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The socio-ecological Nexus+ approach used by the Brazilian Research Network on Global Climate Change

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The Brazilian Research Network on Global Climate Change (Rede CLIMA) is an interdisciplinary network composed of 16 research groups, which interact in different levels and programs. This work aims at building climate change cause–effect research from a 'Nexus+' perspective, considering the added value of flexibility and adaptability of the concept. The article draws on the Nexus literature alongside a case study in São Francisco River Basin, Northeast Brazil. An additional pillar to the Nexus approach is proposed here, the socio-ecological security, which can be defined as a political-territorial dimension of coupled social and ecological systems. A collaborative research-practice frame was applied to the study region, a hotspot of climate vulnerability in Brazil. Our results highlight the need for this fourth component to address socio-ecological sustainability into context.

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Introduction

In response to the urgency that the challenge of global climate change imposes on society, and the critical need for high quality and relevant scientific knowledge to support public policies focusing on these issues, the Federal Government of Brazil established in 2008 the Brazilian Research Network on Global Climate Change – Rede CLIMA. The Rede CLIMA (RC) is a network of 16 interdisciplinary research groups, which interact in different levels and programs, through inter and transdisciplinary approaches. The RC's research activities have been progressively prioritizing the use of interdisciplinary and transdisciplinary methods to address the causes and effects of global climate change at national and regional levels.

Promoted by United Nations (UN) agencies as a key approach to the implementation of the Sustainable Development Goals (SDG), the Nexus approach has found obstacles to be applied where, at first, it is most needed: in low and middle income countries. The widely disseminated Nexus approach is based on the argument that the limited emphasis on the interfaces of water, energy, and food (WEF) securities commonly leads to contradictory interventions and the inefficient use of natural resources [1].

Populations whose livelihoods are directly impacted by climate change, such as traditional populations and family farmers, particularly in low income countries, are among the most vulnerable due to their high climate sensitivity, and low institutional capacity to minimize risks and to respond to negative impacts through informed decision-making at different scales [2–5]. This means that social vulnerability (including the institutional one) and climate sensitivity are intertwined: therefore, this relationship has to be acknowledged for a genuinely holistic Nexus approach. In this sense, public management has the challenge of internalizing actual problems, such as climate change, in a transversal way, crossing the various sectors involved with adaptive capacity building.

Climate vulnerability is a broad concept used to express the propensity of a system – social, ecological or socio-ecological – to be adversely affected by climate hazards,

covering not only internal sensitivity to the climate stimulus (exposure/hazard), but also the inability (adaptive capacity) to cope or to adapt to its impacts [6]. For both, historical, socioeconomic, and institutional aspects play an important role, which has been explored under the so called social vulnerability research [7,8]. In particular, institutional aspects have been paramount for defining the governance landscapes in which adaptation resources and actors interact and move from potential to actual adaptation [9,10]. Political turnovers and insufficient institutional capacity to implement policies in the long run often undermine adaptive capacity [10,11].

Nexus+ conceptualization

Some authors argue that there is little agreement on the WEF nexus' precise meaning, contending that there are many competing – and often overlapping – conceptions [12•,13,14]. Others suggest that the term can be viewed as a buzzword – a word that gains prominence due to a combination of ambiguous meaning and strong normative resonance [15].

We can follow Simpson and Jewitt [12•] who, after reviewing most of the literature on the subject, arrived at a mainstream definition of Nexus stating that "the WEF nexus is [. . .] the study of the connections between these three resource sectors, together with the synergies, conflicts and trade-offs that arise from how they are managed, i.e., water for food and food for water, energy for water and water for energy, and food for energy and energy for food" [12•].

The above-mentioned definition somehow represents the mainstream theoretical understanding of Nexus, as an analytical tool and a catalyzer for technical and scientific research on the resource use and security. In that regard, Nexus focuses on actual, current problems, and promotes innovative thinking about the synergies and trade-offs on resource management in a planet under pressure.

A second theoretical trend about Nexus is more normative than technical: it proposes to look critically at social equity and environmental injustice, pointing out at power asymmetries and demanding that food, water, and energy securities be considered through the needs of the most vulnerable. This normative emphasis – which some view as a combination of ambiguous meaning and strong normative resonance [15] – uses Nexus as a screener of conflict and inequality, as well as a compass to mobilize decision makers and stakeholders toward the question of which kind of future (and world order) we want, leaving no one behind. From that point of view, Nexus has much in common with the interconnected and normative Agenda 2030, the UN Sustainable Development Goals (SDGs).

