through a structured dialogue with the AI agents, produced a pilot concept map that synthesizes the AI's responses to the ten scripted questions. Organized into three thematic clusters — Problematic Situation, Actors Involved, and Challenges to Change — the full map is provided in high resolution as Supplementary Material online due to its size and complexity.

The analysis of the Problematic Situation cluster, illustrated in Figure 2, reveals a systemic structure that links Extreme Weather Events to a cascade of Multiple Impacts, categorized into technical, economic, and social dimensions. According to the map, the technical impacts — such as infrastructure damage and increased pressure on distribution services — lead directly to economic consequences, including losses for consumers and increased CAPEX and OPEX for distribution companies. Additionally, the problem extends into a range of social impacts, including safety risks, public health threats, and heightened social tension, all of which are compounded by a decline in trust in institutions.

The map also highlights how extreme weather events exacerbate social inequality by disproportionately affecting vulnerable populations. This dynamic manifests in several ways. First, these groups often reside in areas more exposed to natural hazards — such as floods and landslides — which heightens risks to personal safety and increases the likelihood of material losses, ranging from household appliances to homes themselves. Second, the electricity infrastructure in these peripheral areas tends to be less robust, increasing their susceptibility to prolonged outages and related hazards. Finally, power interruptions can aggravate food insecurity among vulnerable families, either through the direct loss of refrigerated goods or as a result of rising prices caused by disruptions in the local supply chain.

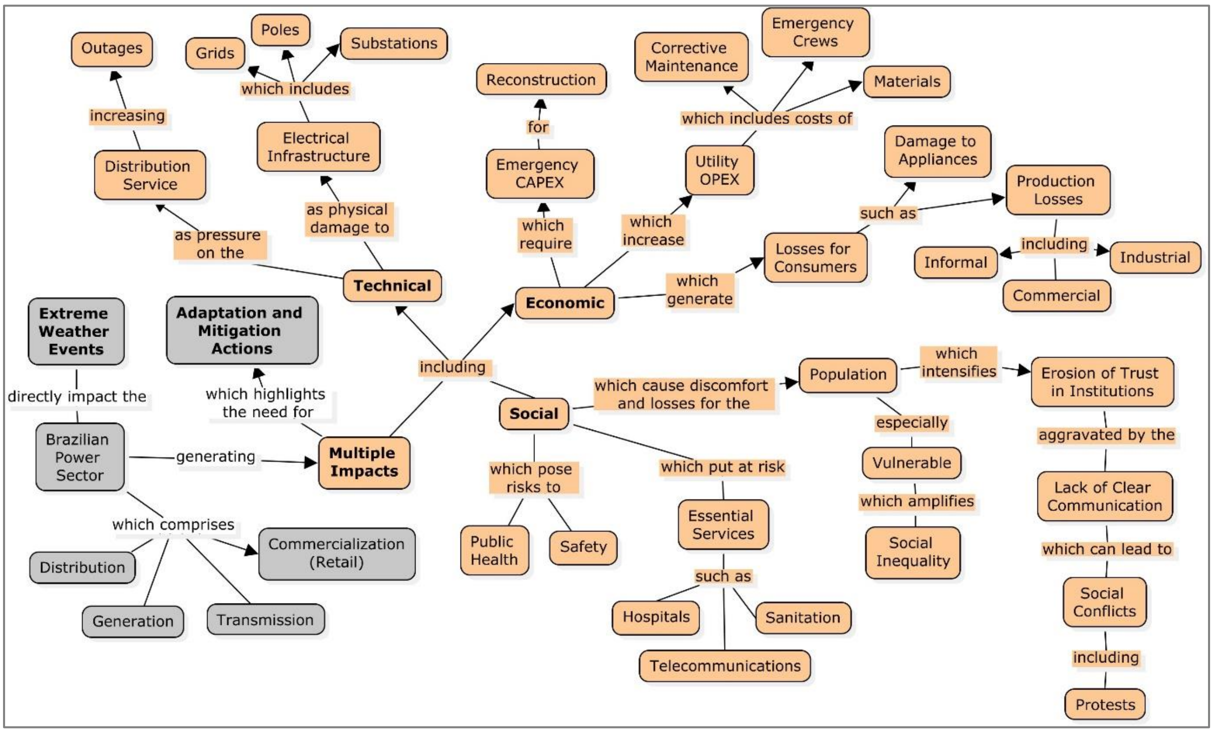

Figure 2. Problematic Situation Cluster from the Phase 1 Concept Map.

In the Actors Involved cluster, shown in Figure 3, the map reveals a network of relationships and tensions that characterize the sector's classical regulatory dilemma. At the center of this dilemma is the Regulator, who must balance multiple and often conflicting objectives: ensuring tariff affordability and service quality for Consumers, while also providing the adequate returns and regulatory stability required by Distributors and Investors for the maintenance and expansion of the electricity infrastructure. Consumers appear as the most vulnerable link in this chain — demanding reliable service and fair pricing, yet directly affected by the real increase in tariffs. These tariffs reflect not only the cost of the service and investments in resilience, but also the cumulative burden of subsidies, levies, and taxes.

Finally, the Challenges to Change cluster, illustrated in Figure 4, synthesizes the main obstacles to enhancing the resilience of electricity distribution systems. Elements such as Regulatory Rigidity, the Short-Term Vision of sectoral agents, and the Scarcity of Financing Sources emerge as critical bottlenecks to systemic advancement. In parallel, the Tensions mapped in this cluster reflect the core dilemmas and trade-offs embedded in the sector's governance structure — most notably, the conflict between Immediate Costs and Future Benefits, the dichotomy between Service Quality and Tariff Affordability, and the tension between Individual (Sectoral) and Collective (Governmental) Responsibility. These tensions act as structural impediments to coordinated and sustainable change.

