THE WATER-ENERGY-FOOD NEXUS

WHAT THE BRAZILIAN RESEARCH HAS TO SAY

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FOREWORD

The Food-Water-Energy (FWE) nexus represents first and foremost a perspective, a way of looking at the world, at problems, at solutions. It provides a view of the three key resource systems of food, water, and energy, not in isolation, but as one system, with many and diverse cross-linkages between the subsystems. So, analytically speaking, it is a unifying concept, a much-needed antidote against the unrelenting pressures towards reductionism, silo-thinking and hyperspecialization. From my original background as a systems ecologist, understanding ecosystem functioning in terms of connected flows of energy and matter, is self-evident and lies at the roots of this discipline. However, human society and its interactions with the natural environment form a highly dynamic social-ecological system of such dazzling complexity, that reductionist approaches seem inevitable to make research and management feasible at all.

Nevertheless, the linkages between the resource systems of food, water and energy are real, and at some point in time create impacts of such magnitude that they can no longer be ignored. We can see this reflected in the history of the FWE nexus concept. In its first form, the concept made its appearance as the Food-Energy nexus in the 1980s. The attention to the interactions between food and energy was sparked by the energy crises and famines in the 1970s. There was a widespread concern that the rising costs of energy would hamper a further increase in food production in developing countries, so that productivity would not keep up with population growth. Research focused for example on alternative energy sources, such as locally produced biogas. In the 1990s, after the 'UN Conference on Environment and Development' in Rio de Janeiro (1992), the nexus concept made way for the more encompassing concept of sustainable development. Yet, in the early 2000s, the concept made its re-appearance in the form of the Water-Energy nexus, this time motivated by concerns about a looming global water crisis, as well as the negative impacts of large hydropower projects. Towards the end of the 2000s, worries about negative impacts of energy crops for biofuel production grew stronger and now more and more publications about this issue started to refer to the 'full' FWE nexus. And after the 2011 Bonn conference on 'The Water, Energy and Food Security Nexus: Solutions for the Green Economy', the amount of research and policy publications on the nexus has exploded. Novel, prominent contexts are sustainable development, energy transition and circular economy.

As also outlined in the introductory chapter, the nexus literature has been criticized for being geographically biassed, in the sense that knowledge is mainly produced by institutions in the Global North, while often meant to be applied in the Global South. Although this probably still applies for most development-oriented research, it does not for nexus research in Brazil, as this book clearly shows. This may not be so surprising, however, given that Brazil is home to both major FWE nexus-related issues such as biofuel production and hydropower, and a highly developed system of universities and research institutes.

The timing of this book is interesting. Ten years after the seminal conference in Bonn, the nexus concept is being increasingly criticized for being vague, abstract, too broad (or too narrow), and above all, impractical. However, what this book makes clear is that the nexus concept not only provides an integrative perspective on the three resource systems, but also that it is a concept that is fruitful in many different disciplines in both the natural and social sciences. This shared interest across a wide range of disciplines offers welcome opportunities for increasingly interdisciplinary studies and understanding. As there is also active interest from policy makers, even a transdisciplinary approach is within scope. Both approaches are much needed to enable the move from knowledge and understanding to practical implementation and real-world problem-solving.

This development is not just wishful thinking: this book already presents some actual examples of inter- and transdisciplinary approaches, with the FWE nexus as a shared lens to better see where problems occur and where sustainable solutions can be found. This makes the book guaranteed an interesting read that will hopefully stimulate a further uptake of these integrative approaches.

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ENERGY

SUMMARY

WATER

INTRODUCTION

The Water-Energy-Food Nexus: what the Brazilian research has to say.

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Understanding and managing the complex interaction between water, energy and food is considered to be one of the major challenges of the 21st century. As global projections indicate that the demand for these resources will increase significantly in the next decades under the pressure of population growth, urbanization, economic development, climate change, diversifying diets and lifestyles, cultural changes and technological transformation, developing sustainable solutions that guarantee resource security became paramount (Hoff, 2011).

It is in this scenario that the water-energy-food nexus came about as an approach that aims to address in an integrated manner challenges related to water, energy and food security, paying special attention to cross sectoral trade-offs and synergies (Hoff, 2011; Bazilian et al., 2011). Some scholars identify the 2007-2008 food price crisis as one of the possible causes that turned the spotlight toward the nexus (Artioli et al., 2017; Bizikova et al., 2013). Many studies, in fact, were developed after this period focusing on the impact of biofuel production on food prices (Bailey, 2013; Chakravorty et al., 2009; Sexton et al., 2008; Zhang et al., 2010). Later on, between 2008 and 2011, a series of workshops were held in the context of the World Economic Forum with the goal of increasing awareness of how global economic growth depends on water security across different links. These discussions showed how the nexus builds from a particular framing of global resource scarcity, in which water security is the central issue, and with severe implications for global economic growth (Allouche et al., 2015). Since then, the nexus has served different agendas, with the research generally accepting that water, energy and food systems are interdependent and that they should be managed as such, for the long-term security of these systems. The nexus has also assumed an important role in the international development agenda, being integrated into regional policy programs, mainly from global north to south countries (Middleton et al. 2015; Wiegleb & Bruns, 2018).

According to Wiegleb and Bruns (2018), nexus research suffers from a geographical bias. In fact, nexus knowledge is mainly produced in developed industrial countries in the Global North, while the location of nexus case-studies and the application of nexus knowledge centers in developing countries in the Global South (mainly in the South-East Asia region).

Driven by the intention of engaging with the geographies of the nexus knowledge, the organizers of this book published in 2020 a review article seeking to present a critical overview of the research produced, up to that point, around the nexus concept in the Brazilian context (Dalla Fontana et al., 2020).

Brazil is a representative case of a country in the Global South in which, even being the richest country in Latin America - which demonstrates its regional relevance -, it also presents a series of inequities resulting from its uneven process of economic development and urban expansion, which culminated in a population in a condition of socio-environmental vulnerability. While the country is the richest in biodiversity on the planet, with more than 15 million different species of plants, insects and animals, distributed in six different biomes spread across its territory (WWF, 2021), its focus on agricultural and livestock production compromises environmental protection efforts. The increase in the demand for resources due to population growth and an urbanized lifestyle also aggravates the impacts of the exploitation of water, energy and other natural resources in the country (Joly et al., 2019).

Dalla Fontana and colleagues (2020) showed that some of the characteristics of the international research on the nexus are also found in the Brazilian research, namely: a predominance of natural scientific, engineering and economic fields and marginal contribution of the social sciences; and the application primarily of quantitative rather than qualitative methods, with very few cases of hybrid methodologies. However, our findings did not support the argument from Wiegleb and Bruns (2018) according to which nexus knowledge is produced in Global North countries and then applied in the Global South. On the contrary, we found a variety of Brazilian scholars (supported by local funding institutions) involved in conducting research regarding the nexus in the Brazilian context.

As it might be expected, research on the nexus is largely related to the hydropower and biofuels sectors and built around discourses of efficiency, optimization, modelling and technological innovation. Instead, what was interesting was that much less attention was given to issues such as the effects of (irregular) urbanization on the water, energy and food resources, and other issues related to poverty and inequality in human access to water, energy and food, which were supposed to be central in the sustainability debate in developing countries.