These two different perspectives about the potential use of the Nexus approach lead us to a broader and deeper issue: which theory underlies this discussion? Robert W. Cox [16•] has coined the famous distinction between problem-solving and critical theory in his seminal article *Social Forces, States and World Orders* [16•].

According to Cox [16•], the strength of the one is the weakness of the other: problem-solving theory can achieve great precision when narrowing the scope of inquiry and presuming stability of the rules of the game, but in so doing, it can become an ideology supportive of the status quo. Critical theory sacrifices the precision that is possible with a circumscribed set of variables in order to encompass a wider range of factors in comprehensive historical change [17].

The risk of focusing on solving some actual, urgent problems is disregarding the long-term consequences of decision-making. In other words, the rather technical, problem-solving approach of mainstream Nexus could be pointed-out as naively serving the purposes of the prevailing – and often unfair – status quo. In regions such as the Semiarid region of Brazil, the poorest and most unequal of the country, 'solving' immediate trade-offs among federal policies on food, water and energy securities could be interpreted as the equivalent of (willing or not) paving the way for the perpetuation of social and environmental injustices.

Through the proposal of a Nexus+ approach, RC's contribution combines critical/normative and technical/problem-solving approaches in a complementary way: as a normative compass guiding policy making – as proposed by the Agenda 2030 – through a context-sensitive, territorial understanding of the reflexivity of socio-ecological systems – as stated by Spangenberg [18], and also as innovative tool for problem solving. The Nexus+ demands both Academia and the stakeholders a joint effort for coordinating particular interests toward the common interest of building a more resilient society in a given territory.

This more realistic and context-based interpretation of Nexus could emulate the Nexus approach by leading to the Nexus+ – with social participation and institutional flexibility and openness in the developing world – thus, placed under the tag socio-ecological security, following the concept of socio-ecological systems proposed by Ebbesson [19].

Nexus+ implementation challenges

Both Nexus definitions present at least the following intrinsic and extrinsic limitations in low-income and middle-income countries such as Brazil. The intrinsic limitations are of theoretical and methodological nature: the water, food, and energy systems generally have different governance regimes, profit schemes, and stakeholders, and exist in silo-structures; thus placing all of them under a globally integrated governance system

appears as an important challenge to be overcome. Therefore, the implementation of a Nexus approach depends on a systematic mechanism where decisions in each silo are taken and reverberate in other silos, explicit and transparently. The Extrinsic limitations are: Nexus has a much greater potential for applicability in high income countries, where it was first conceived, but face enormous information gaps of both data and knowledge in low and middle income countries arising due to the lack of a data systematization culture and long-term policy planning and implementation [10,5].

Particularly, in countries marked by deep socio-ecological inequalities, such a kind of approach needs to be territorialized, through social participation, optimizing the potential embedded in the rich diversity of rural life [20]. The Northeast region of Brazil is an example of this singularity as it is a territory where rural poverty has historically been concentrated [21] in a context of high socio-ecological vulnerability, particularly considering the access and availability of water resources [21].

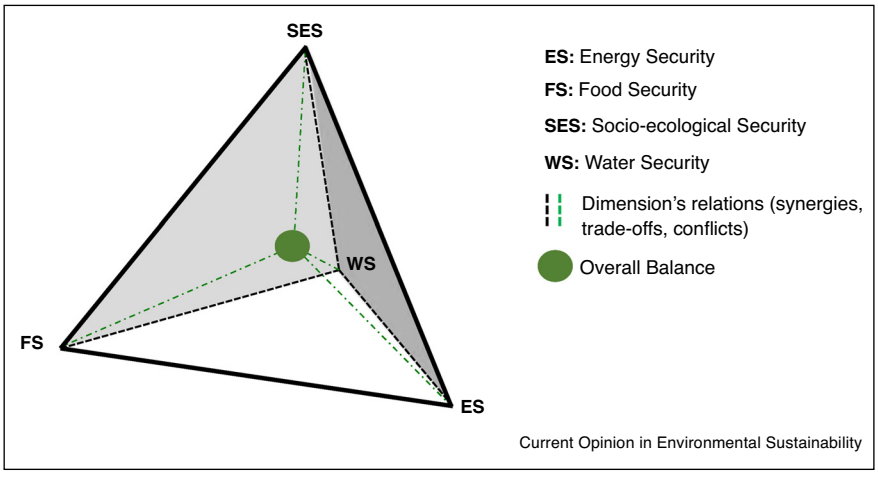
The impacts of recurrent droughts in the region are historical and have been managed for more than 100 years, with emergency measures and top–down development approaches. A new territorial paradigm so-called 'coexistence with the Semi-Aridity' emerged in Brazil's Northeast region in the late 1980s. From an initiative of civil society organizations the paradigm was presented as an alternative to the historical perspective of 'combating the drought', and has inspired the implementation of social protection policies since the early 2000's by the Federal Government.

