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NEXUS VITAE: A METHODOLOGICAL TOOL FOR CONFLICT MANAGEMENT AND COOPERATION IN MULTI-USE RESERVOIRS

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ABSTRACT
The study analyzes the challenges of integrated management of water resources in reservoirs with diverse demands, such as energy generation, human supply, agricultural irrigation, and environmental conservation. He highlights how these demands can generate tensions and conflicts, proposing cooperation and benefit-sharing strategies to mitigate impacts and promote balance between sectors. Combining theoretical and practical concepts, the study adopts an innovative approach that integrates the interactions between water, energy and food, incorporating elements of sustainability and water security with the Transboundary Water Interaction Nexus (TWINS) method. The simultaneity between conflicts and cooperation is analyzed to identify synergies and trade-offs that guide a more efficient management. The main contribution is the Nexus Vitae methodology, structured from historical documentary analysis formed by three analytical layers — Bronze, Silver and Gold. The Bronze Layer identifies historical events that have shaped relationships of conflict and cooperation. The Silver Layer analyzes the phases of reservoir management (planning, implementation, operation, monitoring and adjustments) from social, economic, technological and environmental perspectives. Finally, the Gold Layer integrates these analyses into a conflict and cooperation matrix, highlighting critical zones through a color scale. Applied to the Sobradinho Reservoir (2013-2019), a period marked by severe drought in the São Francisco River basin, the study demonstrates how an integrated approach can support managers and public policy makers. In addition to its academic relevance, it offers practical solutions that can be replicated in other contexts, positioning

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Revista ARACÊ
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itself as a reference for sustainable watershed planning in complex and competitive scenarios.

Keywords: Nexus. Water. Energy. Conflict. Cooperation.

Revista ARACÊ
ISSN: 2358-2472

INTRODUCTION

The water-energy-food nexus conceptually refers to the interactions of connection and dependence that occur between water, energy, and food systems. This approach aims to understand the complex interactions, trade-offs, and synergies since it recognizes that these three systems are closely linked, so that deliberate actions in one sector can culminate in significant impacts on the others.

In the context of shared water resources, the water-energy-food nexus can present itself within contexts of conflict and cooperation. Conflict, which in this study is understood as a process that begins when an individual or group feels negatively affected by another person or group (ROBBINS, 2006), is beyond a small agreement or divergence, it is configured as a deliberate interference, whether active or passive, which blocks the efforts of others to achieve their objectives (CHIAVENATO, 2004).

Cooperation, as stated by Sadoff et al. (2009), refers to the different forms of collaboration to achieve common or distinct but positively related objectives, regardless of whether or not they are responsible for resolving conflicts. When applied in the relationships involving water resources, it plays a fundamental role in the formulation of public policies, in the implementation of actions aimed at its equitable and sustainable use and helps in building trust between the different users who share it.

Assuming that shared waters - which have multiple uses, are governed by certain relationships of conflict or cooperation, there is a high risk of accepting that the existence of one relationship indicates the non-existence of the other. On the other hand, assuming that both can constantly coexist – requires a change in mindset, where oversimplification of the problem of shared waters can be avoided. Therefore, developing a mechanism, a way of thinking to understand how conflict and cooperation coexist, becomes an important way of studying and how these phenomena manifest themselves or are influenced by the environment (MIRUMACHI et al., 2007).

Within the possibility of conflict analysis and cooperation, Mirumachi et al. (2015) propose the *Transboundary Water Interaction Nexus* (TWINS), an innovative approach that, in addition to conceptualizing the dual nature of these phenomena, seeks to interpret the dynamics of changes and their interactions in the context of shared waters. This method presents a visual representation in the form of a matrix, allowing the visualization of conflict and cooperation relationships simultaneously. In addition to emphasizing the coexistence of these dynamics, TWINS questions biased studies that focus exclusively on binary solutions, demonstrating how this analytical tool enables the development of a comprehensive typology of transboundary water relations.

Expanding on this discussion, Allouche et al. (2014) criticized the oversimplification of socio-environmental dynamics in nexus studies. They underscored the importance of a more inclusive approach, which is essential for addressing global inequalities and promoting environmental justice. Equity in access to resources, especially in regions severely affected by water scarcity and energy deficit, should be a guiding principle. In this sense, the incorporation of sustainability in the study of the interactions between conflict and cooperation becomes fundamental, as it allows an integrated view of the challenges that permeate the water-energy-food nexus.

The need to apply the dimensions of sustainability in conflict and cooperation analyses is based on the evaluation of four essential aspects: social, economic, technological and environmental. These pillars reflect the understanding that truly balanced development is only possible when all these areas are considered in an interdependent manner. Each dimension not only influences the others, but also plays a crucial role in mitigating conflicts and promoting cooperation among the actors involved. Based on this understanding, the *Nexus Vitae* methodology was developed, an analytical model for the integrated management of water interactions in the water-energy-food nexus in Multiple Use Reservoirs.

The validation of this methodology was based on the analysis of the Sobradinho Reservoir, operated by the São Francisco Hydroelectric Company (Chesf), which historically faces challenges associated with the coexistence of conflict and cooperation. These challenges involve the dispute over the use of water for multiple purposes, such as irrigation, supply, transposition, energy generation, navigation and environmental conservation. During the period from 2013 to 2019, the Brazilian semi-arid region experienced a severe drought, directly impacting reservoir operations (ANA, 2024). The reduction of flows to levels below the minimum established flow generated disputes between economic sectors with divergent interests, evidencing a context of unequal power and clientelist practices in the management of water resources. The critical analysis of the measures implemented by regulatory agencies and operators during this period revealed how precautionary actions can both intensify conflicts and foster cooperation initiatives.

In this context, the *Nexus Vitae methodology* has demonstrated its potential as an analysis tool to understand and improve water resources management practices at

Revista ARACÊ
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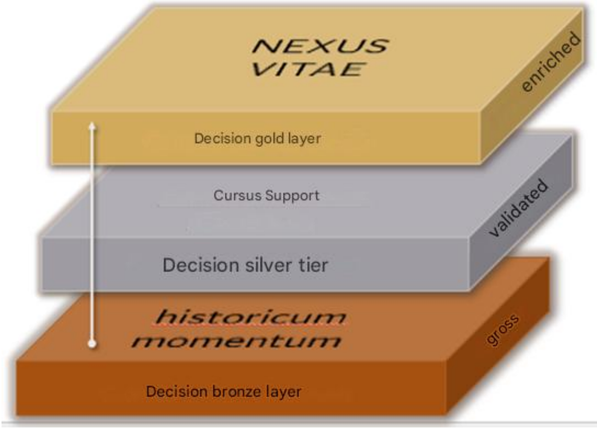
different levels. Its applicability can be expanded to the institutional and governmental spheres, contributing to integrated and sustainable solutions that reconcile the challenges of the water-energy-food nexus with the promotion of a balance between development and environmental conservation.