The most relevant insight derived from the map, however, lies in the propositional connection between the Challenges and the Innovative Solutions. By framing the Tensions not as paralyzing obstacles but as sources of innovation, the map embodies a core principle of complex thinking: it is precisely through the creative management of paradoxes that the most resilient and adaptive solutions emerge (Lins, 2018). This perspective suggests that overcoming systemic barriers may not require the elimination of tensions, but rather the capacity of actors to harness them as drivers of transformation.

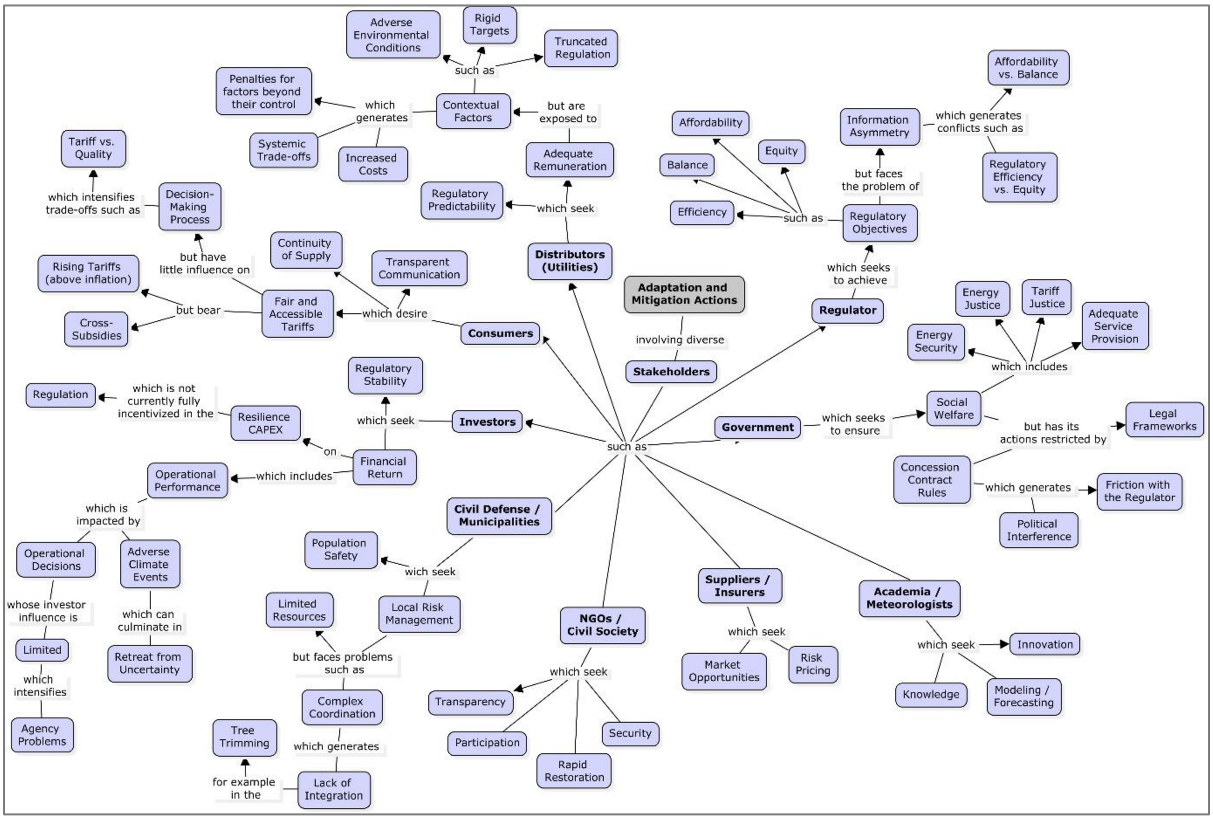

Figure 3. Stakeholders Involved Cluster of the Phase 1 Concept Map.

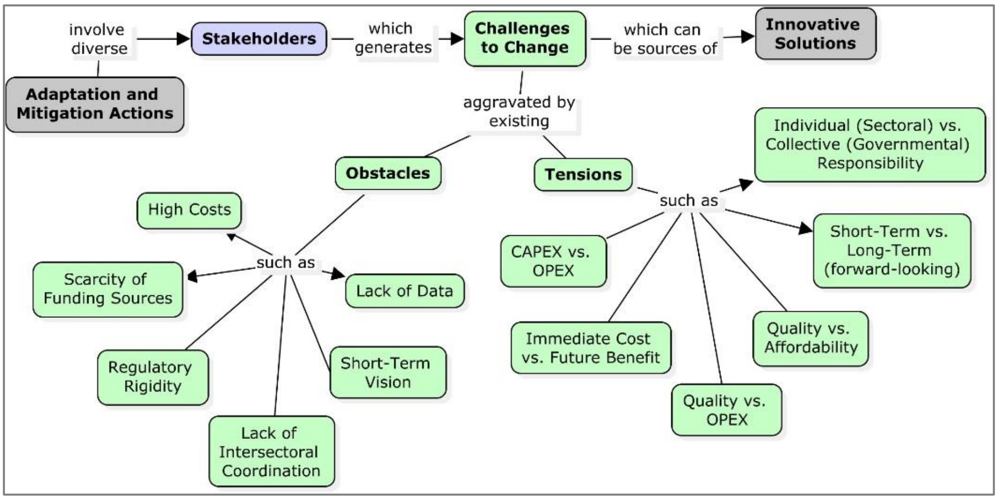

Figure 4. Challenges to Change Cluster of the Phase 1 Concept Map.