Becoming aware of the presence of several researchers from different disciplinary fields and Brazilian institutions, each with different experiences of working on the nexus and with potentially distinct opinions about it, gave us the first idea to organize this book. Furthermore, the interesting insight that we got from the initial review of the Brazilian research on the nexus (Dalla Fontana et al., 2020), and the fact that since then more research has been rapidly produced on the subject and new projects have begun, made us believe that going deeper and giving international visibility to the research developed on the nexus in Brazil was worthwhile.

This initiative emerged by the Brazilian researchers in the GLOCULL Project, "Globally and LOCally-sustainable food-water-energy innovation in Urban Living Labs" (Forum Belmont/Sugi/JPI - Fapesp), a transdisciplinary research that combines an integrated, model supported assessment of local-global interactions in the WEF nexus, including research institutions from seven countries (Austria, Brazil, Germany, South Africa, Sweden, Netherlands, United States). The support from the São Paulo State Research Foundation (FAPESP) was decisive to put this effort forward, bringing together researchers not only from the state of São Paulo, but also from other regions of the country, showing the importance of this kind of funding for the research in Brazil.

In this book, we aim to gather academic researchers that bring empirical and theoretical elements to critically reflect on how the concept of the nexus is being incorporated into research in Brazil, and whether and how the nexus is making any contribution to enhance knowledge in different scientific fields. Their contributions also shed light on what are the main societal problems in the Brazilian context that the nexus is helping to better understand and find possible sustainable solutions.

In assembling this book, we have tried to represent: i) the variety of different topics addressed in the Brazilian research on the nexus, ii) the different academic disciplines, and iii) the geographic foci covered in the studies, including authors from institutions of all five regions of the country.

The book is composed of 15 chapters, which are organized in three parts. The first part collects chapters that address issues of nexus and governance at different scales (i.e., river basin, city), looking at decision-making processes, instruments and actions, and how the integrative approach of the nexus can bring societal benefits for different stakeholders at different scales. The chapters in the second part bring some more critical considerations on the nexus approach, engaging in discussions about equity, fair access to resources, and recognizing different perspectives and ontologies. The need to maintain a balance between social, economic, and environmental interests transpires from all chapters in this section, as a reminder of how nexus research can be enhanced according to the sustainable development principles. Finally, in the third part, there is a collection of studies that deal primarily with the development and application of methodologies for the assessment of nexus resource efficiency, production of quantitative evidence, data and indicators.

Part 1: Nexus and governance

In chapter 1: *'Belo Monte through the Food-Water-Energy Nexus: the disruption of a unique socioecological system on the Xingu River'*, Juarez Carlos Brito Pezzuti and colleagues explore the current situation of the Xingu River, in the north of Brazil, which is an emblematic and contentious Food-Water-Energy Nexus case study involving a water conflict imposed by the recent hydropower expansion into the Amazon. The Belo Monte Hydropower complex impounded and diverted waters of the Xingu River, disrupting the natural flood pulse and affecting trophic and reproductive relations between seasonally flooded forests, as well as the riverine wildlife, with severe negative impacts on productivity and food security of river-dwelling and indigenous people. The authors note that the nexus offers a useful conceptual start in understanding interlinkages across sectors that span the social and ecological parts of the system, but far-reaching changes are needed in terms of the governance systems that underpin decision making about large infrastructure developments.

In chapter 2: *'Analysis of the water, food and energy nexus for governance of river basins: the case of the San Francisco River'*, Maria do Carmo Sobral and colleagues put a spotlight on how the nexus relates to issues of river basins governance. In particular, the authors analyze the governance of the San Francisco River, and show how, whilst there are advancements in the participation of civil society, government agents and other interested sectors and users of water resources in decision-making, conflicts between multiple uses still exist; although they can be minimized by applying an integrated planning and management of water, energy and food. The chapter brings interesting reflections on multilevel governance concerning water, energy and food issues, particularly in future scenarios of water scarcity in the Brazilian semi-arid regions.

In chapter 3: *'Instruments of environmental and productive intervention from the perspective of the nexus water, energy and food: an analysis of the context of the Cantareira Water Production System'*, Rafael Eduardo Chiodi and colleagues connect the nexus with different instruments that promote environmental protection and forest restoration in the area of the Cantareira System. The authors discuss the relevance of the State as a formulating and executing agent of those instruments, and the importance of its sectoral organization and the delimitation of a spatial scale in order to guide nexus intervention processes. In the attempt to identify a more integrative perspective of the instruments under the nexus approach, the study reveals the dilemma between prioritizing environmental conservation or agricultural production in the context of public interventions, which is a classic contradiction in the Brazilian context.

In chapter 4: *'Governing Food-Water-Energy Nexus using Green and Blue Infrastructure (GBI) in Brazilian Cities'*, Marc Picavet and colleagues draw on the literature to analyze the interactions between Green & Blue Infrastructure (GBI) and water, energy and food systems and the potential for innovation in GBI to benefit nexus systems in urban contexts. The authors then delve into the case of the city of Florianopolis, which launched the Zero Waste by 2030 program with the objective of increasing recycling, composting and waste reduction. In this case, the authors demonstrate how innovative urban agriculture initiatives governed with the participation of different stakeholders, can contribute towards improving the linkages between food, water and energy consumption and production in the city. The chapter concludes by suggesting how other Brazilian cities can learn how innovation in GBI and urban governance can reduce the risks of insecurity in local nexus systems in response to rapid urbanization and climate change challenges.

In chapter 5: *'The water-energy-food nexus in local urban planning strategies: the case of São Paulo, Brazil'*, Fabiano de Araújo Moreira and colleagues utilize the study case of the 2014 Strategic Master Plan of the city of São Paulo to fill the gap of the underrepresentation of studies with local public policies analyses through the lens of the nexus. The authors reveal the focus of the document in the actions related to water, while energy and food are less represented, and the relevance of the "land use" as an important link between the nexus elements, and as a priority policy area on which local authorities can act to address the nexus. This kind of research helps recognize gaps in the local urban agenda and includes social and urban aspects, which are usually lacking in current nexus studies.

Part 2: Critical reflection on the nexus

In chapter 6: *'Situating the subject on the WEF nexus research: insights from a critical perspective'*, Thainara Granero de Melo and Rosemeire Aparecida Scopinho offer a critical interpretation of how two related but opposite conceptions - the entrepreneurial and the collective subject - can express distinct rationalities underlying the sustainable development discussion. In doing so, they reveal the necessity of an ontological debate around the concept of the social subject, giving expression to social, political and justice domains of the nexus regarding local realities and vulnerable groups in the Brazilian context. They finally argue that a critical nexus approach in the Brazilian context requires understanding subjects, subjectivities, livelihoods and everyday relationalities tying neoliberalism and its ongoing renewal of colonial structures of exclusion.