The present article draws on the Nexus literature and brings the integrate research experience of Rede CLIMA to propose an additional interface dimension in NEXUS: the socio-ecological security, defined as a political-territorial dimension of coupled social and ecological systems, that favors adaptation in the presence of climate stresses (Figure 1).

This work aims on building climate adaptation research from a 'Nexus+' definition which considers – while still recognizing the importance of conceptual clarity – the added value of flexibility and adaptability of the concept [22,23]. The RC's research seeks to develop a more realistic context-sensitive understanding of the interconnections between sectors, scales, and stakeholders, as well as integrated approaches, to minimize trade-offs and maximize synergies between sectorial policy responses. Moreover, the need to develop integrated approaches has been identified by RC after several years of research activities conducted by its research groups, as a strategy to enhance the interplay across the different disciplines involved in climate change research. The novel Nexus+ approach has been developed to reinforce interdisciplinary dialogue and was applied by RC for the first time in the São Francisco River Basin, followed by another research project on policy conflicts in the Amazon region [41••].

Our research network has been investigating the vulnerability and adaptive capacity of socio-ecological systems in water-scarce territories of Brazil that are severely affected by droughts, through its Integrative Socio-ecological Security Research Project (PI-SSA, in Portuguese). The PI-SSA focuses on identifying knowledge gaps and public action strategies that may promote the resilience of social and ecological systems within the São Francisco River Basin through the Nexus+ approach, and involves six different research groups from major Brazilian universities, responsible for studies on regional

Figure 1



The four dimensions approach of RC's Nexus+, while mainstream Nexus approach is based only in water, energy and food securities.

development, urban planning, health, biodiversity/ecosystems, water resources, and renewable energy.

Methods

In response to earlier criticism to Nexus [24•,25•], RC's research assumes that there can be no single methodological approach or framework to implement the Nexus concept due to the diversity of cases and issues being investigated. Instead, our network identified the most suitable and feasible approaches to represent the interlinkages across the four sectors of the Nexus+ definition, according to the concept of territoriality from the perspective of political geographers, operating in an unevenly leveled social power field, as summarized by Fall [26]. Accordingly, this paper presents the main results of the implementation of several research tools, starting by a process of multi-scalar, transdisciplinary dialogue with governmental and nongovernmental actors, initiated in 2017. The initial dialogues had an 'agenda-setting' approach, seeking to identify a set of priority themes regarding the elaboration, decision-making, and implementation processes of public and collective actions in the São Francisco river basin. It included stakeholders such as the Articulation of the Brazilian Semi-arid region (ASA) and regional and federal entities such as the São Francisco River Basin Committee (CBHSF), the Brazilian Center for Research on Farming in the Semi-arid region (Embrapa Semiárido), the Federal University of the São Francisco region (Univasf), the Ministry of Environment (MMA) and the Ministry for Social Development (MDS).

The São Francisco river basin covers 636.217 km^2, of which 54% in the Brazilian Semi-arid region [27]. The states of Bahia and Pernambuco, located in the lower-middle course of São Francisco river, were selected for fieldwork due to their marked climatic risk and vulnerability [27,28]. The latest drought lasted for six years – from 2012 to 2017 [29] – and is considered the most dramatic since the 1960s [30].

The study covers a span of 17 socio-ecologically contrasting municipalities located in the states of Pernambuco and Bahia under the influence of Sobradinho Dam Reservoir. In this region, agriculture comprises a complex mosaic of activities, including, on the one hand, irrigated perimeters together with highly diversified smallholder farming systems and livelihoods such as fishing, beekeeping, subsistence agriculture, livestock (mainly goats), and the extraction of native species. The selection of study's stakeholders and territories followed a mapping of around 600 public policies dedicated to water, energy and food at different scales.