An analysis of the complete concept map generated in Phase 1 reveals that economic tensions in the electricity sector go beyond the simple relationship between cost and remuneration, extending into the realm of tariff policy. The map highlights that the electricity tariff is not merely a price signal but a complex instrument of state policy and a site of dispute among competing interests. The presence of cross-subsidies and other increasing charges illustrates how the tariff is often leveraged to pursue broader policy objectives — such as industrial promotion and regional development — that extend beyond the sector itself. This strategic use of tariffs creates macroeconomic trade-offs that surpass the decision-making capacity of the sectoral regulator, whose institutional mandate remains focused on tariff affordability and regulatory balance.

For a final interpretation of these results, the analysis draws on the framework of paradoxes in complex systems proposed by Lins (2018). The tensions identified in the concept map are not merely conflicts to be resolved or eliminated, but rather expressions of inherent paradoxes that characterize the system's complexity. A salient example is the challenge of advancing new frameworks and remuneration models for investments in resilience. This difficulty can be interpreted through the lens of the "Preservation vs. Evolution" paradox, in which the imperative to maintain regulatory stability and the functionality of existing processes comes into direct tension with the need for adaptive transformation in response to emerging threats and changing conditions.

Similarly, the multiplicity of conflicting objectives among stakeholders — such as the regulator, distributors, and consumers — reflects the "Part vs. Whole" paradox, in which efforts to optimize individual components of the system may undermine the resilience of the system as a whole. Finally, the challenge of formulating a unified national regulation for a country marked by profound regional disparities exemplifies the "Diversification vs. Integration" paradox. This paradox underscores the need to strike a delicate balance between promoting isonomy through systemic integration and simultaneously respecting local specificities, thereby enabling more equitable and context-sensitive planning and regulatory models.

3.2. Concept Maps of the Human Agents Interviewed

The application of Phase 3 of the methodology, using the concept map generated in Phase 1 as a reference artifact, enabled the elicitation and structuring of three distinct and complementary mental models of the problem, obtained through interviews with human agents HA1, HA2, and HA3. Analysis of the individual maps, presented below, reveals three distinct and highly complementary mental models. The emergence of this rich cognitive diversity serves as empirical evidence of the effectiveness of the methodological strategy, which was designed not to seek a single consensus, but to construct a more holistic understanding of the problem from these partial, yet essential, perspectives.

HA1's concept map presents an operational-managerial perspective of the problem, as illustrated in Figure 5. Its structure is predominantly causal and linear, mapping the cascade of Multiple Impacts stemming from Extreme Weather Events. The emphasis lies on the concrete and procedural dimensions of the system, highlighting elements such as Physical Impacts on the Network, Interruption Peaks, and the corresponding responses, including the need for Structured Crisis Governance and Intersectoral Articulation. HA1 adopts a pragmatic viewpoint, centered on the operational functioning of the system and its mechanisms for responding to disruptions.