In chapter 7: *'Youth knowledge and perceptions about the water-energy-food nexus: challenges and learning gained from interdisciplinary research on education for sustainability'*, José Antonio Perrella Balestieri and colleagues address the nexus from a particular perspective that differs from most of the other mainstream research on the nexus. In fact, they start by recognizing the need of understanding people's point of view - the end-users of water, energy and food resources - about the nexus, and they argue that, through this understanding, it is possible to address crucial issues, such as (un)equal access to resources. The chapter is provided with an overview of some of the results from the *'(Re)connect the nexus: young Brazilians'* experiences and education about food-water-energy' project that aimed to examine children and young people's grasp, experience and participation in the WEF-nexus in their everyday lives and how this could guide public policies or education for sustainability.

In chapter 8: *'Qualitative and participatory research experiences on social-ecological attributes of the water-energy-food nexus'*, Leandro Giatti and Lira Luz Benites Lazaro address two topics that, although different from each other, are both fundamental to advance nexus research in the Brazilian context, namely: i) the nexus from the perspective of vulnerable urban communities; and ii) the nexus in social actors' discourses in the Brazilian agro-industrial sector of bioethanol. First, the authors give insights on how the nexus should be recognized as an opportunity for dialogue from social practices in peripheral communities, where alternatives for synergies can reconnect these local situations with the conservation of ecosystems and their services. They do so by reporting on the experience of the ResNexus project, carried out in a vulnerable urban community in the city of Guarulhos, in the Metropolitan Region of São Paulo. Secondly, the authors show the expansion of crops for ethanol production in Brazil that has been emptied from the debate of some concerns regarding the interdependencies between water resources, land use, food production and energy. The chapter then concludes discussing the importance of qualitative research for the necessary democratization and hybridization of knowledge.

In chapter 9: *'Forest security as a fourth dimension of the water-energy-food nexus: empirical evidence from the Brazilian Caatinga'*, Lucas Alencar and colleagues introduce a fourth element into the nexus, namely forest security, as a fundamental link between water, energy and food security. The chapter supports the argument that basic components of human well-being such as access to safe and sufficient amounts of water, energy and food are clearly linked to ecosystem services provided by forests. The authors examine issues of deforestation, degradation and development in the Brazilian Caatinga, one of the country's poorest regions which still retains nearly half of its original forest cover, and how these have an impact on livelihood and poverty via the WEF nexus.

Part 3: Resources efficiency and methodologies

In chapter 10: *'Nexus Pampa: The NEXUSMESMIS approach applied at watershed scale'*, Vicente Celestino Pires Silveira and colleagues apply the MESMIS systemic methodology, which is based on a socio-environmental approach, bringing a perspective that aims to understand the relationship between the need for production (food and energy) and the preservation of natural resources (soil, water, forests, and biodiversity). In said case, the nexus enables building the attributes that generate indicators embracing economic, social, and environmental elements. The methodology was applied in the watershed scale, which proved to be relevant for a more efficient assessment of the weaknesses and strengths of the use and the management of the natural resources in the area.

In chapter 11: *'Efficiency Analysis of Brazilian cities: The effect of Food, Energy, and Water Nexus (FEW Nexus) on Municipal Human Development Index',* Paulo Nocera Alves Junior and colleagues are mainly concerned to understand how different production and consumption patterns of water, energy and food have an impact on socio-economic and environmental indicators. Therefore, they develop and apply to Brazilian cities a composite index able to evaluate the efficiency of cities in converting nexus-based variables into higher levels of Human Development Index. The results of different Brazilian cities are compared and discussed taking into account geographical differences with the final objective of providing evidence for multicriteria decision-making to guide the development of public policies.

In chapter 12: *'Collaborative Methodological Approaches Towards Water-Energy-Food Nexus'*, Jean P. H. B. Ometto and colleagues discuss the methodological strategies for a collaborative process between researchers from several institutions in a project of the nexus in the Cerrado and Caatinga, in the northeast of Brazil. This process aimed at the definition of the local scale and diagnostic indicators for the project, in the first two phases of this project, in order to ease integration and joint decision-making among researchers, and to support the next stage of the project: the scenario construction - participatory research. The authors revealed the importance of developing continuous dialogue spaces to enhance a reflexive process of construction and analysis of data, process, and perspectives from the diversity of technical areas involved. Furthermore, several elements throughout the process indicate they are an important step towards transdisciplinary nexus research.

In chapter 13: *'A methodology framework to access the impact of rural practices in the food - water - energy security Nexus',* Ana Paula Turetta and colleagues present a methodology developed for the evaluation of the food - water - energy (FWE) security nexus for rural landscapes in Atlantic Forest biome, using the concept of multifunctional agriculture. This methodology aimed to evaluate the "availability and stability" of the nexus resources through a number of steps, like the construction of a database, literature review, public policies survey and participatory workshops for the definition of landscape attributes and indicators. The authors highlight the pros and cons of this methodology, especially regarding the relevance of the participatory approach and the inclusion of the existing political instruments at different levels, which should be integrated in the discussion, so the decision makers can prioritize and provide interventions considering the 'nexus' interlinkages.

In chapter 14: *'Biomethane as a fuel for the transport sector in Brazil and the United States: An analysis based on the water - energy- food nexus'*, Janaina C. P. Lofhagen and colleagues show the potential and limitations of using biomethane as an alternative energy source for Brazil and the United States, by estimating the demand and the local availability of biomethane in both countries. The authors use the concept of the nexus to discuss the potential effects of the adoption of biomethane as a primary fuel in the transport sector, since it promotes the anticipation of potential trade-offs and synergies for the improvement of the national development models.

In chapter 15: *'Relationship between resource-oriented sanitation and the Nexus approach: water, energy and food perspectives on management and technologies'*, Fernando Jorge Correa Magalhães Filho and colleagues explore the potential of resource-oriented sanitation technologies and how these relate to the nexus, particularly via nutrient recovery and water reclamation for fertilizer production, and energy generation (e.g., biogas). The chapter discusses the importance of introducing sustainable technologies to save and enable the recycling of water and nutrients, as well as promote energy efficiency in public water and sanitation services. On the other hand, the authors point out the challenges to be faced in the Brazilian context, which have to do with lack of data to support the development of public policies.

The book covers a wide range of subjects that reflect the variety and richness of themes that can be approached through the nexus lens in the Brazilian context. The goal of the book is not to exhaust the topics or solve specific problems, but instead, to offer to an international audience what is a fair portrait of Brazilian research on the nexus, showing its strengths and weaknesses, and potential directions for the future.

Some chapter's highlight how part of Brazilian research on the nexus follows the footsteps of mainstream international research, by focusing on efficiency, optimization, modelling and technological innovation. However, the same chapters show that the availability of reliable data and the production of new quantitative evidence are crucial for taking actions and supporting decisions based on nexus principles. Other researchers interpret the nexus as an opportunity to bring together actors from different sectors and administrative levels in order to set transversal objectives in the sustainable agenda at different scales. Furthermore, a group of researchers are still hesitant about accepting the normative stands of the nexus without going through a process of adjustments that must take into account the specific priorities of the Brazilian context and different ontologies and epistemologies in order to develop legitimate and salient research and solutions.