NEXUS *VITAE METHODOLOGY*

The methodology for the development of the *Nexus Vitae* analysis method was developed to facilitate the understanding and management of conflicts and cooperation in a multi-use Reservoir. The *Nexus Vitae* is structured into three analytical layers—Bronze Layer, Silver Layer, and Gold Layer—each performing a specific function, as can be seen in Figure 1. Each layer and its use in the panel will be further detailed below.

Figure 1. Nexus Vitae *Decision Layers*



Source: prepared by the author

BRONZE LAYER - *HISTORICUM MOMENTUM*

The methodological analysis starts from the base layer, the Bronze Layer entitled *Historicum Momentum*, as it reflects the essential function of this layer: to capture and highlight the decisive historical moments that shape the trajectory of the management of a multiple-use Reservoir. In practice, *Historicum Momentum* allows one to analyze not only the direct impact of past events, but also the contexts that led to conflicts, adaptations, and forms of cooperation between events involving the Reservoir. These moments, when mapped and organized in this layer, form the basis of an analysis that supports more consolidated decisions, offering a perspective that extends from the past to the future and guides the other analytical layers of the *Nexus Vitae*.

Revista ARACÊ
ISSN: 2358-2472

Process of Analysis of the *Historicum Momentum Layer*

- ***Documentary Survey:*** the compilation of historical data of multi-use reservoirs includes a broad analysis of documents and records that can reveal critical events that are fundamental for current and future management. It is interesting to identify data about its construction, including initial planning, costs, financing, environmental impact studies and the sectoral expectations involved in the project. In addition, episodes of floods and droughts are particularly relevant, as they allow mapping the environmental and social impacts caused by climate variations and the way in which the demands and demanders related to the Reservoir have responded to these pressures over time. Other aspects of interest include social and institutional conflicts, which may arise from issues of water allocation, impact on local communities, or tensions between sectors such as agriculture, power generation, and sanitation. Documentation of structural interventions, such as technological expansions, adaptations or renovations, also provides insight into the changing needs and priorities of the Reservoir. By compiling this data, it is possible not only to understand the events that defined the trajectory of the data, but also to identify patterns and strategies that were effective or problematic.
- ***Identification of Impacts:*** for each event surveyed, its effect is recorded, thus seeking to provide a comprehensive context for each documented impact, such as records of the effects on local communities, on the ecosystem, and on the various uses of the Reservoir, from documentary sources, critical milestones that have affected the relationships of demands and management over time can be identified. Thus providing a clear overview of how the Reservoir has evolved and the challenges faced.
- ***Data structuring***: after the documentary survey and the ordering of the Reservoir events, the input data should follow the structure shown in Table 1.

Table 1. Structuring for data entry in the Nexus Vitae panel.

Ordination	Year	Event	Primary Effect
0			
1			
...	...	...	...

Source: prepared by the author

This structured file ensures that the analysis of historical data is consistent and usable in subsequent layers, such as the Silver Layer and the Gold Layer. In this way, the

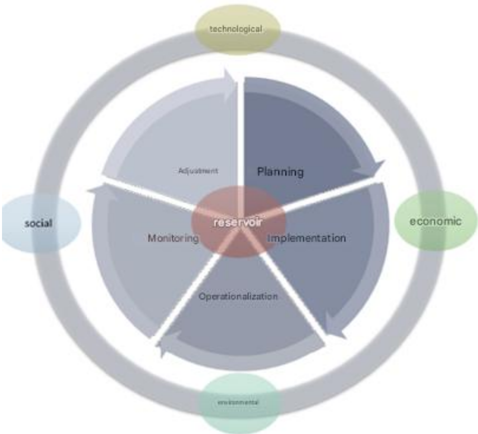
Revista ARACÊ
ISSN: 2358-2472

Bronze Layer not only documents the past, but also allows subsequent layers to have a reference point, offering an understanding of the challenges and opportunities for intervention based on past experiences. It serves as the reference base, allowing decision-makers to understand, in a systematic and visual way, the challenges faced in the management of the Reservoir over time.

SILVER LAYER – SUSTENTATIO CURSUS

The Silver Layer, entitled S*ustentatio Cursus*, reflects its central purpose: to sustain a continuous "course" or "path" of sustainable development, guided by the analysis of fundamental aspects that guarantee balance and resilience in the use of the Reservoir. For this layer, two stages are proposed, the first called PIOMA Dimension, refers to an initial framing carried out to identify which phase the Reservoir was in at the time of the selected historical event, represented in Figure 2, in the internal cycle. This initial framing cycle guides the guidelines for the second stage – Sustainability Dimension – external part of Figure 2, in the identification of deficiencies and potentialities for conflict and cooperation.

Figure 2. Integrative cycle of evaluation of sustainable management in a multiple-use reservoir



Source: prepared by the author

The analysis details how deficiencies in one or more dimensions of sustainability can increase the degree of risk of conflicts between users, while balanced and responsible management favors cooperation. In each of the phases of the cycle, risk weights are assigned that reflect the impact of the actions (or the lack thereof) in promoting an environment of cooperation or tension. This relationship with the Bronze Layer strengthens the decision-making basis in the *Nexus Vitae methodology*, ensuring that the accumulated knowledge serves as a guide for a more cooperative and resilient management.

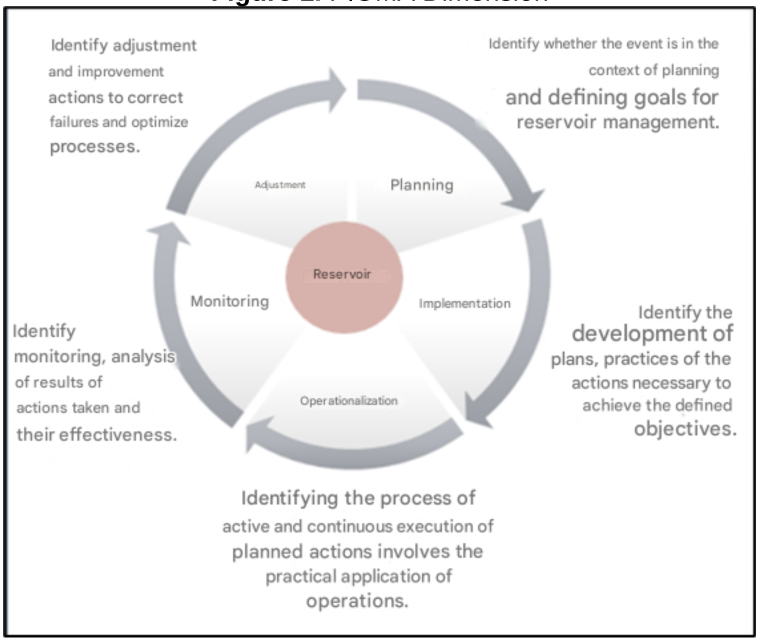
Revista ARACÊ
ISSN: 2358-2472

PIOMA Dimension

Composed of planning, implementation, operation, monitoring and adjustment, this dimension serves as a classifier that facilitates the identification and contextualization in which the Multiple Use Reservoir was in each event that was previously listed in the *hitoricum momentum* of analysis, its analysis structure can be seen from Figure 3. By identifying the PIOMA dimension in the initial phase, it facilitates more effective categorization where efforts and adjustments were most needed, whether in the planning phase of new policies, in the implementation of practices, in the operationalization of management routines or the reservoir itself, in the monitoring of results or in making adjustments for optimization.