In order to add the 'fourth' axis of the analysis (socio-ecological security) the resulting policy inventory was refined through the application of semi-structured interviews and workshops with representatives of governmental and non-governmental organizations, which expresses their personal perceptions regarding the most relevant actions and the main policy challenges from a Nexus+ perspective.

In total, RC conducted 100 interviews in 17 municipalities (10 in Pernambuco and 7 in Bahia) with representatives of six different social groups, ranging from rural and peri-urban areas – smallholder farmers, *quilombolas* (maroons), indigenous communities, communities that still practice collective use of pasture land (Fundos de Pasto, in Portuguese), collectors of recyclable waste, and related representatives from several organizations, such as CBHSF, Embrapa, Univasf, IRPAA, COOPERCUC, APOINME, among others.

Under the given adverse climatic conditions, interviews sought to go beyond the water, energy and food approach and explore socio-ecological security issues such as land tenure, housing systems, family, water, environment, health, food, energy, work, mobility, and migration. Interviewees were encouraged to give details of their personal perceptions and coping strategies.

The information collected was used as primary data for a qualitative analysis of the context of vulnerability – exposure, sensitivity, and adaptive capacity – at both the family level and the regional (political-institutional) landscape. Perceived impacts of the drought on actors' lives and decision-making process were crosschecked with secondary data on regional climatic impacts extracted from peer-reviewed articles [3,29,30,21,31] and official databases, such as the Agriculture Census [33], IBGE's annual agricultural surveys, and the Municipal Human Development Index (HDI) Brazil Atlas, among others.

Results and discussion

Water, food, and energy conflicts

Given the context of long-lasting droughts that affected the region during this study, results pointed out water resources as a top priority issue – and also as a main source of conflict – for the interviewed regional actors. In the case of irrigation projects, described impacts included the contamination of soils, rivers, tributaries, and underground springs, due to the use of pesticides and chemical fertilizers – which has been officially denounced by public command and control organs such as the National Ministry of the Environment [32]. Additionally, a major infrastructure project, the Transfer of the São Francisco River is on-going since 2007. The project is a large-scale integration of basins benefiting four North-eastern states in Brazil, and is expected to improve the livelihood of some 10 million people, but also to increase water conflicts along its original basin.

More recently, the deficiency of drainage systems in irrigation projects has been associated with increased soil

salinization and linked human health problems, already identified by some of RC research groups [3,30]. The tensions generated by those impacts have led to conflicts that go beyond water issues and arise in especially arid regions such as in the Cabrobó desertification nucleus in Pernambuco state (Belém, São Paulo, Cabrobó, and Floresta) and in the region of Rodelas, in Bahia state – an area particularly vulnerable to erosion and desertification. Additional factors described by the interviewees, and that are often disregarded by mainstream, non Nexus + approaches, include the deforestation of riparian forests, inefficient central pivot irrigation systems, inadequate management of soils and their constant revolt by the intensive use of machinery.

In most of the lower-middle São Francisco River, the native vegetation (known as Caatinga) continues to be converted into pastures by livestock producers, with negative impacts on soil compaction and degradation, silting of rivers and water runoff. Finally, most of the timber used for charcoal and firewood for agricultural, pasture and domestic energy purposes comes from deforestation [33].

Imbalances between water supply and demand also affect food and nutritional security, leading to changes in the supply of food at the local level and mirroring heterogeneous power asymmetries in the territory. The control of water flows as a means of regulating water scarcity negatively impacts on livelihoods linked to traditional fishing, fish farming, and rice cultivation in marginal lagoons, undermining the cultural, social, and economic reproduction of riparian populations.

Regarding livestock production, during the long drought extensive family cattle ranchers settled in the lower-middle São Francisco area had to reduce their bovine cattle herds by more than 45%, while increasing the more resilient caprine herds by 43%, showing a recurrent pattern during drought periods.

In spite of the many policies regulating water resources at different scales that were identified in our mapping, such as sanitation, hydropower, and irrigation policies, the interviews confirmed that promoting the access to water that is safe for human consumption is still a challenge in the region. The implementation of the One Million Cisterns Program, one of the emblematic social technologies promoted by the 'Coexistence with Semi-Aridity' paradigm, has been considered a key strategy to promote – although still limitedly – the storage of drinking and production water during the rainy season [34]. The Coexistence with Semi-Aridity paradigm's principles are: saving resources in abundance during the rainy season and rational management during periods of water scarcity; promoting social technologies grounded on Brazilian environmental, cultural and institutional conditions; decentralized governance model in which the civil society plays an active role [35,36]; a contextualized education system, which promotes (at least, in theory) a learning process grounded on the cultural and environmental reality of the semi-arid region [31].