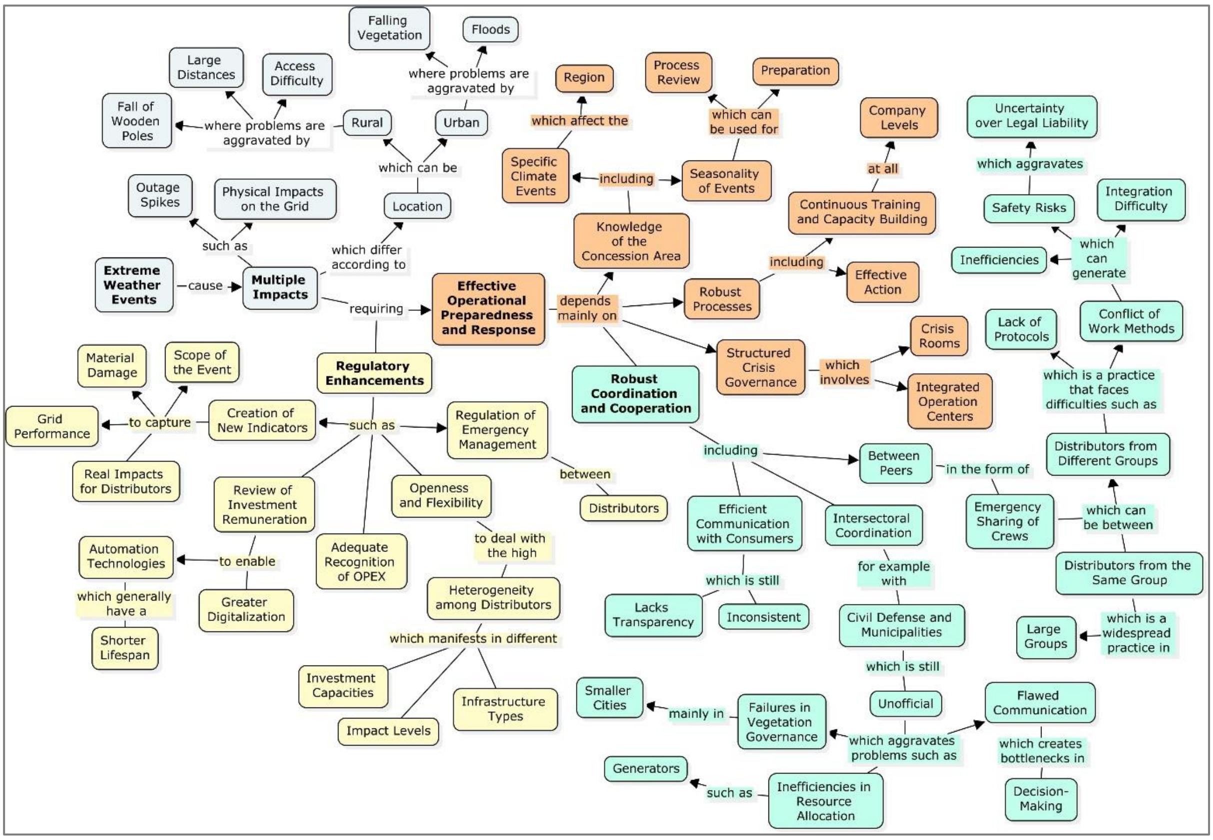

Figure 5. Concept Map of Human Agent 1 (Operational-Managerial Perspective).

Adding a critical socio-political dimension, HA2's concept map offers a new perspective on the problem (Figure 6). Rather than beginning with the climate event itself, the map is structured around a sense of Injustice on the Periphery and widespread dissatisfaction with the Burden of Tariffs and Taxes, particularly in relation to the perceived quality of the electricity service. The core concepts are rooted in political critique and distributive justice, with notions such as Vectors of Injustice — including Historical Privilege and Inefficiencies in the Tariff Model — occupying a central role. HA2's analysis shifts the focus away from technical failures and toward the structural inequities embedded in the system, which are both exposed and intensified by extreme weather events. The map challenges the current Social Function of electricity distributors and calls for solutions that are grounded in Responses to Real Human Needs.

Finally, HA3's concept map operates at a higher level of abstraction, presenting a systemic-reflexive perspective (see Figure 7). Rather than describing the problem directly, the map focuses on the different epistemological frameworks through which the problem is conceptualized. At its core lies a dichotomy between a Traditional Reductionist View, grounded in a Purely Economic-Financial Logic, and a Systemic and Multidisciplinary View that the complexity of the context demands. The map introduces critical concepts such as Self-deception and Institutional Inertia to explain the mechanisms by which the system resists transformative change. HA3's analysis, therefore, constitutes a meta-analysis of the stakeholders' mental models, illuminating how entrenched worldviews shape and constrain responses to the resilience challenge.

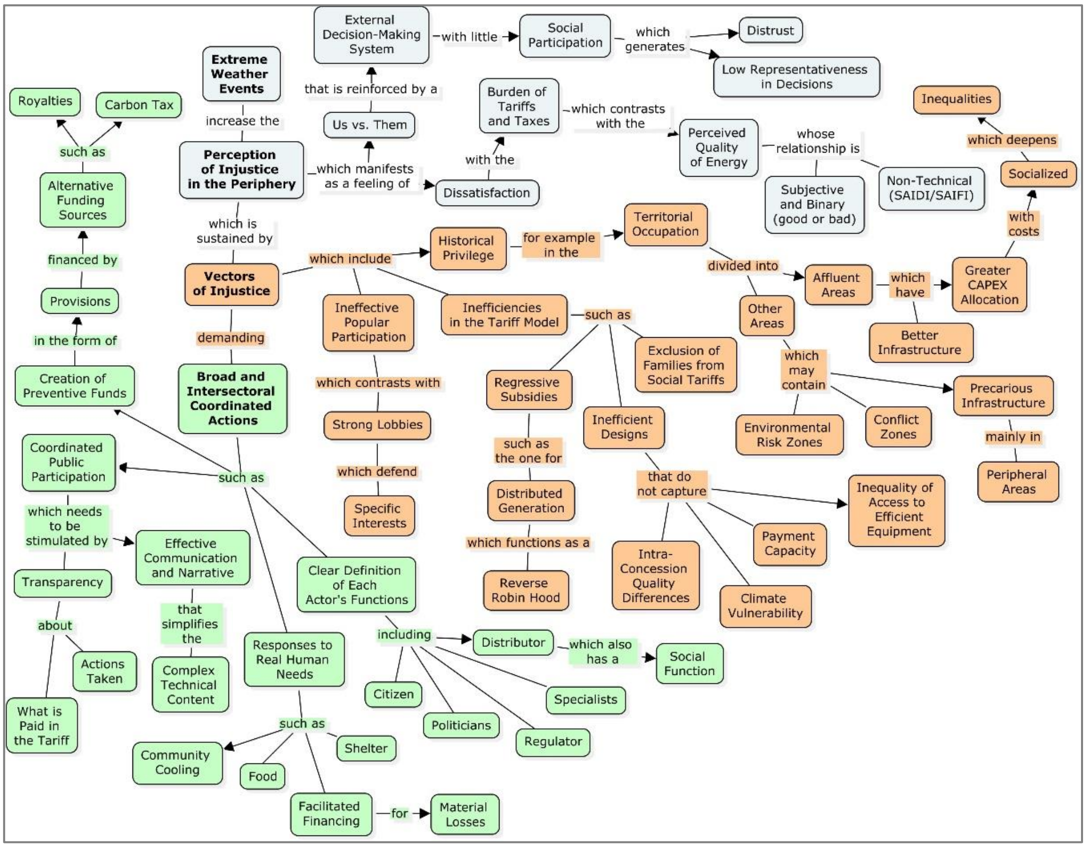

Figure 6. Concept Map of Human Agent 2 (Critical Socio-Political Perspective).