With PIOMA acting as a point of convergence, the Silver Layer offers a sequence of phases that examine, holistically, how each action contributes to sustainable cooperation or where it poses a risk of conflict, providing a clear path for the application of historical lessons in a balanced and cooperative management. To identify which phase a Reservoir may be in from the documentation, it is important to consider the following aspects:

Figure 1. PIOMA Dimension



Source: prepared by the author

1. **Planning:** if the historical records indicate the definition of the project's bases and the participation of stakeholders, the reservoir may have gone through the planning phase. To confirm, it is essential to check initial documents with goals and strategies, feasibility and environmental impact studies, as well as consultation

Revista ARACÊ
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records and *feedback* from communities, experts, and regulatory bodies. Examples of documentation: strategic plans, feasibility reports, risk maps, and records of public consultation meetings.

2. **Implementation:** If the history highlights the execution of the planned actions, the reservoir may be in the implementation phase. To identify, check records that confirm the application of sustainability strategies and examine construction reports that evidence sustainable technology practices or impact mitigation measures. Example of documentation: progress reports, records of compliance with environmental standards, documentation of construction processes.
3. **Operation:** If the documentation includes the routine of use and continuous adjustments, the reservoir may be in the operation phase. To identify, look for records of operational activities, documents that evidence adaptations for efficiency and sustainability, and records of response to unforeseen events, such as droughts or floods. Example of documentation: operational records, maintenance procedures, operational adaptation reports.
4. **Monitoring:** If there is a systematic analysis of the impacts, the reservoir may be in the monitoring phase. To identify, look for formal reports such as audits and impact studies, verify environmental, economic, and social monitoring processes, and analyze documents that assess the effects on communities and ecosystems. Example of documentation: environmental audits, water quality monitoring, social impact reports, periodic reviews.
5. **Adjustment:** If the reservoir has undergone regular alterations and sustainable improvements, it may be in the adjustment phase. To identify, look for documents on monitoring-based corrections, records of adaptations to new challenges, and review processes for continuous improvement of sustainability. Example documentation: continuous improvement reports, operational adaptations, corrective action plans, and procedure update documents.

These guidelines provide a basis for analyzing what stage the multiple-use reservoir is in. Using historical documentation of planning, construction, operation, monitoring and adjustment, it is possible to identify the current stage and understand the level of integration of sustainable practices in each phase of the cycle.

Revista ARACÊ
ISSN: 2358-2472

Sustainability Dimension

Following the PIOMA Dimension phase, this stage deepens the analysis of the four dimensions of sustainability – social, economic, technological, and environmental – examining how each impacts conflict risk and the feasibility of cooperation in the context of a multi-use reservoir. This integrated model allows for a more comprehensive and detailed view of the factors that influence stability and relational dynamics among users. In this phase of analysis, each dimension is evaluated individually, but with a focus on the integrated contribution to its overall sustainability. This means that risks are weighed considering both the specific characteristics of each dimension and their role in the larger system.

Each Reservoir event is examined within the four dimensions of sustainability. For each event, a weight will be assigned to each dimension, considering the practices applied in its planning, implementation, operationalization, monitoring and adjustment phases. The absence or deficiency of these actions in a given dimension increases the weight of risk, signaling a greater predisposition to tensions and conflicts among those involved. It is then considered that sustainable dimensions with a higher weight value indicate a greater probability of the emergence of conflicts and barriers to cooperation, while dimensions with lower weight reflect greater stability and cooperation among those involved. In each dimension, weights will be assigned according to their situation in relation to sustainability, as follows:

0. **Low risk**: indicates stability and cooperation among users, signaling that sustainable practices are well established and that there is a low probability of conflict arising.
1. **1 - Medium risk**: represents a moderate potential for conflict, suggesting that some sustainable actions may be insufficiently implemented or lack continuity, slightly increasing the risk of tension.
2. **2 - High risk**: points to a strong absence or deficiency of sustainable practices, highlighting a high predisposition to conflict and a low capacity for cooperation.

The sum of these weights in each historical event generates a subtotal that reflects the degree of conflict and cooperation associated with that event, as exemplified in Figure 4, and thus this layer will then be consolidated into the Gold layer.

Revista ARACÊ
ISSN: 2358-2472

Figure 4. Silver Tier – their respective weights and subtotals of conflict and cooperation risks

Cursus Support				
PIOMA dimension	sustainability dimension		conflict risk	risk cooperation
verification	social	2	6	4
	technological	1		
	economic	2		
	environmental	1		

Source: prepared by the author

GOLD TIER – *NEXUS*

The Gold Layer – *Nexus*, represents the most refined level of the analysis, where the potential for conflict and cooperation between the various *stakeholders* involved in the management of the Multi-Use Reservoir is examined in detail. The previous layers complement this analysis by providing a deeper dive into the data of each dimension, allowing the identification of the events in the conflict and cooperation matrix in this layer to be consolidated. This data integration process facilitates the identification of areas that need intervention and helps in the development of strategies to promote cooperation and mitigate conflicts in the context of multi-use Reservoirs.

In this layer, whose proposal is to perform a validation based on a conflict and cooperation matrix, it was elaborated with different levels of cooperation and conflict, providing an organized view on how these events are distributed in terms of risk and stability and were based on the TWINS studies, which provides an advanced reference for the interpretation of interactions between users in regions where the management of water resources is shared (MIRUMACHI, 2015). And its completion will be carried out for each event analyzed, which facilitates the visualization of patterns and allows an in-depth analysis of the dynamics between cooperation and conflict in each event studied.

To understand where the event values will be positioned in the Matrix, it is enough to cross the subtotals of each event obtained from the Silver Layer and cross them with the intervals of the weights referring to the axes of conflict intensity and cooperation (horizontal), as outlined in Figure 5. The Gold layer structures the understanding of the dynamics of sustainability in environments where different interests need to be reconciled, revealing the areas with the greatest propensity for tensions and those with the greatest potential for collaboration.