Water-related conflicts (especially for irrigation and consumption purposes) are in fact, widely linked to other Nexus axis: energy generation, especially regarding the operation of the dams, which are controlled by the National System Operator (ONS) and managed by São Francisco Hydropower Company (CHESF). As the main natural source of energy generation in the Northeast, the regional energy grid is highly dependent on the São Francisco River (which relies, in turn, on rainfall amount). Interviewees pointed out to questionable operating practices regarding water use, including the unpredictability of water levels in the different stretches, due to the variations of turbines flow. This affects the navigability and the water supply to some municipalities and the inversion of the natural regime of floods and droughts, changing the characteristics of the ecosystems [33]. As a side effect, this top–down, context-insensitive regulation negatively impacts both food security and tourism.

In the lower-middle São Francisco, the minimum acceptable restriction rate downstream of the Sobradinho dam was established at 1300 m^3/s. Because of the long period of drought; however, the National Water Agency (ANA) has used two main strategic measures to preserve minimum stock levels of water in the Sobradinho and Xingó reservoirs. The first of these measures was the reduction of the minimum discharge, from 1300 to 600 m^3/s. The second strategy was the establishment of the so called 'River Day', a day per week in which water withdrawal, except for human and animal supplies, are restricted. Yet, the impacts of those measures on a wider spectrum, mainly on ecosystem services, are still to be properly assessed [37], as well the saline intrusion of ocean tide in the lower São Francisco stretch, close to the river mouth.

These procedures could be formally described as 'Nexus–coherent' since they take into account the trade-offs between energy generation and water priorities. However, from a Nexus+ perspective, they are clearly counterproductive because they disregard existing governance agreements among institutions involved in basin management, such as ANA, ONS, CODEVASF and their users [32]. Therefore, Nexus+ reminds us that conflicts for resource use are often accompanied by centralized political-institutional structures that jeopardize institutional capacity and effective management of common-pool resources and complex changes [37].

Integration of public policies and transparency

As the mapping of around 600 public actions shows, the Ministry of Integration (MI) and CODEVASF

(Development Agency of the São Francisco and Parnaíba Valleys) are institutionally and financially very active in building hydric infrastructure in Brazil's Semi-arid region. It is worth noting a paradigm shift regarding the action and aims of CODEVASF and the MI, a shift that can echo, as previously noted, a parallel change of approach, from Nexus to a Nexus+. While CODEVASF directed the establishment of irrigated perimeters (settlements of small to medium scale farms), irrigation channels and dams as a part of its mission to 'modernize' agriculture and drought response actions [38], the Ministry of Integration (MI), in turn, is fostering the management of drought from the identification of vulnerabilities and the formulation of monitoring and prevention programs based on the concept of coexistence with semi-aridity [39,40].

It is also important to highlight that the One Million Cisterns Program (P1MC) has been implemented by ASA and the MDS since 2003 and was complemented by the 'Water for All' Program, coordinated by MI, in 2012. In the first program, participatory methodologies and pre-moulded plate cisterns were mainly installed by ASA in partnership with the local communities (after receiving training), while the second program opted to change the implementation methodology by using polyethylene cisterns produced by foreign companies. This change has disregarded contextual factors and fed conflicts among local actors. In effect, it was questioned by civil society stakeholders, particularly those involved in ASA, for their low potential for local income generation, the lack of ownership and the lowering levels of community engagement during the implementation processes [40].

The 'rigidity' of the mainstream Nexus approach was also evidenced as far as land tenure is concerned, as included the Agrarian Reform agenda.[6] Despite the formal programmatic coherence with the objectives of productive inclusion and promotion of food security, the effective Agrarian Reform experience showed little or no connection with other agricultural policies, such as incentives for irrigated fruit production. The energy agenda has also been disconnected from agricultural and water policies, in spite of public investment concentrated in this sector and the high degree of conflicts it still engenders today [40]. Both agendas, agrarian and energetic, were highlighted as the main sources of conflicts after the interviews with stakeholders representing smallholder farming and indigenous populations, lacking access either to water or land. This finding was achievable from the application of the fourth dimension of our Nexus+ approach, where the socio-ecological security is assessed at both the family level and the regional (political-institutional) landscape (Figure 1).