Hopefully, with this book we will stimulate debate among researchers in Brazil to develop new research projects that make use of hybrid methodologies bringing together perspectives from different disciplines and actors in order to better understand nexus related problems in the Brazilian context and develop the most appropriate solutions. Moreover, we expect to introduce Brazilian nexus research to an international audience in a way that fosters two-ways knowledge exchange and opens up new possibilities for collaborations to address global issues related to water, energy and food.

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PART 1

NEXUS AND GOVERNANCE

CHAPTER 1

Belo Monte through the Food-Water-Energy Nexus: the disruption of a unique socioecological system on the Xingu River.

By Juarez Carlos Brito Pezzuti[1], Jansen Zuanon[2], Camila Ribas[3], Florian Wittmann[4], Fernando d'Horta[1], André Oliveira Sawakuchi[5], Priscila Fabiana Macedo Lopes[6], Cristiane Costa Carneiro[7], Alberto Akama[8], Biviany Rojas Garzón[9], Thais Mantovanelli[10], Philip Martin Fearnside[3], Lindsay C. Stringer[11]

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1. Introduction

The Xingu River has headwaters in the heart of the ancient central Brazil shield and travels northwards for circa 2000 km until reaching the Amazon River (Figure 1). The Xingu stands out not only as a major tributary of the Amazon River, but also because of its unique riverine landscape. It forms a huge and abrupt curve of 130 km length regionally known as the Volta Grande of Xingu (Big Bend of the Xingu) before it reaches the lowlands of the Amazonas sedimentary basin at a place known as Belo Monte; a location that lends its name to the most expensive and controversial infrastructure project in Brazil's history. The objective of this chapter is to unpack the Belo Monte dam case using a nexus lens that considers the relationships and feedbacks between different system components, with a particular focus on water, energy and food. We argue that the adoption of a more integrated approach can allow better governance decisions to manage Belo Monte's impacts across the various sectors.

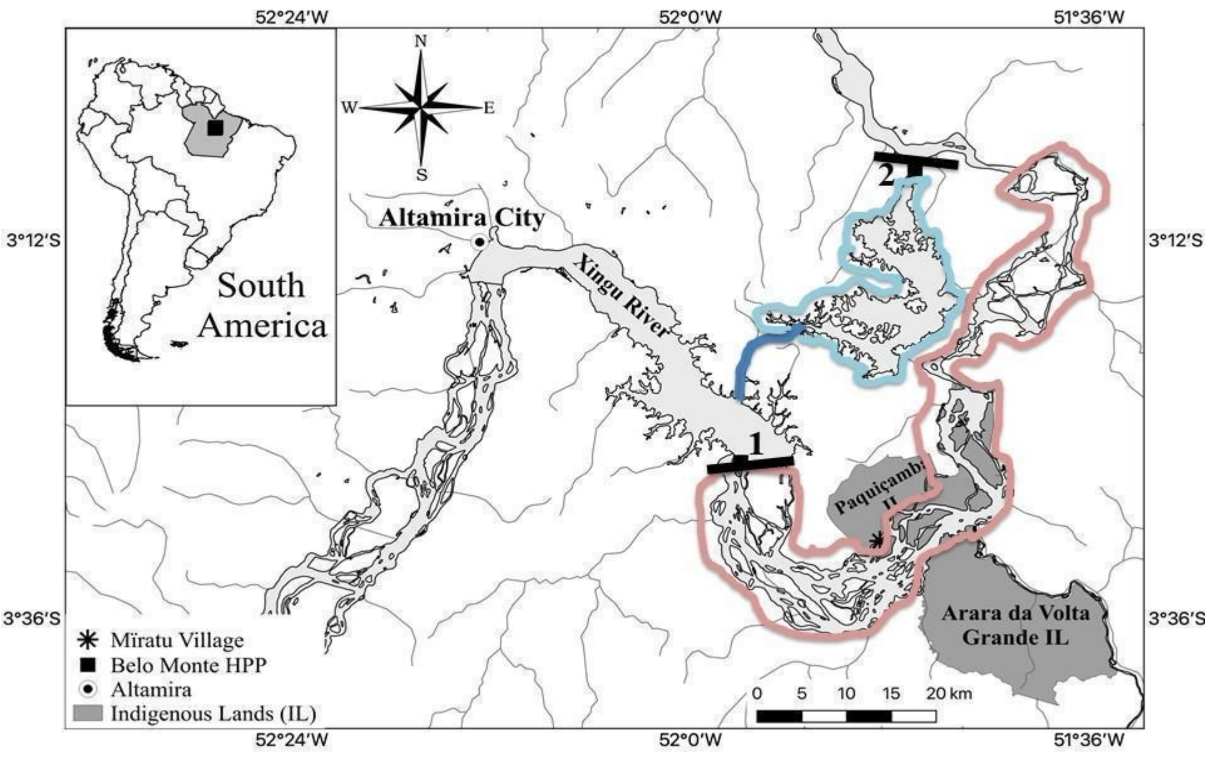

Figure 1. Belo Monte hydropower plant (HPP) at the Volta Grande of the Xingu, Pará, Brazil. The axis of each dam is represented by a black bar: 1. Pimental and 2. Belo Monte dams. The colored contours represent, respectively, the diversion channel (dark blue), the Intermediate reservoir (light blue) and the dewatered sector of the Volta Grande (reddish).
Source. Elaborated by the authors.

Belo Monte engineering involves a dam in the Xingu mainstem (Pimental dam) to form a reservoir (Xingu reservoir) allowing the diversion of most of the Xingu's discharge through an artificial channel that feeds a second reservoir (Intermediate reservoir) within an impounded valley, flooding dry lands and former stream channels. Most of the water now flows through this artificial system, leaving the Volta Grande with a fraction of its original discharge, with direct effects on two Indigenous Lands (ILs), two riverine communities and hundreds of scattered families that have the traditional riverine lifestyle and subsistence basically dependent on fish for food and income (Adams et al., 2017; Francesco et al., 2017). The building of the dam started in 2011, and the two impoundments were completed in September 2015, forming the Xingu reservoir, the diversion channel, the Intermediate reservoir, and the de-watered Volta Grande. Belo Monte was completed in November 2019, when the last of the 18 turbines started functioning at the main powerhouse in the Intermediate reservoir dam. Although the amount of water deviated is proportional to the quantity of energy to be produced due to the run-of-the-river design, the higher the water volume deviated from the river, the greater the impacts on the Volta Grande socioecological system.

The effects of this engineering feat on the socioecological system cross-cut water, energy and food are severe. The relationship among these sectors can be framed as a nexus or point of connection, whereby actions and decisions in one part of the system or in one sector, are recognized to have important impacts on, and interdependencies with, the other parts of the water-energy-food triad (Bazilian et al., 2011). Taking a nexus approach can be a useful way to understand the interactions between each part of the system, drawing upon available data and model projections (Keskinen et al., 2016). A nexus approach can also inform decision making so that proper risk assessments and mitigation measures can be enacted prior to development activities, supporting evaluations that use approaches such as Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA). It further offers a way of supporting policy alignment and coherence across sectors (Smajgl et al., 2016).