Revista ARACÊ
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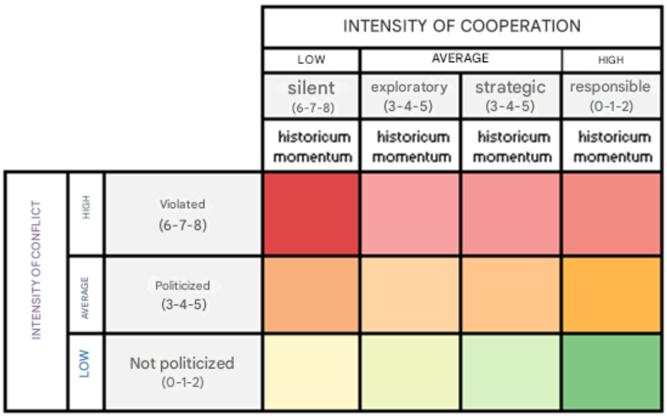
Figure 5. Conflict and Cooperation Matrix Outline for the Gold Tier – Nexus



Source: prepared by the author

The analysis goes beyond traditional indicators, focusing on an in-depth reading of the historical, economic, technological, environmental and social conditions that shape the behavior of *stakeholders* in the Reservoir.

Definition of Conflict Regions in the matrix

The process begins in the Silver layer, where specific weights are assigned to each event evaluated in the sustainability dimensions. The sum of these weights in each event generates a subtotal that reflects the degree of conflict and cooperation associated with that event. These Silver layer subtotals are then used as identifiers of the exact position of the event in the Gold layer's conflict and cooperation matrix. The matrix is organized with intervals of specific weights of conflict intensity (on the vertical axis) and cooperation (on the horizontal axis), these intervals of the conflict and cooperation matrix are based on the studies of Grünwald et al. (2020) which is an evolution of Mirumachi (2015) methodological proposal, which is detailed below:

- High Conflict Regions (6-7-8) | *Securitized conflict:* occur when the sum of the weights for all dimensions (social, economic, technological, and environmental) approaches the maximum value, indicating a generalized absence of effective actions. In this scenario, conflicts occur when extraordinary actions, outside of regular political processes, are adopted to justify strategic measures that maximize specific benefits. In multi-use reservoirs, this often involves prioritizing interests such as power generation or water security, to the detriment of social and environmental aspects (MIRUMACHI & ALLAN, 2007). For example, the construction of dams for hydroelectric generation may be presented as essential for economic and energy growth, but it results in significant impacts such as expropriations, loss of agricultural land, and reduced access to water for downstream populations. This type of conflict reflects inequalities in the use and control of resources, with benefits concentrated in specific sectors and high social costs for the most vulnerable communities. Understanding the securitized conflict in reservoirs is essential to propose solutions that promote more balanced governance and mitigate the negative impacts of these strategic decisions.

Criterion: Sum of the weights of the Silver layer that resulted in values from 6 to 8.

- Medium Conflict Regions (3-4-5) | *Politicized conflict*: In these countries, the potential for conflict is significant, but cooperation can still be feasible through adjustments in the sustainability dimensions. Politicized conflict occurs, for example, when divergent interests – such as water supply, power generation, and agricultural irrigation – begin to dispute the use of the same resources without adequate allocation or negotiation mechanisms. In this situation, the actors involved, such as governments, local communities, productive sectors and environmentalists, have their needs recognized, but face challenges to reconcile priorities in a balanced way. A striking feature of these regions is the potential for transformation. While the level of conflict is significant, it is still in a middle zone, where there is room for negotiations and adjustments. This suggests that, with the implementation of specific strategies, it is possible to reverse the scenario for more effective cooperation. The transition to lower levels of conflict and greater cooperation depends on managers' ability to identify imbalances and act proactively. Thus, medium-conflict regions should be seen not only as challenges, but as opportunities for building more resilient and inclusive governance systems.

Criterion: Sum of the weights of the Silver layer that resulted in values from 3 to 5.

- Low Conflict Regions (0-1-2) | *Non-politicized conflict*: It is characterized by an environment of low conflict intensity, in which actions related to the dimensions of sustainability – social, economic, technological and environmental – are being widely implemented effectively. Under these conditions, the risk of disputes arising between reservoir users is reduced, creating a favorable scenario for cooperation and shared management of resources.

Criterion: Sum of the weights of the Silver layer that resulted between values from 0 to 2.

- High Cooperation Regions (6-7-8) | *Responsible cooperation*: This is characterized by an advanced level of understanding among strategic actors, who agree

Revista ARACÊ
ISSN: 2358-2472

on coordinated procedures and actions, but opt for non-legally binding cooperation. This type of cooperation, while not mandatory, is underpinned by mutual commitments based on trust and a shared interest in sustainable reservoir management. In the context of multi-use reservoirs, responsible cooperation can be observed in situations where the various user sectors – such as energy, human supply, irrigation, navigation and environmental conservation – converge on agreements on the management of water resources. Although the absence of legal ties may pose a risk to the continuity and effectiveness of agreements, Responsible Cooperation stands out for its flexibility and ability to adapt to contextual changes, being especially useful in multiple-use reservoirs, where interests are diverse and often conflicting. When well conducted, this approach strengthens the foundations for future more robust and legally binding cooperation.

Criterion: Sum of the weights of the Silver layer that resulted in values from 6 to 8.

- Regions Medium Cooperation (3-4-5) | *Strategic cooperation*: In this range, cooperation still exists, but there are moderate gaps in the implementation of sustainable actions. Users collaborate on certain aspects, but there is tension and the need for adjustments in some dimensions. Strategic actors identify shared objectives and carry out joint actions, but technical, administrative and legal details are still discussed in forums and meetings. It represents an intermediate stage in the process of collaboration between strategic actors, in which common objectives are identified, but disagreements persist about the methods or approaches to achieve them. This type of cooperation is characterized by the exchange of ideas and frequent negotiations, where actors work together on practical actions, even if they face technical, administrative or legal divergences. Although strategic cooperation denotes advances in dialogue and joint actions, it also highlights the need for more robust mechanisms to mediate and resolve disagreements. Creating a collaborative action plan with deadlines and goals can help turn differences into opportunities for learning and improving reservoir management, promoting a more solid path to long-term sustainability.

Criterion: Sum of the weights of the silver layer that resulted in values ranging from 3 to 5.

Low Cooperation Regions (0-1-2) | *Exploratory cooperation*: characterizes contexts where interactions between reservoir users are marked by tensions and mistrust, reflecting a significant absence of cooperation. In these situations, the factors that make up the dimensions of sustainability (social, economic, technological and environmental) have

Revista ARACÊ
ISSN: 2358-2472

severe flaws, resulting in a high risk of conflict and the difficulty of implementing joint actions for the sustainable use of water resources. Overcoming this level of cooperation requires structural efforts, such as the implementation of participatory governance mechanisms, improvement of technological infrastructures, and investment in environmental recovery. In addition, it is crucial to promote social inclusion and continuous dialogue, creating minimum conditions for a transition from conflictual interactions to more advanced stages of cooperation.

Criterion: Sum of the weights of the silver layer that resulted between values of 0 and 2.