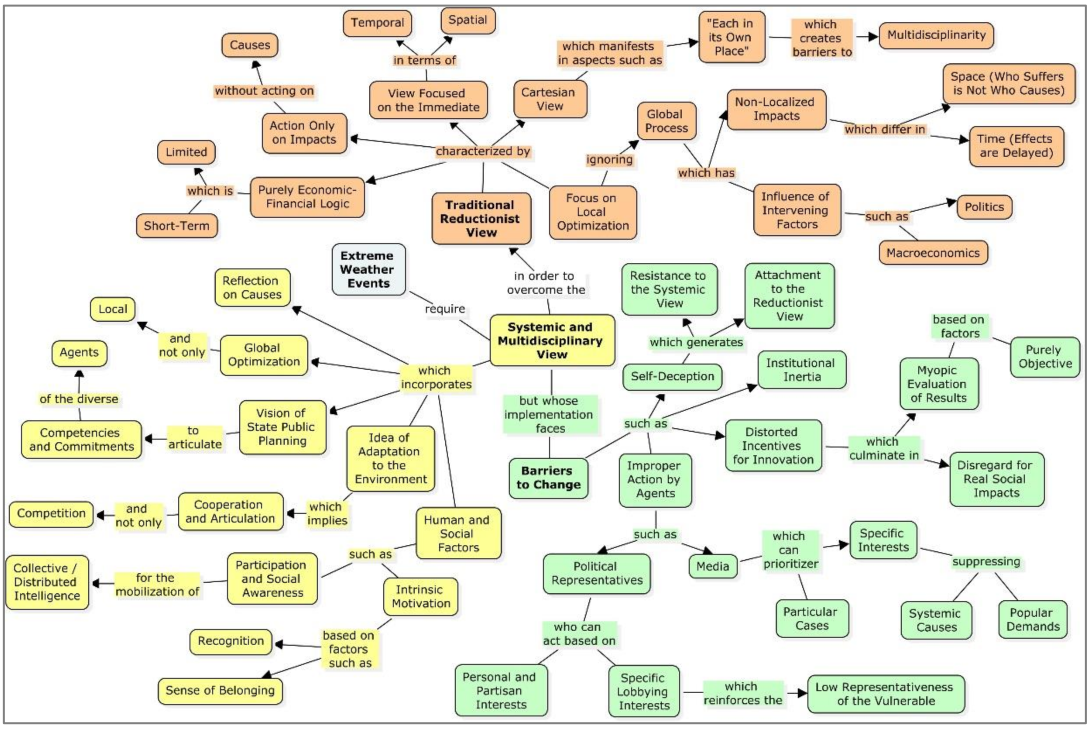

Figure 7. Concept Map of Human Agent 3 (Systemic-Reflective Perspective).

In summary, the three concept maps are not contradictory, but rather complementary, each illuminating a distinct layer of the complex problem. The HA1 map reveals the operational complexity, focusing on infrastructure, crisis response, and coordination mechanisms. The HA2 map highlights the political and justice dimensions, exposing structural inequalities and questioning the legitimacy and fairness of the current system. Finally, the HA3 map interrogates the dominant paradigms that shape the resilience debate and poses that the most significant barriers to a more resilient system are paradigmatic, rooted in the entrenched mental models that prevent systemic learning and innovation. It is precisely at the intersection — and, more significantly, within the tensions — between these three valid yet partial perspectives that the system's core paradoxes emerge most clearly, as will be explored in the following section.

3.3. Convergences and Divergences

The joint analysis of the four concept maps generated in Phases 1 and 3 reveals that the differing views on the problem are not merely subjective opinions, but rather representations of partial and internally coherent realities. The points of tension and synergy that arise from this comparative exercise can be more deeply interpreted through the framework of paradoxes in complex systems (Lins, 2018). This theoretical lens reframes challenges not as flaws to be corrected or contradictions to be resolved, but as inherent polarities within the system that must be constructively managed. By embracing these paradoxes as essential features of the system — rather than as obstacles — the analysis opens up pathways for more adaptive and integrative responses.

HA1's concept map presents an operational-managerial perspective of the problem, as illustrated in Figure 5. Its structure is predominantly causal and linear, mapping the cascade of Multiple Impacts stemming from Extreme Weather Events. The emphasis lies on the concrete and procedural dimensions of the system, highlighting elements such as Physical Impacts on the Network, Interruption Peaks, and the corresponding responses, including the need for Structured Crisis Governance and Intersectoral Articulation. HA1 adopts a pragmatic viewpoint, centered on the operational functioning of the system and its mechanisms for responding to disruptions.

The first and most immediate conclusion from the comparative analysis is that each agent effectively mapped a different definition of the "problem". The Phase 1 map, developed with AI agents, offered a panoramic and logically structured perspective; HA1 emphasized an operational-managerial challenge; HA2 highlighted a problem rooted in socio-political injustice; and HA3 focused on a paradigmatic conflict between contrasting modes of thought. This fragmentation clearly illustrates the "Part vs. Whole" paradox. According to the framework of complex systems (Lins, 2018), the tendency toward specialization — whether in the form of an engineer's technical lens or a regulator's economic framework — reinforces a resistance to multidisciplinary and multiperspective integration. Each actor, in optimizing their understanding of a specific subsystem, may inadvertently hinder the emergence of a coherent systemic vision. In this case, such fragmentation directly undermines the pursuit of true systemic resilience.