Nexus approaches are becoming increasingly important in decision making because they show that impacts of dams are rarely restricted to the sites where they are located. For example, the implications of the Belo Monte hydropower complex are far reaching and span multiple temporal and spatial scales, affecting different aspects of the environment and society (Stringer et al., 2018). Indigenous and traditional riverine communities are often already marginalized and lack a voice in decision making, even though they are severely impacted by dam construction in terms of land expropriation, subsistence, and livelihood opportunities. A nexus approach can help identify where inequalities might be exacerbated and reinforced, similar to approaches such as the Integrated Water Resources Management (IWRM) (Stringer et al., 2021), albeit with a broader focus on interlinkages across sectors.

Yet, the nexus approach is not without criticism for viewing water, energy and food purely as resources, while neglecting the ecological or environmental processes that extend beyond such a resource conceptualization (Grenade et al., 2016). In the Belo Monte case, the two dams affect the water and sediment flows, with consequences on the downstream and upstream floodplains and fisheries. Furthermore, the nexus in the Amazon is also interlinked with other factors to the same degree as climate and land use changes, which can be particularly disruptive in the Brazilian context where there is a heavy reliance on hydropower and natural resources that support people's livelihoods (Mercure et al., 2019). The rainy season in the Amazon is driven by the South American Monsoon System (SAMS), which is active during the austral summer (Marengo, 2004). The Amazon rainforest is a critical element of the SAMS and supports the recycling and long-distance transport of moisture (Lovejoy & Nobre, 2018) to central and southeast Brazil, supplying water to most rivers with installed hydropower plants in those regions. Hence, deforestation across the Amazon Basin is another threat to water and energy security in Brazil. Forest loss combined with climate change (IPCC, 2021) can lead to severe reduction in water availability and hydropower generation in the Xingu River (Stickler et al., 2013; Sorribas et al., 2016), strengthening water conflicts in the Volta Grande.

2. The Brazilian licensing system and policy

The Brazilian licensing system was legally established in 1986, through the creation of the Environment National Policy (SISNAMA, 1986) and subsequent resolutions, as well as State licensing laws mirroring the federal resolution. The main document for evaluating any large enterprise project is the Environmental Impact Study (Estudo de Impacto Ambiental/EIA) and must be considered in decision-making. The national licensing agency is the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA, Portuguese acronym here and thereafter) through its Environmental Licensing Directory (DILIC). The DILIC technical staff may access any other studies and information available to support the licensing process, and they usually do, but the decision is based on the EIA in a three-step process: the Previous Licensing (Licença Prévia, LP), Installation Licensing (Licença de Instalação, LI) and the Operation Licensing (Licença de Operação, LO). After obtaining the Previous Licensing, the Basic Environmental Plan (PBA) is the guideline document which has to be presented for attaining the Installation License. The PBA includes the monitoring, mitigating, management and compensating programs during implementation and operation of the enterprise. A critical factor that hinders this system to effectively prevent or mitigate social and environmental losses is an interpretation of the Licensing Law. The National Environment Council (CONAMA) determines since 1986 that the Entrepreneur is responsible to present and conduct studies, programs and reports, without establishing independent oversight mechanisms (SISNAMA, 1986). Studies are mostly conducted based on hiring private consulting companies according to the rules of the private sector, obeying the business-as-usual and marketing rules. The contracting company has control over what is to be included, demonstrated, suggested, and interpreted so that the consulting company is compelled to defend the interests of the contracting party. Additionally, the consulting company is usually bound by contract rules, in which the consultants sign confidential contractual clauses that forbid them from commenting, writing, and publishing anything without the express authorization of their contractor. Complete databases generated by the consultancy are given to IBAMA, which makes them publicly available, but there is no control, either from IBAMA or from other independent stakeholders, of processes occurring between data collection and data submission. In the Belo Monte case, the EIA was developed by Leme (2009), a private consultancy company with extensive experience in licensing governmental infrastructure projects.

Thus, consulting companies act in accordance with market interests and continue to neglect the social and environmental impacts sometimes stated in their own official reports. This situation applies to the Belo Monte case, in which the systematic neglect of predicted impacts in the official reports, which were vehemently contested by fisher families and leaders, led the Miratu Yudjá community to start their own independent monitoring, in partnership with several research institutions (Pezzuti & Carneiro, 2015).

3. The Amazon's River pulsing system

The Flood Pulse Concept (FPC) proposed by Junk et al. (1989) detailed how the complex and intertwined aquatic and terrestrial ecosystems combine to create a uniquely dynamic environment. The Aquatic Terrestrial Transition Zone (ATTZ) role is thoroughly described, and its unique features hold the key factors explaining the high productivity of seasonally flooded ecosystems, such as the igapó forests of clear water Amazonian rivers, such as the Xingu.

The combination of the monsoon climate and a geological framework favored the formation of a continental-scale flooding pulse system and the world's largest river basin, the Amazon River and its tributaries (Welcomme, 1979; Junk, 1997; Goulding, 2013). The magnitude of a flooding pulse has both spatial and temporal dimensions that affect the entire ecosystem. Floodplain plants adapt their biological cycles to the seasonal inundation, usually synchronizing flowering and fruiting with the high-water season. Flooding peaks and relief determine the extension of seasonally flooded areas and, therefore, the amount of feeding and spawning habitats for the aquatic fauna. The duration of flood represents the amount of time to feed, grow, and to complete the reproductive cycle.

Amazonian seasonally flooded habitats are crucial for the global carbon budget. These are the most species-rich floodable forests on Earth, which, in addition to its many endemic tree species, also provide shelter and habitat for numerous aquatic and terrestrial species of invertebrates and vertebrates, many of them restricted or seasonally dependents to these environments (e.g. Goulding, 1988; Haugaasen & Peres, 2005; Bezerra et al., 2010; Schöngart et al., 2010; Junk et al., 2015). These forests have plenty of diversified suitable microhabitats for fish reproduction. Fruits, nuts, leaves, stems and other plant parts furnish the food chain basis for an incomparable freshwater community. The floodplains host some of the most diverse freshwater wildlife in the world, including the richest community of fishes with over 3,000 species (Dagosta & de Pinna, 2019; Oberdorff et al., 2019). Other important groups of herbivores that depend to different degrees on the flooded forests include 15 species of freshwater turtles and the Amazon manatee (Vogt, 2008). Top predators, which play an important role over the entire food chain, include four species of crocodilians, two of otters and three river dolphins, apart from carnivorous fishes and several birds that feed on aquatic prey.

Despite the long history of human presence along the Xingu River and intense use of natural resources, hundreds of fish species and several turtles are still abundant in the basin. In fact, the Xingu River holds one of the highest known diversity of fish in the Amazon Basin (Pérez, 2015; Winnemiller et al., 2016). Said diversity and productivity are intrinsically related to the magnitude of the seasonal flooding pulses (Castello et al., 2015; Isaac et al., 2016; Pinaya et al., 2016; Bayley et al., 2018; Castello et al., 2019), which in the past supported a human population that was likely twice the current one (Prestes-Carneiro et al., 2016). Turtles (Podocnemididae), for example, have been widely used by autochthonous human inhabitants of the river floodplains. Their relevance to the local subsistence persists despite a history of often unsustainable exploitation (Freitas et al., 2020). For example, from the early 1700s, the Portuguese colonizers developed a system to produce and export turtle egg-oil, using indigenous labor and knowledge (Bates, 1864) in a wasteful and unsustainable manner that endured for at least 200 years (Pereira, 1954; Smith, 1974). Yet, Podocnemidid river turtles are still abundant all over the basin, including *Podocnemis unifilis* (Alcântara et al., 2013), and *P. expansa,* particularly in the lower Xingu (Carneiro, 2017).