VALIDATION OF THE *NEXUS VITAE METHODOLOGY*

Nexus *Vitae* is a methodology that organizes and proposes a visualization of historical data on topics related to the water, energy, and food nexus, focusing on sustainability and the dynamics of conflict and cooperation. The validation of the methodology aimed to evaluate its effectiveness in capturing the dynamics of conflict and cooperation inherent to the management of water resources in such a complex system, so it was carried out based on the historical survey of the Sobradinho reservoir, located in the São Francisco River Basin, one of the most relevant regions for water management in Brazil. This Reservoir plays a strategic role, serving multiple uses, such as hydroelectric power generation, agricultural irrigation, human supply and environmental conservation. However, the management of these uses often results in conflicts between the various sectors involved, especially when it comes to their construction, and in periods of water scarcity, such as those experienced between 2013 and 2019 (ANA, 2022).

Based on historical data, critical events were analyzed from the perspective of the water-energy-food nexus, showing how regulatory and operational decisions impacted the different actors and sectors. The results obtained reinforce the relevance of the method as a decision support tool, capable of providing valuable *insights* for managers and public policy makers, promoting cooperation among the various users and mitigating potential conflicts.

STRUCTURE OF INPUT DATA

To start the application of the layered analysis methodology, the Bronze layer - *historicum momentum was initiated*, in which an input file in .csv format was used, which

Revista ARACÊ
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should follow a four-column structure and the data entered should be standardized as described below, and represented in Chart 1. With the data from the historical survey of the Sobradinho Reservoir, the most relevant events that permeated risks of conflict and cooperation were listed, from the construction of the Reservoir to the last event related to water scarcity. These events were defined based on the historical survey used to validate the panel.

1. **Sorting**: This column defines the sequence of events. It is recommended to use incremental numbering (e.g., 1, 2, 3, ...) so that the data is displayed in an orderly fashion, especially for temporal views.
2. **Year**: This column contains the year the event occurred. It allows you to filter and group the data by period, facilitating the chronological analysis of events.
3. **Event**: This column describes a brief description of the event, provides context to the user about what happened at each point of time. Clarity and objectivity in the texts in this column are essential for the user to quickly understand what each event represents.
4. **Primary Effect**: This column identifies the main effect or the most relevant impact that the event caused. It allows for additional categorization of events, which helps in analyzing impact patterns. This column can contain short textual data or category codes, depending on the level of detail you want.

Table 1. *Historicum momentum* – structure for entering data in the Dashboard

Ordination	Year	Event	Primary Effect
0	1970	Construction of the Reservoir	Hydropower production
1	1976	Expropriations	Reservoir Filling
2	1976	Flooding of areas	Reservoir Filling
3	1979	UH Sobradinho begins operationalization	Electricity generation
4	1984	Prolonged drought	Retreat of the banks / lack of water for consumption and irrigation / impacts on the crop
5	2013	Water scarcity	Resolution No. 442/2013: First major measure to reduce the minimum flow from 1,300 m³/s to 1,100 m³/s, marking the beginning of water adaptations in the face of severe scarcity.
6	2015	Water scarcity	Resolution No. 713/2015: Established the limit of 900 m³/s as a new minimum level, valid until the end of 2015. This change was a response to the continued low rainfall in the basin. / navigation problems (stretch between Sobradinho and Juazeiro), industrial abstractions /in water intakes for water supply /in agricultural projects
7	2016	Water scarcity	Resolution No. 1,283/2016: Allowed the flow of 700 m³/s until March 2017, one of the lowest recorded at the time. The measure included

Revista ARACÊ
ISSN: 2358-2472

			rigorous environmental monitoring to assess the impacts.
8	2017	Water scarcity	Resolution No. 1,291/2017: Authorized the lowest level so far, of 550 m³/s, adopted continuously as of October 2017. This decision considered the worsening of the drought and aimed to guarantee the minimum volume in the reservoirs.
9	2019	Water scarcity	Resolution No. 90/2018: Renewed the minimum flow authorization, of 550 m³/s, with emphasis on continuous monitoring of water conditions.

Source: prepared by the author

On the Silver tier - *Sustentatio Cursus*, the individual analysis was carried out for each event, where they were initially framed in the respective PIOMA dimension and later, based on the justifications based on the documentary rereadings, their respective weights were applied in the Sustainability dimension. The justifications for the attribution of weights in the Sustainability dimension in each event are contained in Chart 21. For each dimension of sustainability, only a single weight was assigned. In Figure 6, the evolution of the layered analysis is presented, already aggregating the Bronze and Silver layers being filled in from extensive documentary rereadings, and being validated, it is possible to see the consolidated values of each dimension and the sum referring to the weights for the dimension of conflict and cooperation.

Table 2. Justifications of the weights of the Sustainability dimension for each event.

Ordination	**PIOMA Dimension**	**Sustainability Dimension – attribution of weights and justifications**			
		Environmental	**Economic**	**Social**	**Technological**
0	**Planning** initial phase of idealization and conception of the project. This period was marked by technical, environmental and socioeconomic studies that supported the decision to build the reservoir.	**Weight 2**: The flooding of a vast area has caused significant impacts on the local ecosystem, including the loss of natural habitats and changes in the water dynamics of the river.	**Weight 2:** The project boosted regional development by promoting energy generation, but also brought costs associated with managing environmental and social impacts.	**Weight 2**: Construction has entailed the displacement of local communities, generating complex social challenges, such as land loss, resettlements, and changes in traditional ways of life.	**Weight 1**: The implementation of technology for the construction of the reservoir was significant for the time, but represented a moderate advance in the context of hydraulic engineering, considering industry standards.
1	**Implementation** The event reflects the practical actions to make the project viable, including resettlements and	**Weight 2:** Significant impact due to the removal of native vegetation and	**Weight 2:** High costs related to expropriations and resettlements.	**Weight 2:** Large displacement of local populations, causing cultural losses and	**Weight 1:** Low technical innovation involved; process already established for

Revista ARACÊ
ISSN: 2358-2472

	adaptation of the flooded area.	loss of biodiversity.		socioeconomic challenges.	projects of this scale.
2	**Implementation** The flooding is part of the direct process of implementing the reservoir, with immediate impacts on the environment and communities.	**Weight 2:** Habitat destruction, changes in the local hydrological cycle, and increased methane emissions due to decomposition of flooded biomass.	**Weight 1**: Indirect costs related to the flooded areas, including loss of productive land.	**Weight 2:** Additional displacement and knock-on effects on communities adjacent to flooded areas.	**Weight 1**: The filling process follows conventional technical standards.
3	**Operation** This event marks the beginning of the reservoir's regular activities for power generation, meeting the planned objectives.	**Weight 1:** Residual environmental impact; stabilized operation after construction events.	**Weight 1**: Significant economic contribution from the production of electricity, but little reflection was made of the improvement in the economy in the region.	**Weight 1:** Indirect benefits from power generation, but no immediate direct impact on communities.	**Weight 0:** It represents a technological milestone for the time, consolidating large-scale hydroelectric generation in Brazil.

Source: prepared by the author.