Consistent with literature that highlights significant institutional barriers to the implementation of innovative energy practices in the aftermath of extreme weather events (Agostino, 2024), the difficulty in implementing innovative solutions emerged as a central theme across all the concept maps generated. This challenge can be interpreted through the lens of the "Preservation vs. Evolution" paradox. HA1 emphasizes the need to maintain the operability of current processes, while HA2 highlights historical privilege as a sustaining force of the status quo. Both reflect the Preservation pole of the paradox. In contrast, the growing urgency to adapt to extreme climate events expresses the system's call for Evolution, which, in the framework of complex systems, entails confronting and overcoming entrenched barriers to change. In this context, the study does not merely reveal a state of paralysis; rather, it makes the tension explicit and facilitates a structured dialogue around it, supporting the management of both poles of the Preservation vs. Evolution paradox: on one hand, the necessity of regulatory stability to ensure investor confidence (Preservation); on the other, the need for flexibility and innovation to secure the system's long-term resilience and adaptability (Evolution).

The tension between the demand for unified regulation and the operational autonomy of local utilities embodies the "Centralization vs. Distribution" paradox. While the prevailing regulatory model favors the centralization of authority and information within formal hierarchies — particularly the regulator — effective resilience increasingly appears to arise from the distributed intelligence, creativity, and contextual knowledge of local agents. This dynamic is further complicated by the "Multiplicity vs. Identity" paradox, which emerges clearly in the analysis of actors. Traditional regulatory and economic models tend to assume agents with fixed, singular identities — for instance, the "profit-maximizing firm". However, the concept maps reveal the plurality of roles occupied by individuals: a single actor may simultaneously be a sector professional, a consumer bearing the burden of tariffs, and a citizen experiencing the social consequences of systemic failures. According to Lins (2018), neglecting this internal multiplicity and the diverse viewpoints it generates constitutes a major barrier to systemic solutions. Recognizing and integrating these layered identities is therefore essential for advancing toward more resilient and adaptive governance models.

Furthermore, the entire research process can be interpreted as a form of systemic intervention, aiming to shift the system's cognitive stance from Self-deception toward Metacognition. Self-deception is expressed when institutional inertia — the persistent adherence to rules, routines, and optimization strategies is increasingly misaligned with the complexity of the current context. In contrast, metacognition refers to the system's capacity to reflect on its own mental models, questioning underlying assumptions, and thereby unlocking new avenues for transformation. In this sense, the methodology adopted — particularly through the use of an external artifact (the AI-generated concept map) as a stimulus for dialogue — functions as a catalyst for this metacognitive process. By confronting agents with a structured yet externalized representation of the problem, the research encourages a critical distancing from habitual frames of reference, thus creating conditions for cognitive expansion and the emergence of innovative, adaptive solutions.

Therefore, the methodology itself — and the distinct knowledge structures produced by AI and human agents — embodies the paradox of the "Internal Subject vs. External Object". The concept map generated by the AI is not inherently objective; rather, its systemic and multi-perspective nature is a direct result of the application of the Systemic Inquiring Network (SIN). This method compels the AI to synthesize a broad landscape of information, thus simulating the detached analysis of an "External Object". In turn, the maps from the human agents provide the rich, complementary perspectives of the "Internal Subject". Their analyses are not merely subjective, but are deeply contextualized, shaped by lived experiences and normative values that offer essential, grounded insights which the AI's logic alone cannot provide. HA3's contribution, by adopting a systemic and reflexive standpoint, elevates the analysis to a second-order observation, wherein the act of observing the system is itself problematized. It acknowledges that the observer is part of the system observed, and that this recursive engagement — the subject experimenting as subject — is a crucial driver of systemic evolution. Ultimately, the methodology reveals that a truly complex understanding requires embracing the permeability between observer and observed, integrating the objectivity of analytical detachment with the depth of subjective introspection.

Finally, the fundamental divergence between the concept maps can also be interpreted through the lens of Donaldson's "practical inference" framework (2021), which distinguishes between non-intrinsic values, justified by their contribution to external goals, such as economic performance, and intrinsic values, deemed worthwhile in and of themselves, such as dignity, fairness, and social inclusion. Both the AI-generated map — which produces its systemic view through the SIN method but lacks the lived experience of values — and HA1's managerial perspective — focused on instrumental goals, such as cost containment, operational efficiency, and system reliability, often suppressing broader social values — reflect a logic of justification grounded in non-intrinsic (instrumental or derivative) values.

In contrast, HA2's map — centered on themes of equity, justice, and the lived experience of vulnerable communities — articulates a system of reasoning based on intrinsic values. This is where HA3's systemic view crucially differs from the AI. While both produce a systemic analysis, HA3's is a reflexive critique, informed by lived experience, that integrates and weighs these conflicting value architectures and different paradigms of thinking — a meta-cognitive leap the AI cannot perform (Dreyfus, 1992; Vallor, 2016).

The sector's paralysis, therefore, is not only the result of structural complexity or governance dilemmas, but also the manifestation of a deeper axiological conflict: a clash between value architectures, where the pursuit of efficiency and cost-effectiveness (non-intrinsic values) is in tension with the imperatives of social justice and democratic legitimacy (intrinsic values). This reframing helps illuminate why consensus is so difficult: what is at stake is not merely how to act, but what counts as a justifiable reason for action.