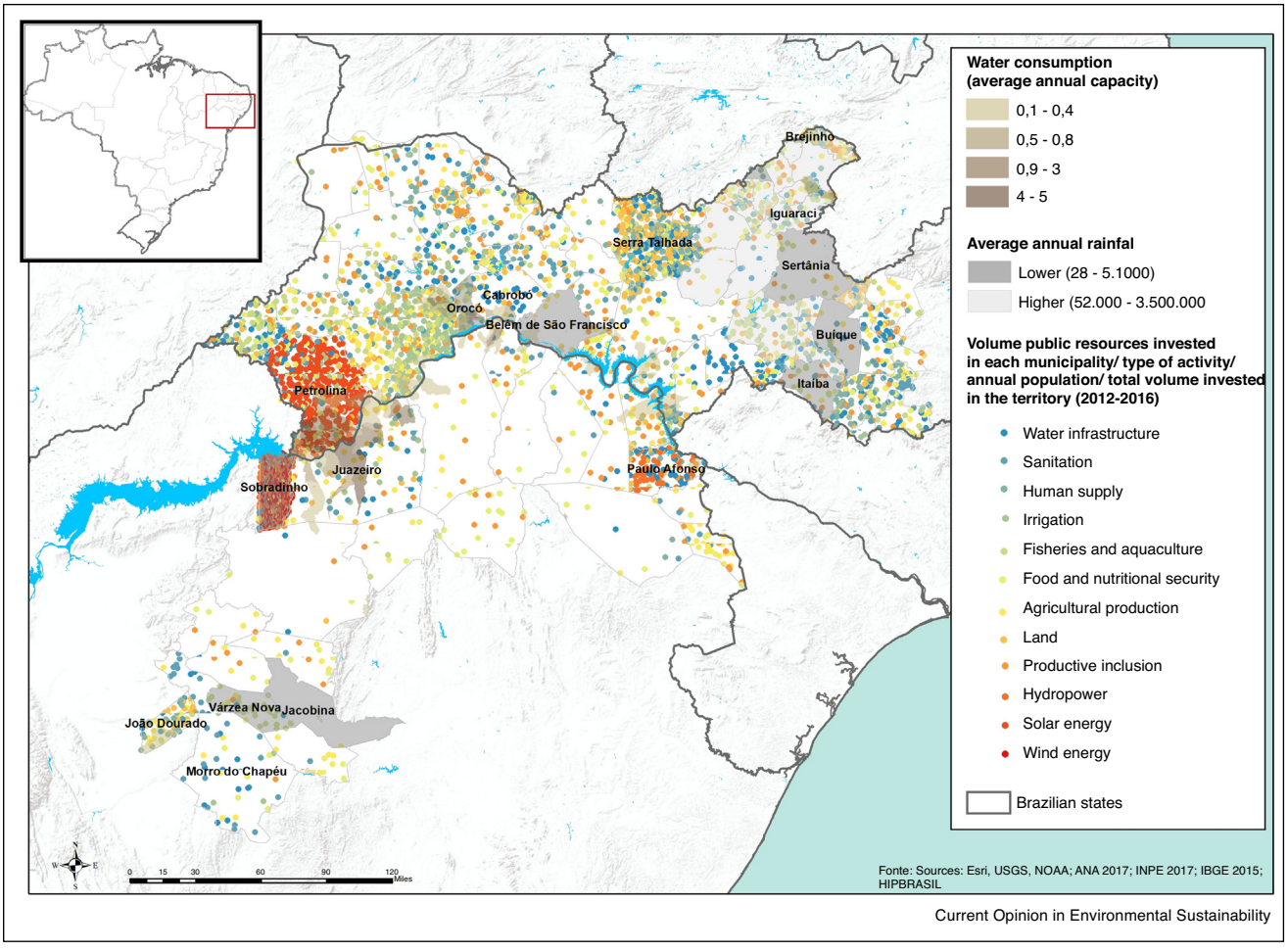
[6] Government-led or government-backed redistribution of agricultural land.