Table 2. Justifications of the weights of the Sustainability dimension for each event - continued.

Ordination	PIOMA Dimension	Sustainability Dimension – attribution of weights and justifications			
		Environmental	**Economic**	**Social**	**Technological**
4	**Monitoring** The prolonged drought requires continuous monitoring to mitigate its effects and adjust reservoir operations	**Weight 2:** Reduction of aquatic biodiversity and increased exposure of soil on the margins, resulting in erosion.	**Weight 2:** Significant losses in agricultural production and increase in water abstraction costs.	**Weight 2:** Losses for rural communities, which faced water shortages for consumption and irrigation.	**Weight 2:** Little-explored technological solutions to mitigate impacts.
5	**Adjustment** This event characterizes a crisis situation, where emergency actions were necessary to adapt water management	**Weight** 2: Reduction of the useful volume of the reservoir, impacting the aquatic fauna and flora.	**Weight** 2: Reduction in energy generation and losses in economic activities associated with water.	**Weight 2:** Affected water-dependent communities for drinking and agriculture.	**Weight 1:** Solutions to shortages still limited; palliative measures adopted.

Revista ARACÊ
ISSN: 2358-2472

	to extreme conditions.				
6	**Adjustment** Emergency measures to reduce the flow aimed to meet the hydrological conditions and minimize the impacts of the shortage.	**Weight** 2: Impacts on the navigability and aquatic ecosystems of the São Francisco.	**Weight** 2: Agriculture and industry faced significant losses due to water restriction.	**Weight 2**: Problems in navigation and water collection directly affected communities and industrial sectors.	**Weight 1:** Technological solutions for mitigation still limited.
7	**Adjustment** Progressive flow reductions reinforce the need for continuous operational adjustments in the face of a prolonged crisis.	**Weight 2**: The severe restriction has drastically impacted aquatic and terrestrial ecosystems.	**Weight 2**: Broad losses in resource-dependent economic sectors	**Weight 2**: Acute shortages affected water-dependent farming and urban communities.	**Weight 1:** Emergency technological measures still insufficient.
8	**Adjustment** This event reflects the continuity of crisis management, with actions aimed at mitigating the impacts of a critical hydrological situation.	**Weight 2**: Worsened environmental conditions due to the extreme reduction of the reservoir level.	**Weight 2**: Intensified economic losses, including increased energy and agricultural costs.	**Weight 2:** Expansion of supply and irrigation problems, directly affecting the well-being of communities.	**Weight 1:** Technological advances have begun to be explored to mitigate impacts.
9	**Adjustment** - This event remains operational adjustments to deal with the lingering effects of water scarcity.	**Weight 2**: Persistence of severe environmental impacts, including ecosystem degradation.	**Weight 2**: Economic losses continued in multiple sectors due to the water crisis.	**Weight 2**: Communities faced prolonged restrictions on access to water for consumption and production.	**Weight 1:** Emerging use of technology for water monitoring and management.

Source: prepared by the author.

Revista ARACÊ
ISSN: 2358-2472

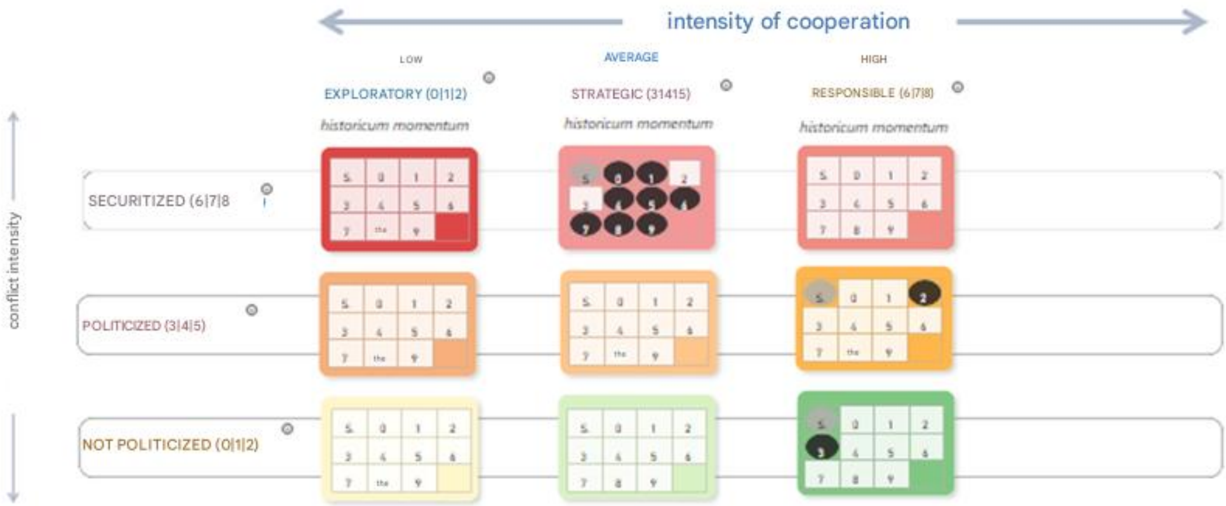
Figure 6. Consolidated framework of the Bronze and Silver decision layer.

	Historicum momentum				*Sustentatio Cursus*				
	Ordenação	Ano	Evento	Efeito Primário	dimensão PIOMA	dimensão sustentabilidade		risco conflito	risco cooperação
INÍCIO DA OPERAÇÃO DO RESERVATÓRIO	0	1970	Construção do Reservatório	Produção de energia hidroelétrica	planejamento	ambiental	2	7	3
						econômica	2		
						social	2		
						tecnológica	1		
	1	1976	Desapropriações	Enchimento do reservatório	implementação	ambiental	2	7	3
						econômica	2		
						social	2		
						tecnológica	1		
	2	1976	Inundações de áreas	Enchimento do reservatório	implementação	ambiental	2	6	4
						econômica	1		
						social	2		
						tecnológica	1		
	3	1979	UH Sobradinho inicia a operacionalização	Geração de energia elétrica	operação	ambiental	1	3	7
						econômica	1		
						social	1		
						tecnológica	0		
	4	1984	Estiagem prolongada	Recuo das margens / falta de água para consumo e irrigação / impactos na lavoura	monitoramento	ambiental	2	8	2
						econômica	2		
						social	2		
						tecnológica	2		
ESCASSEZ HÍDRICA NO RESERVATÓRIO	5	2013	Escassez hídrica	Resolução nº 442/2013: Primeira grande medida para redução da vazão mínima de 1.300 m³/s para 1.100 m³/s, marcando o início de adaptações hídricas frente à escassez severa.	ajuste	ambiental	2	7	3
						econômica	2		
						social	2		
						tecnológica	1		
	6	2015	Escassez hídrica	Resolução nº 713/2015: : Estabeleceu o limite de 900 m³/s como novo patamar mínimo, válido até o final de 2015. Esta mudança foi uma resposta à continuidade das baixas precipitações na bacia. / problemas na navegação (trecho entre Sobradinho e Juazeiro), captações industriais /em tomadas d´água para abastecimento de água /em projetos agrícolas.	ajuste	ambiental	2	7	3
						econômica	2		
						social	2		
						tecnológica	1		
	7	2016	Escassez hídrica	Resolução nº 1.283/2016: Permitida a defluência de 700 m³/s até março de 2017, uma das menores registradas na época. A medida incluiu monitoramento ambiental rigoroso para avaliar os impactos.	ajuste	ambiental	2	7	3
						econômica	2		
						social	2		
						tecnológica	1		
	8	2017	Escassez hídrica	Resolução nº 1.291/2017: Autorizou o patamar mais baixo até então, de 550 m³/s, adotado de maneira contínua a partir de outubro de 2017. Esta decisão considerou o agravamento da seca e visou garantir o volume mínimo nos reservatórios.	ajuste	ambiental	2	7	3
						econômica	2		
						social	2		
						tecnológica	1		
	9	2019	Escassez hídrica	Resolução nº 90/2018: Renovou a autorização de vazão mínima, de 550 m³/s, com ênfase no monitoramento contínuo das condições hídricas.	ajuste	ambiental	2	7	3
						econômica	2		
						social	2		
						tecnológica	1		