The study's finding — that managing conflicting yet complementary perspectives is a key driver for innovation — resonates with established frameworks in public policy and adaptive governance. The dynamic interplay observed between the different mental models mirrors the core tenets of adaptive governance, which proposes that for "wicked problems", solutions must emerge from participative processes that embrace uncertainty and competing goals (Guerin, 2007). This principle is not merely theoretical; it has been demonstrated in practice in contexts ranging from stakeholder engagement in the United Kingdom's public health research (Laird *et al.*, 2020) to the adaptive co-management of natural resources in New Zealand (Guerin, 2007). Ultimately, these cases confirm that for complex socio-technical systems, the solution lies not in choosing one perspective over another, but in creating a structured process where the tension between them becomes the engine for adaptive and innovative public policies.

3.4. Pathways to Action: Systemic Leverage Points for Enhancing Resilience

The analysis presented thus far provides a comprehensive and multifaceted diagnosis of the resilience challenge, revealing the systemic paradoxes that underpin policy paralysis. While this characterization offers significant cultural and analytical value, a crucial question remains: how can this deeper understanding guide the formulation of more effective interventions? To bridge the gap from diagnosis to action, we turn to the work of Donella H. Meadows (2008) on systems thinking.

In her seminal book, Thinking in Systems, Meadows (2008) identifies twelve “leverage points” which she presents as a hierarchy of increasing effectiveness. She argues that while most policy efforts focus on low-impact levers (e.g., changing parameters and numbers), the most profound changes arise from intervening at deeper levels of the system’s structure.

For this analysis, the six highest-impact levers from her model were selected to form a qualitative framework designed to be both complete enough to capture the system's core dynamics and parsimonious enough to guide a focused intervention. The paradoxes identified in our analysis — such as "Part vs. Whole" and "Preservation vs. Evolution" (Lins, 2018) — are not merely problems to be solved, but signals that point directly to these high-impact leverage points.

Accordingly, this section proposes six concrete pathways for action, each targeting a different systemic leverage point. These proposals are not meant as simple solutions, but as starting points for a structural redesign aimed at enhancing the resilience of the electricity distribution system. They are summarized in Table 3.

Table 3: Proposed Interventions based on Systemic Leverage Points

Leverage Point (Meadows, 2008)	**Systemic Tension (Lins, 2018; Donaldson, 2021)**	**Proposal**	**Explanation**	**Justification**
6. Information Flows (The structure of who has access to information)	“Part vs. Whole”; “Metacognition vs. Self-Deception”	Develop and implement multidisciplinary and multi-perspective indicators for resilience.	Moving beyond purely technical grid metrics to formally include social, environmental, and public health factors in regulatory and policy assessments.	Manages the "Part vs. Whole" paradox by providing a holistic view of the system. It also challenges "Self-Deception" by making previously 'invisible' social impacts explicit, forcing the system to reflect on its true performance and fostering “Metacognition”.
5. Rules (Incentives, punishments, and constraints)	“Diversification vs. Integration”	Design and apply a "Menu of Contracts" to tailor resilience levels and investments to local needs.	This involves allowing regulators and utilities to negotiate bespoke contracts with varying levels of resilience and investments, resulting in corresponding tariff adjustments for specific areas.	Manages the "Diversification vs. Integration" paradox by creating regulatory flexibility. This approach rewards superior performance where it is most needed and avoids imposing uniform costs, moving beyond a rigid, one-size-fits-all policy.

4. Self-Organization (The power of the system to evolve its own structure)	“Centralization vs. Distribution”	Empower local self-organization by fostering social participation in resilience planning and incentivizing community-led solutions, such as microgrids.	This involves creating formal governance channels for communities to co-design resilience plans and offering financial or regulatory incentives for developing local assets, such as community-owned microgrids.	Manages the "Centralization vs. Distribution" paradox by strengthening the 'distribution' pole. It leverages local knowledge and distributed intelligence to build resilience from the bottom up, complementing — rather than replacing — the existing centralized system.
3. Goals (The stated purpose of the system)	“Preservation vs. Evolution”	Shift regulatory goals from ex-post cost recovery to ex-ante proactive investment in resilience.	This means moving beyond traditional ex-post remuneration of "prudent" restoration costs. Instead, it involves creating models that value and remunerate proactive, risk-based resilience expenditures, including both capital investments (e.g., grid hardening, automation) and operational readiness (e.g., advanced crew training, crisis simulations), before extreme events occur.	Changes the core incentive structure from reactive restoration to proactive preparedness, directly tackling the "Preservation vs. Evolution" paradox by valuing innovation.
2. Paradigms (The shared mindset from which the system arises)	“Internal Subject vs. External Object”	Shift the decision-making paradigm from seeking a single "optimal" solution to managing multiple, valid perspectives.	This involves using facilitated dialogues and problem-structuring methods to create a shared space where stakeholders can safely explicate, compare, and negotiate their diverse mental models.	Directly manages the "Internal Subject vs. External Object" paradox. By making subjective mental models (the "Internal Subject") explicit data for analysis, it allows the system to move beyond debates over a single "objective reality" toward the co-creation of more robust policies.
1. Transcending Paradigms	Clash of Values (Donaldson, 2021)	Foster a governance paradigm that shifts from	This involves creating an institutional space that recognizes the	Addresses the deepest source of conflict by shifting the focus from “how to act” to understanding “what counts as

(The power to get out of paradigms and choose them freely)		value-conflict to value-acknowledgment.	legitimacy of both instrumental values (e.g., efficiency, cost) and intrinsic values (e.g., equity, justice, dignity) in policy debates, rather than treating one as superior to the other.	a justifiable reason for action" for different stakeholders. This allows for truly novel and equitable solutions to emerge.