This magnificent aquatic diversity and productivity also favored intense occupation of the floodplains by humans, and the development of cultures adapted to a riverine way of life coupled to the hydrological cycles. Even today, the people living along the margins of major Amazon River tributaries have one of the highest daily fish consumption levels in the world, reaching up to 800g per capita/day (Corrêa et al., 2014). Fishing has adapted to a spatial and temporal mosaic of ecological contexts and opportunities, with gears, techniques and bait being used accordingly. The Xingu River dwellers are not an exception, and their diet is based on fish and manioc (Almeida, 2018; Mesquita, 2020). Since the beginning of the Belo Monte dams' construction, fish consumption is declining in the region, especially at the *Volta Grande* of Xingu (Pezzuti et al., 2018).

4. The Amazing Volta Grande of the Xingu River: a turbulent pulsing system

The extensive Amazonian rapids are still poorly known, despite the fact that they hold a unique fauna and flora, many of which adapted to living in fluvial environments with high water velocity, as the rheophilic fishes (Winemiller et al., 2016). The Xingu, and the Volta Grande stretch in particular, is composed of a complex array of braided bedrock channels with several abrupt bends, powerful rapids, and abundant low waterfalls, characterizing the most prominent rheophilic environment in the entire Amazon basin. The Xingu River clear waters associated with these extensive rapids led to the development of the most diverse rheophilic fish fauna of the Amazon (Perez, 2015), with at least 45 species exclusively inhabiting the Xingu rapids. This condition also characterizes a highly productive system during the low-water season, and it is responsible for the development of the unique aquatic flora and fauna.

5. Belo Monte's threats to the seasonally flooded ecosystems of the Xingu River

Amazonian large-river wetlands cover an area of 750.000 km2 and are classified by varying sediment and nutrient loads of river waters, which are traced to the geology of their catchments (Junk et al., 2011). While most of the sediment- and nutrient-rich white-water rivers drain the Andes highlands and foothills, black- and clear-water rivers drain terrains of the Guyana and Central Brazilian Shields with exposed crystalline rocks or that are covered by sandy soils. Their water has a lower content of suspended solids, with reduced concentration of electrolytes, and is acidic. While black-water rivers have a dark, reddish-brown color that derives from the accumulation of dissolved organic compounds from adjacent sandy forest soils, clear-water rivers, such as the Trombetas, Tapajós, Xingu and Araguaia-Tocantins, usually have mostly transparent to greenish waters. Clear-water rivers are most common in the eastern part of the Amazon basin, and their upper and middle courses are characterized by diverse rocky beds dominated by sediment bypassing (Wittmann and Junk, 2016). The Xingu floodplains encompass an area of approximately 37,000 km2, of which about 90% covered by different types of vegetation (Melack & Hess, 2010).

The amplitude between low and high-water levels in the middle-lower course of the Xingu amounts to 4-5 m on average, with the highest water levels occurring in March-April and the lowest water levels occurring in September-October (Schwatke et al., 2015). The floodplain forest of the Xingu can be divided into pioneer vegetation mostly composed of open shrub and tree formations established on the rocky islets, on riverbanks and along sandy bars, whereas stabilized sandy bars form slow-water areas susceptible to the deposition of fine-grained sediments (silt and clay) covered by closed-canopy forests (igapó forest, sensu Prance, 1979). Flood height and duration exert considerable control on tree species composition and diversity because floodplain tree species have developed specific morpho-anatomical (i.e., aboveground root systems, hypertrophied lenticels) or physiological (i.e., leaf-shedding during the high-water period, often combined with growth reduction or cambial dormancy, timing of reproductive phenology to the high-water period, etc.) adaptations to flooding (i.e., Schöngart et al., 2002; Wittmann et al., 2016; Householder et al., 2021).

The Belo Monte hydroelectric complex has an unprecedented effect on the igapó flora and fauna. These impacts are caused, mainly, by (1) permanent flooding of igapós upstream of the Pimental dam, (2) significant reduction in stream discharge and water levels in the Volta Grande area, particularly during the high-water season, and (3) flood-pulse changes downstream of the Belo Monte dam.

Although the impacts of altered flood regimes on the Xingu igapó flora are yet to be studied, results from other hydropower dams in the lowland Amazon reported dramatic effects. These include mass mortality of flood-tolerant tree species at the higher flood-levels, as well as the replacement of flood-adapted tree species by secondary ones originating from the adjacent terra firme in the upper, less flooded parts of the floodplain (i.e., Assahira et al., 2017; Lobo et al., 2019; Schöngart et al., 2021). These environmental impacts may extend to the river courses over hundreds of kilometers (Resende et al., 2019). In addition, the temporal shift of low- and high-water regimes disturbs reproductive cycles and energy storage of many floodplain tree species, which have adapted to the seasonal predictability of the flood pulse during hundreds of thousands of years. Ultimately, endemic tree species of the Xingu River will be most endangered through extinction at regional scales, with still-unknown consequences for the aquatic and terrestrial food chains, along with the traditional use of floodplain resources by humans (Schöngart et al., 2021). Further impacts, such as the reduction in sediment- and nutrient transport, trophic changes through reduced stream flow and elevated water temperatures, and the loss of hydrological connectivity are certain, although not yet studied.

6. The so-called "Consensus Hydrograph", the Belo Monte energy generation and the de-watered Volta Grande of Xingu

The amount of water diverted from Volta Grande defines the Belo Monte's energy generation. The water diversion to the dam occurs according to a monthly hydrograph known as "Consensus Hydrograph" (Leme, 2009), a contentious name given the absence of any local stakeholders other than the entrepreneur, the national electricity company (Eletrobrás) and the National Electric Energy Water Agency (ANEEL) in its elaboration. This hydrograph scheme imposes a severe dewatering of the Volta Grande, limiting the peak wet-season discharge to 4,000 m^3/s and 8,000 m^3/s (Hydrograph A and B) in alternate years, respectively, while keeping the dry-season discharge to levels as low as 700 m^3/s. These represent a diversion of 81.5% and 72.2% of the river's historical peak discharge, respectively.