Public funding has been used as an indicator of public policy priorities in the energy, food, and water axes. In that regard, a 'picture' of the territoriality of policy priorities and major programmatic overlaps was taken through the geo-referencing of the proportional volume of public resources invested in each sector and in each municipality. Data visualization of the 'direct support financing' (including credit, development, insurance, infrastructure investment, income transfer, public procurement, and food distribution) evidenced a marked spatial concentration in the energy agenda, geographically centered around the Sobradinho, Petrolina, and Paulo Afonso regions. This includes not only investments in hydropower and wind power, but also solar energy. The lower-middle São Francisco, with an average precipitation of 350–800 mm per year is also the region that presents the greatest water stress in the whole basin, considering the average for the river basin, of 1036 mm [33]. In the Northern area, where average annual precipitation presents the lowest values, the main investments were devoted to food and nutritional security, with a marked concentration around the municipality of Serra Talhada. However, in more critical regions under desertification processes, such as the Cabrobó desertification nucleus, these investments are proportionately smaller. The results of our research highlight the need to reinforcing the promotion of multilevel governance in the region, such as social participation and policy integration in a cross-scale arrangement [39,40], which reinforces the need of using a Nexus+ approach [41••].

Figure 2 results have led us to the last bottleneck to the application of the mainstream definition of Nexus, limited to policy coherence: the lack of transparency regarding funding allocation and, especially, of funding use. In this regard, RC's comprehensive public policy mapping evidenced a dramatic lack of transparency in open data, such as cross-sector and cross-scale public investments, that should be available to everyone by law, enabling a qualified social participation in policy making. For example, the federal law No. 12,527 – Law on Access to Information (LAI) entered into force in 2012 and regulated, defining procedures, deadlines, and responsibilities, the general right of access to information established by the Brazilian Constitution. Other open data laws include the Fiscal Responsibility Law, the Administrative Procedure Law, and the Habeas Data Law.

As for information access, difficulties were readily confirmed in the field, during the interviews with municipal public agents from Petrolina and Juazeiro: in spite of their many efforts to cover the gaps by informally sharing data through social media (especially in private Whatsapp groups), local decision-makers and stakeholders described serious information gaps of mainly two types: i) an objective, measurable one, which is the already mentioned endemic/chronic information gaps arising from the lack of systematization and

Figure 2



Public investments (2012–2016) per action and municipality of lower-middle São Francisco. Source: Ref. [40].

organization of data vital for decision making, and ii) a more subjective, abstract problem, mentioned by the interviewees which is related to a local practice of not sharing (or even hiding) key information from political opposition between consecutive municipality's offices and between different municipalities. It is reasonable to understand such a practice as part of a continuum of clientelism practices that historically modulated the power structure in the region [42,43].

Furthermore, our results show that the reproduction of interventions based on large infrastructure investments without capillarity in the territory and without articulation with other key sectors for local livelihoods, such as smallholder farming and indigenous territories, has contributed to the renewal of conflicts for the use of scarce common-pool resources. Aspects such as soil salinization, income inequality, and lack of sanitation infrastructure also engenders significant impacts on food (in)security and human health indicators.

Conclusion

The Nexus approach on food, water, and energy security has gained increasing capillarity in international and national agendas. Even though it has produced many theoretical investigations, the application of Nexus to specific regions still has to demonstrate its ability to structure analyses in order to inform concrete decision-making, especially in developing countries suffering the negative impacts of climate change.

This empirical ability was tested through the work of RC in Brazil's Semi-arid region, alongside the basin of the lower-middle São Francisco River. The application of the 'mainstream' Nexus approach (restricted to the study of the synergies and trade-offs among food, water, and energy sectors) revealed to be very limited – especially at the local governmental level – by epistemological and practical questions, such as low local institutional capacity (including policy discontinuity), imbalances in social

participation and the lack of information transparency. This limitation was highlighted from the interviews conducted with smallholder faming and indigenous populations representatives in the study region, as part of the socio-ecological security assessment of Nexus+.

Finally, our results indicate the importance of emphasizing the interfaces between the sectors of the water–energy–food nexus from a socio-ecological and territorial perspective, by applying a bottom–up research approach that enables highlighting policy weaknesses. Possible solutions include the implementation of a Nexus+ approach fostering the co-creation of a comprehensive information platform, as well as effective social participation mechanisms in policy making and implementing, so that imbalances among social groups can be properly addressed.

Conflict of interest statement

Nothing declared.

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- •• of outstanding interest

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