The interventions proposed in Table 3 should not be viewed as a menu of independent options, but as an interconnected strategy targeting the system at different levels. The development of multidisciplinary and multiperspective indicators (Leverage Point 6), for instance, is a foundational step. It provides the rich information necessary to effectively design and implement a "Menu of Contracts" (Leverage Point 5), as regulators would have a clearer, evidence-based view of the specific socio-environmental risks in each area. Without such data, any attempt at creating differentiated tariffs would be arbitrary and difficult to legitimize.

Similarly, empowering local self-organization through community participation and microgrids (Leverage Point 4) creates both the social legitimacy and the technical capacity needed to support a shift in regulatory goals toward proactive investment (Leverage Point 3). When communities can articulate their own resilience needs and even develop their own solutions, it generates bottom-up pressure that helps overcome the institutional inertia inherent in the "Preservation vs. Evolution" paradox. This process can be formally facilitated through mechanisms such as "regulatory sandboxes" — controlled environments that allow for real-world experimentation with novel technologies and local business models on a limited scale, providing crucial evidence to inform broader policy changes.

Ultimately, the success of these more concrete interventions hinges on the willingness of stakeholders to engage with the system's deeper leverage points: its paradigms. The proposal to use the hybrid methodology within systemic governance forums (Leverage Point 2) is therefore central. It offers a structured process for moving beyond debates over a single "objective" reality toward a more sophisticated management of multiple perspectives. This, in turn, paves the way for the highest leverage intervention: fostering a governance culture that transcends value-conflict (Leverage Point 1). By creating a space where the clash between instrumental and intrinsic values can be acknowledged and negotiated, rather than won or lost, the system can unlock pathways for policies that are not only more resilient but also more fundamentally equitable.

This approach moves beyond seeking a single "fix" and instead cultivates a process of continuous learning and adaptation — a critical capability for navigating the complex challenges posed by extreme weather events.

4. Conclusion

This study investigated how structured interaction between artificial intelligence and human cognition can be employed to deepen the understanding of a complex and pressing issue: the impacts of extreme weather events on electricity distribution systems. The findings demonstrate that this synergy is highly productive. Operating under principles akin to the Theory of Mind, AI contributed to the generation of a comprehensive and systemic pilot concept map, which served as a rich reference artifact for guiding interviews with human agents. This approach enabled not only a corroboration of the initial findings but also a deepening and critical reframing of the initial structure, revealing three distinct yet complementary mental models: the operational-managerial perspective (HA1), the critical socio-political perspective (HA2), and the systemic-reflective perspective (HA3). The final analysis shows that the sector's persistent tensions are manifestations of structural paradoxes, the management of which is essential for advancing resilience.

The contributions of this work are of a theoretical, methodological, and practical application nature. Theoretically, it demonstrates the analytical power of integrating complexity science frameworks to interpret empirical energy policy challenge. Methodologically, the study presents a core innovation by adapting the CHAP2 method and extending structured AI dialogue techniques into the domain of socio-technical problem structuring, offering a novel, transparent, and replicable path for future research. Finally, the contribution in terms of practical application is twofold. It first delivers a diagnostic tool for regulators and policymakers to map the landscape of stakeholder perspectives that shape policy decisions. More importantly, it moves beyond diagnosis to offer a prescriptive framework of systemic interventions (Table 3), grounded in Meadows' (2008) theory of leverage points. By targeting the system's rules, goals, and paradigms, these proposals provide a robust, theory-based guide for designing more effective and equitable public policies for climate resilience.

It is important to acknowledge the boundaries of this study. The findings from Phase 1 are inherently shaped by the researches' central role in guiding the AI dialogue through the proposed Systemic Inquiring Network method. Therefore, the most promising avenue for future research lies in testing the broader applicability of this method and the hybrid methodology as a whole. Replicating the framework in other "wicked problem" domains — such as health system planning, sanitation, or urban mobility — would be a valuable step in assessing the transferability of its approach to different socio-technical contexts.

In sum, this article argues that facing the challenges of climate change in an increasingly complex and uncertain world requires innovation not only in technologies, but also in the cognitive and methodological tools we use to understand reality. Problem structuring — enhanced through synergistic collaboration between human and artificial intelligence — emerges as a promising approach for transcending the paralysis induced by systemic paradoxes and collaboratively building more resilient futures.

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Glossary

ANEEL - Agência Nacional de Energia Elétrica (Brazilian Electricity Regulatory Agency)

CHAP2 - Complex Holographic Assessment of Paradoxical Problems

CoT - Chain-of-Thought

HA1, HA2, HA3 - Human Agent 1, Human Agent 2, Human Agent 3

HILF - High Impact, Low Frequency

LLM - Large Language Model

MME - Ministério de Minas e Energia (Ministry of Mines and Energy)

NIS - National Interconnected System (Brazil)

OR - Operations Research

PSM - Problem Structuring Method

SAIDI - System Average Interruption Duration Index

SAIFI - System Average Interruption Frequency Index

SIN - Systemic Inquiring Network

ToM - Theory of Mind

Supplementary Material

Supplementary Material 1: Structured Interview Script with AI.
https://doi.org/10.5281/zenodo.17070225.

Supplementary Material 2: Complete pilot concept map generated from the dialogue with AI agents, showing all thematic clusters and their interconnections.
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