According to the Brazilian Constitution, the licensing legislation and the EIA, the Belo Monte complex should maintain the biodiversity, the ecosystem services, and the river-dependent livelihoods, including their subsistence practices and food security. Despite the risks that such a change to the local flow would represent, the licensing agency (IBAMA) did not assess its ecological consequences. Yet, the EIA of Belo Monte (Leme, 2009) pointed out that a peak discharge of at least 15,000 m^3/s during the wet season would be necessary to allow an expressive flooding pulse in the Volta Grande and, thus, the maintenance of the seasonal ecological processes, including the access of flooded environments to freshwater wildlife. River turtles, for instance, are able to access the floodplains for feeding only when the discharge reaches a minimum of 13,000 m^3/s. An independent study conducted by the Juruna indigenous community of Miratu village, in partnership with researchers from the Federal University of Pará (UFPA) and the Socioenvironmental Institute (ISA), has shown that fishes would need similar conditions to access floodplains for feeding and spawning (Pezzuti et al., 2018; Zuanon et al., 2021). The same study concluded that the minimum discharge of 700 m^3/s during part of the dry season would hinder navigation conditions for riverine communities living along the de-watered reach. Despite these facts, the operation of Belo Monte under the "Consensus Hydrograph" was authorized. Eleven years later with Belo Monte hydropower complex working at its full capacity, a complementary study conducted by the operating company (Norte Energia, 2020) confirmed that Hydrographs A and B would prevent the inundation of respectively 35,600 ha (99.6%) and 30,748 ha (86.4%) of the seasonally flooded ecosystems along the Volta Grande. The impacts that had been projected in the official EIA study (Leme, 2009), including decreased fish catchability, altering fish-landing composition, effects on the physiology and growth of fish species, and decreasing fish consumption by indigenous and traditional families living in the area impacted by Belo Monte, have materialized since 2016 (Norte Energia, 2018; Almeida, 2018; Pezzuti et al., 2018; Mesquita, 2020). Fish consumption, for example, has decreasing since 2013 (Lopes et al., submitted). Despite the numerous studies attesting to direct and indirect effects of hydropower dams on aquatic wildlife (Moll, 1997; McAllister et al., 2001; Moll and Moll, 2004; Pérez, 2015), fisheries, regional food security and quality of life (Marmulla, 2001), the official monitoring program (Plano Básico Ambiental, or PBA) claims that the negative effects on the socioecological system in the Volta Grande cannot be a causally linked to the hydrological changes in the Xingu imposed by Belo Monte (Norte Energia, 2018).

The independent monitoring led by the Juruna indigenous people denounces the gravity of the ongoing collapse of the region due to hydrological changes caused by Belo Monte (Pezzuti et al., 2018). In 2016, the first year after the damming of the Xingu River, was also the driest year of the basin since the beginning of discharge monitoring in 1931. In 2016, the peak discharge of the Xingu reached only 10,000 m^3/s due to a severe drought, which is half of the historical average of 20,000 m^3/s (Table 1).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sept	Oct	Nov	Dec	Sum	Reduction* %
Mean monthly discharge m/s (1931-2008)	7720	12736	18139	19985	15591	7065	2877	1563	1066	1115	1870	3735	93462	-
Year of 2016	2442	6379	7798	10693	6127	2732	1550	890	745	991	1635	3726	45708	51.1
Provisional IBAMA Hydrograph	3100	10900	14200	13400	5200	1800	1300	900	750	760	1000	1200	54510	41.7
Consensus Hydrograph A	1100	1600	2500	4000	1800	1200	1000	900	750	700	800	900	17250	81.5
Consensus Hydrograph B	1100	1600	4000	8000	4000	2000	1200	900	750	700	800	900	25950	72.2

Table 1. Historical monthly average discharge of Xingu River at Altamira.
Source. National Waters Agency (ANA, https://www.snirh.gov.br/hidroweb/).
* Compared to the average annual discharge (1931-2008)

Flooding was minor, even though the river discharge was significantly higher than both Hydrographs A and B. The occurrence of a historical dry year just after river impoundment brought synergistic impacts and provided evidence that ecosystems will be more threatened with the presence of dams under climate change, which is expected to increase the duration and intensity of the dry season in the eastern Amazon (IPCC, 2021). The year of 2016 was nicknamed by the Juruna as the “year of the end of the world”, as it marks a dramatic scenario of decrease in the water flow and high mortality of fish and tracajás (Podocnemis unifilis), a culturally important river turtle species.

The Juruna’s engagement in carrying out independent monitoring of the impacts of Belo Monte has been a fundamental instrument in the struggle for the rights of the peoples of Volta Grande and a response to the unreliable assessments underestimating impacts that mark the dam’s licensing and operation processes. In the words of Natanael Juruna, "We are not monitoring only our own death nor the death of fish and tracajás. Our monitoring is aimed at defending life in the Volta Grande of the Xingu and at stopping the Consensus Hydrograph" (translated from Portuguese).

The water diverted from the Volta Grande is causing an unprecedented permanent drought condition never before experienced in the region, possibly surpassing the water-discharge variations observed in the last 4,000 years (Bertassoli Jr. et al., 2019). Volta Grande water comes from the central Brazil highlands and depends on the Amazon Rainforest and Cerrado forest covers, not only in the Xingu Basin, but in the whole Amazon to supply moisture for the inland propagation of the South American Summer Monsoon (SASM). Thus, rainfall over the Xingu Basin depends on the presence of the Amazon forest (Stickler et al., 2013; Lovejoy & Nobre, 2013), where less forest means less water for the Xingu. The availability of water in the eastern Amazon, where the Xingu flows, could further decline in the coming decades with climate change (IPCC, 2021). Some studies suggest that climate change could lead a reduction up to 50% in the Xingu's flow in the coming decades (Sorribas et al., 2016). The dam project was made based on the availability of water based on data from previous decades, a period when the Xingu Basin had greater forest cover and when the threat of anthropogenic climate change was still poorly understood. Therefore, the hydroelectric plant is outdated, with its design unsuitable to operate in a sustainable way under current and future hydrological conditions. The current climate change and deforestation scenarios could further intensify the conflict over water imposed by the "Consensus Hydrograph".

Conflicts over the Volta Grande's waters date back to a first attempt to establish a dam in the region, during the Brazilian dictatorship period: a hydropower project known as Kararaô. Despite the highly adverse political moment, Kararaô was halted, while Belo Monte was not, even though the latter has likely faced fierce opposition, at least since 2009, when the claims to have access to the public audiences of the project were denied. The construction was paralyzed several times due to occupation of construction sites and due to judicial decisions, but the building of the dams and the diversion channel and reservoirs soon returned due to powerful political pressures. In November 2020, another year severely affected by drought and amid the COVID-19 pandemic, and five years after the release of the installation license for the Belo Monte hydropower plant, indigenous and riverine peoples in Volta Grande, for the second time, occupied and paralyzed the BR-230 Highway (Transamazônica) for five days. Once again, they denounced the serious impacts of the Belo

Monte water diversion, as manifested in their occupation letter, "We are here with our lives to defend Xingu's life. Belo Monte wants to kill us slowly, as it is doing with the Xingu, with plants, animals, fish. But let's not die without screaming. We are here showing our cry for water and life. Stop killing us! Stop stealing the waters of the Xingu!" (Translated from Portuguese).

The Belo Monte hydropower engineering modus operandi has continued to feed the conflict over the Xingu's water. Despite an installed capacity of 11,233 MW, the natural variation in the river flow only guarantees the effective average capacity of 4,571 MW (Leme, 2009) and only at the social and ecological expenses of the Consensus Hydrograph. As of today, after rounds of political and judicial battles, IBAMA has made a controversial agreement with Norte Energia and authorized the operation of Hydrograph B in February 2021. On June 16th, attending a petition from the Public Ministry, a Judge suspended the operation and demanded the adoption of the Provisional Hydrograph suggested by the technical Board of IBAMA, but the demand was ignored by the President of the institution. Norte Energia's reply came through an indirect attempt to terrorize society, by using the media to argue that the non-adoption of the Consensus Hydrograph would represent an average energy generation capacity loss of 1,800 MW in 2022. According to them, this loss would imply an additional cost of 3.5 billion Brazilian Reais (around US$ 700 millions) for the Integrated National System (Sistema Integrado Nacional, or SIN), which has an overdependence on hydropower.