Source: prepared by the author.

Ending with the Gold – *Nexus layer*, the values referring to the weights applied to the Sobradinho Reservoir can be seen in Figure 7, whose Conflict and Cooperation Intensity Matrix, the position of each event was selected, according to the consolidation of the weights of the Silver layer, in relation to the weights of the cooperation and conflict matrix. After recording all the events in the matrix, the final visualization showed where the historical events are concentrated, allowing us to verify the influence of sustainability on the dynamics of conflict and cooperation. The matrix presented reflects the distribution of historical events in the Sobradinho Reservoir, where there is a significant concentration of events at high levels of cooperation and medium levels of conflict, positioned at the intersection of securitization and strategic cooperation.

Figure 2. Gold Tier – Nexus: conflict and cooperation matrix.



Source: prepared by the author

Revista ARACÊ
ISSN: 2358-2472

DISCUSSION

The history of water management in the Brazilian Northeast reveals complex challenges, shaped by climate irregularity and the coexistence of multiple economic, social, and environmental interests. From the historical records of droughts in the sixteenth century to contemporary impacts, the São Francisco Basin, particularly in its largest reservoir, Sobradinho, emerges as an essential field of study to understand the effects of climate change on water resources management. The flow reduction operations, implemented since 2013, illustrate an attempt to adapt to critical water scarcity events, but also expose the complexity of the interactions between economic sectors and users dependent on this vital resource.

By applying the Nexus Vitae *layered analysis methodology*, it was possible to investigate how regulatory decisions impacted the different sectors involved. This analytical tool reveals synergies and *trade-offs* that are often overlooked in industry analyses. For example, the gradual reductions in flows, carried out by Chesf, preserved the interconnected electrical system, but generated significant adverse consequences for irrigated agriculture, river navigation, and human supply in cities such as Petrolina and Juazeiro.

From a social point of view, the reduction in flows has exacerbated tensions between the energy and irrigation sectors, compromising harvests and causing economic losses. According to CBHSF reports (2020), river transport was severely impaired, highlighting the need for structural interventions, such as dredging and channel maintenance. In the environmental field, lower water availability and changes in flow patterns affected local biodiversity and water quality, creating additional challenges for managers and communities.

This scenario shows that decisions made during periods of water crisis require long-term strategic planning. The predominance of reactive responses, based on emergency resolutions by ANA and IBAMA, reinforces the perception that there are still significant gaps in Brazilian water governance. This is corroborated by Conti et al. (2013), who highlight the clientelist tradition and the unequal distribution of resources as factors that perpetuate structural vulnerability in the semi-arid region.

Despite these difficulties, the management process of the Sobradinho reservoir also demonstrated the potential for cooperation. Technical meetings promoted by the CBHSF, involving actors such as Chesf, irrigators and local communities, provided the exchange of information and the search for shared solutions. The development of the *Nexus Vitae methodology*, with its analytical layers, reinforced the ability to visualize in an integrated way the effects of decisions on different dimensions of sustainability – social, economic, environmental and technological.

These results indicate that water management in Brazil needs to incorporate holistic and participatory approaches, aligned with the principles of the water-energy-food nexus. The experience in Sobradinho highlights the importance of strengthening governance instruments, promoting greater integration between the different user sectors and prioritizing long-term strategies that balance conflicting demands. Future studies may explore the application of the *Nexus Vitae* method in other contexts, expanding its relevance as a tool for sustainable analysis and planning in multiple-use systems.

CONSIDERATIONS FOR THE APPLICATION OF *NEXUS VITAE* TO THE SOBRADINHO RESERVOIR

The results presented reveal a significant predominance of historical events located in the categories of "Securitized Conflict" and "Strategic Cooperation". This configuration indicates a marked dynamic in the Sobradinho Reservoir, where conflicts are often intensified by emergency and centralized decisions, while cooperative efforts seek, albeit partially, to mitigate the impacts of these conflicts through strategic joint actions.

The predominance of the 'Securitized Conflict' reflects situations in which actors resort to exceptional measures to deal with crises, such as water scarcity and the need to prioritize certain uses of the reservoir over others. These measures, while effective at critical moments, often do not follow broadly participatory processes, which can increase tension between impacted sectors. In the context of the Sobradinho Reservoir, this is manifested in events such as the reduction of minimum flows for energy generation, which often negatively affect urban supply, irrigation and navigation. These conflicts emerge mainly from the inability to simultaneously meet environmental, social and economic demands, especially in scenarios of prolonged drought. The securitized nature of these actions shows that, in periods of water stress, reservoir management has prioritized emergency and centralized responses, focusing on the maintenance of essential services, such as energy generation. However, this approach limits the engagement of local and regional actors, reducing the possibility of integrated and sustainable solutions.

The significant presence of events in the category of 'Strategic Cooperation'

Revista ARACÊ
ISSN: 2358-2472

demonstrates that, despite the tensions, the actors involved are able to identify common objectives and promote joint actions. In the case of the Sobradinho Reservoir, this is reflected in practices such as the holding of intersectoral forums, technical meetings and negotiations on minimum flows. Such initiatives seek to harmonize conflicting interests, even if disagreements persist as to how to implement the proposed measures. In the context of Sobradinho, it is evident that, although there are efforts to create spaces for dialogue and joint decisions, these processes often come up against the complexity of the demands and the disparity of power between the sectors. This suggests that in order to maximize the benefits of cooperation, it is necessary to strengthen institutional mechanisms and promote more inclusive and participatory governance.

The results indicate that the Sobradinho Reservoir operates in a zone of unstable equilibrium between intense conflicts and moderate strategic cooperation. This configuration reflects both the structural challenges of multiple-use management and the resilience of the actors involved in seeking temporary and contextual solutions. However, it is clear that the current administration lacks more robust mechanisms to prevent conflicts and transform strategic cooperation into responsible cooperation, with legally binding commitments and long-term solutions.

THE ROLE OF METHODOLOGY FOR PUBLIC POLICIES AND INTEGRATED MANAGEMENT

The development of public policies and the integrated management of strategic resources, such as water, require robust methodological approaches, capable of contemplating the complexity of the interactions between the social, economic, environmental and technological dimensions. The methodology proposed in this work demonstrated not only its effectiveness as a tool for analysis and diagnosis, but also its potential to support more assertive and inclusive political and technical decisions. This structure allows analyzing the evolution of the challenges faced by reservoir users, evidencing trends and gaps in the governance of water resources. In the field of public policies, such an approach offers a scientific basis for decisions that reconcile divergent interests, promoting a balance between economic development and environmental protection. For example, in the case of the Sobradinho Reservoir, the results pointed to a prevalence of securitized conflicts and strategic cooperation. This evidence can guide policies aimed at crisis prevention, such as investments in water-efficient technologies and

Revista ARACÊ
ISSN: 2358-2472

the strengthening of basin committees, as well as encourage the transition to responsible cooperation models.

Integrated management requires that public policies consider the interdependence between different dimensions of sustainability. The proposed methodology addresses these dimensions in an integrated way, evaluating not only historical events, but also their impacts on economic, social, technological, and environmental aspects. This multidimensional approach is essential for public policies aimed at multi-use reservoirs, as it allows the identification of critical points that need priority intervention. In the case of Sobradinho, the methodology revealed that water scarcity crises have wide-ranging implications, affecting everything from urban supply to energy generation and irrigation. Integrated policies, based on this analysis, can prioritize actions that mitigate the impacts of these crises, such as improving sustainable agricultural practices and implementing strategies to increase the system's water resilience.

LIMITATIONS AND POSSIBILITIES OF REPLICATION IN OTHER CONTEXTS

The methodology developed to analyze the dynamics of cooperation and conflict in multi-use reservoirs has significant potential for application in other natural resource management contexts. However, like any scientific and technical approach, it also has limitations that need to be considered when evaluating its adaptability to different scenarios. Among the main limitations of the methodology is the reliance on reliable and comprehensive historical data. The proposed analysis requires detailed information on past events, their impacts, and the institutional responses implemented. In contexts where data collection is limited or fragmented, such as in regions with less infrastructure or weak governance, the full application of the methodology can be compromised.

In addition, the methodology is based on an analysis structure that presupposes the interaction of sustainability dimensions (economic, social, environmental and technological). This multidimensional approach, while comprehensive, may not capture cultural or institutional particularities that influence resource management in different contexts. Despite the small limitations, the methodology has characteristics that favor its replication in different contexts. First, its analytical framework, based on the relationship between conflict intensity and cooperation, is flexible enough to be adapted to new scenarios. For example, the analysis matrix can be recalibrated to include dimensions or indicators specific to a given context, such as social justice issues, food security, or crossborder governance.

The methodology also stands out for its ability to integrate multiple actors and perspectives. This feature is particularly useful in natural resource management contexts that involve local communities, private sectors, and government agencies, such as in transnational watershed management. Application in an international context could, for example, explore how countries with different levels of development and priorities can achieve strategic cooperation, even in the face of securitized conflicts. Another possibility is its application in different types of resources, such as renewable energy management, forests, or coastal areas. To successfully replicate the methodology in other contexts, it is essential to make adaptations that consider local particularities. One of the first adaptations needed is the personalization of the indicators used to measure the dimensions of sustainability. For example, in a context where the social issue has greater weight, indicators such as community participation and equity in the distribution of benefits can be prioritized. In addition, application in contexts of areas with low governance may require the incorporation of conflict mediation tools and trust-building strategies among actors. These adjustments not only increase the applicability of the methodology, but also expand its impact as an integrated management tool. When adapted appropriately, the methodology has the potential to become a powerful tool to address global sustainability challenges and to promote a more inclusive, cooperative, and resilient governance model.

CONCLUSION

The study presented brought significant contributions to the understanding of the water-energy-food nexus in the context of conflict management and cooperation in multiple-use reservoirs, with a focus on sustainability and equity in the use of these essential resources. From the analysis of the Sobradinho reservoir, it was demonstrated that the interactions between the water, energy and food systems demand integrated approaches, capable of identifying synergies and *trade-offs*, promoting a management that balances the interests of the various actors involved.

One of the main contributions of this research was the adaptation of the TWINS method to local contexts, integrating the dimensions of social, environmental, economic and institutional sustainability. This approach enabled a simultaneous and in-depth analysis of the dynamics of conflict and cooperation, demonstrating that these phenomena coexist intrinsically and that their management requires strategies that transcend binary

Revista ARACÊ
ISSN: 2358-2472

solutions. The Nexus Vitae panel, developed and validated in this work, proved to be a robust tool to identify impact patterns and support strategic decision-making in highly complex scenarios.

The results highlighted the relevance of public policies that incorporate an intersectoral vision, considering the interdependencies between the systems of the AEA nexus. Reservoir management, especially in contexts of water scarcity, must prioritize transparency in decision-making processes and the inclusion of all stakeholders, including local communities, agricultural producers, energy resource managers, and other sectors dependent on these resources. The lack of integration between regulatory bodies and the fragmentation of interests were pointed out as recurrent challenges, reinforcing the need for institutional strengthening and practices that promote trust among the various users.

Another relevant point was the identification of the importance of incorporating emerging technologies, such as real-time monitoring systems, computer modeling, and artificial intelligence, to improve data collection and analysis. These tools can enable more agile and effective management, reducing the vulnerability of water systems in critical scenarios, such as periods of prolonged drought. In addition, the impacts of climate change on the dynamics of conflict and cooperation were pointed out as a crucial theme for future studies, considering the increase in pressure on water resources and the intensification of regional inequalities.

The application of the Nexus Vitae panel in the Sobradinho reservoir demonstrated not only the validity of the developed methodology, but also its potential for replicability in other contexts. Its holistic approach offers a solid foundation for the analysis of complex water systems, allowing the identification of more equitable and sustainable solutions. Future studies can explore the application of this method in international scenarios, considering transboundary contexts and watersheds with diverse socioeconomic characteristics.

It is concluded that the balance between the demands of water, energy and food is a challenging task, but essential for the promotion of sustainable development. This work not only advances scientific knowledge about the EEA nexus, but also provides a practical tool for managers and public policy makers. By integrating the dimensions of sustainability and promoting collaboration between different sectors, the approach proposed here contributes to mitigating conflicts and strengthening cooperation mechanisms, representing an important step towards a more efficient and inclusive management of water resources.

Revista ARACÊ
ISSN: 2358-2472

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