In addition to the social and ecological impacts in the Xingu, recent studies have shown that the Belo Monte hydropower plant emits a significant amount of greenhouse gasses (GHG). Despite its run-of-the-river design, the Belo Monte hosts large reservoirs that inundated dry lands and favored conditions for emissions of carbon dioxide (CO2), and especially methane (CH4), which are generated from flooded vegetation and soils. The Belo Monte reservoirs emitted from 15 to 55 kg CO2eq MWh−1 during the first two years of operation, increasing three times the GHG emissions in the area compared to pre-impoundment emissions (Bertassoli Jr. et al., 2021). Projecting future GHG emissions from Belo Monte is a complex issue because they will depend on both future water availability (which has a nexus with global climate change and Amazon deforestation) and the hydrograph used for energy generation.

Finally, it is important to note as well that a nexus approach is, perhaps, insufficient for assessing the full impacts on the socioecological system. Wider system pressures are also important because dam construction is linked to other large infrastructure enterprises. For example, the Volta Grande is also threatened by another major project: a mining installation by the Canadian company Belo Sun Mining Ltda. The Volta Grande mining project aims to become the largest open-pit gold mine in the country. Less than 50 km from the main dam of the Belo Monte hydropower plant and 9.5 km from the Paquiçamba Indigenous Land (IL), the project envisages the use of cyanide in the management of ore minerals - an extremely toxic substance for both aquatic and terrestrial ecosystems - and the project's environmental studies predict that the risk of mining dam failure would be high.

7. Conclusions

This chapter has shown how the damming of the Xingu River to build the Belo Monte hydropower plant has severe detrimental impacts for marginalized societal groups across all aspects of the water-energy-food nexus. Those people who are most dependent on natural resources and maintenance of the river flooding pulse for their survival have strongly resisted this development, yet their voices remain unheard. Given projected climate change, increasing deforestation, significant GHG emissions and increased frequency of severe droughts, the energy production from the Belo Monte hydropower plant is called into question, raising issues about its feasibility to deliver what was intended in terms of stable output of clean renewable energy. The Belo Sun environmental impact assessment fully ignores both the impacts of Belo Monte in the region and the detrimental combined effects that these two large projects will likely have on the local socioecological system. This example demonstrates that, while the water-energy-food nexus offers a useful conceptual start in understanding interlinkages across sectors that span the social and ecological parts of the system, an explicit focus on governance remains vital to capturing the interplay among multiple interventions on the whole system. Stringer et al. (2018) argue that consideration of a second nexus, a policy-institutions-knowledge nexus, is central to improved governance, so that detrimental ecological impacts can be reduced and more equitable outcomes achieved for all. In the context of sustainable development and making progress towards the United Nations Sustainable Development Goals (SDGs), if Brazil is to advance and ensure that Agenda 2030's vision that "no one gets left behind" is considered, then far-reaching changes are needed in terms of the governance systems that underpin decision making about large infrastructure developments in order to more comprehensively assess and mitigate their adverse socioecological outcomes.

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CHAPTER 2

Analysis of the water, food and energy nexus for governance of river basins: the case of the San Francisco River

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1. Introduction

Dealing with water crises has required governments to change their ways of acting and articulating to implement governance models which facilitate exchanging experiences and enable the necessary measures for an adequate response in a timely manner (Mendonça, 2019). Thus, the nexus approach emerges in response to this demand, with its proposal characterized by managing these resources in an integrated manner, taking decisions which identify the direct or indirect impacts on all sectors.

There is a growing concern globally about water, energy and food security related to an expected increase in demand for these resources due to climate variability, population growth and human interference with the management of natural resources. One of the most important questions related to short-term extreme events is whether their occurrence is increasing or decreasing over time, meaning whether there is a tendency towards scenarios which are favorable to the occurrence of these events. The variability and changes in the intensity and frequency of extreme events not only depend on the rate of change in the medium of a given variable, but also on the occurrence of changes in the statistical parameters which determine the distribution of that variable. Climate change is expected to alter precipitation values and increase the variability of precipitation events, which can lead to even more intense and frequent floods and droughts (FBDS, 2009).

Although debates about the need for integrated management of natural resources for sustainability are not so recent, it was from 2011 that the Water-Food-Energy (WFE) nexus approach gained prominence. The WFE nexus can be defined as a paradigm for the public management of natural resources, directed toward qualitative and quantitative assessments of interrelated and interdependent systems. Its objectives involve shared management, strategic and adaptive planning, formulating related public policies, synergy between multiple sectors and the application of sustainable solutions (for example, water and energy efficiency actions) in any context (Torres, 2020).

Giatti et al. (2016) claim that applying the water, food and energy nexus is a new perspective for interpreting and intervening with a focus on sustainable development aimed at social inclusion and reducing inequities. However, there are serious challenges in obtaining the necessary data and information to understand the chains of resource which are intrinsic to the study objects under the spatial and temporal dimensions. This perspective is confirmed by Albrecht et al. (2018) by asserting that the provision of water, energy and food security can be achieved through an approach which integrates management and governance across sectors and scales.

The river basins management has the compatibility of multiple uses of water resources among its prerogatives. This increasingly urgent challenge demands efforts to understand how multiple uses are related and influence each other. Water, food, and energy are interdependent elements, although this characteristic is constantly disregarded by public policies and sectoral bodies responsible for them.

There are difficulties in dealing with the application of management instruments due to the territory of the river basin, the water resources require shared management with public administration, sanitation agencies, institutions linked to agricultural activity, navigation, electrical sector and environmental management, among others. Each of these sectors corresponds to a distinct administrative division of the river basin (Arroyo, 2018).

In this context, studying the theme of water, food and energy enables identifying the relationships between the sectors to adequately manage them, and as far as possible in an integrated manner. The study of governance becomes essential, as it helps understand the role of civil society and government agents responsible for the effectiveness of management, as well as provide elements for analyzing institutions, rules and procedures used for decision-making. Thus, the multilevel governance demanded by these sectors must act seamlessly to make the multiple uses of water compatible.

An analysis performed by Galaitsi (2018) revealed that the WFE nexus is closely interconnected with governance, economic forces, and socio-environmental factors. Giatti et al. (2016) highlight the following challenges to the rationality of the WFE nexus: (i) the issue of scale and the search for better systemic performance; (ii) the temporal issue and uncertainties of climate change; (iii) the challenge of multilevel and multisectoral governance. In addition to the challenges mentioned above, according to Albrecht et al. (2018) the perspective of this nexus is that the provision of water, energy and food security can be achieved through a point of view which integrates management and governance across sectors and scales.

The hydrographic basin of the San Francisco River is known for having national integration, with 2,800 kilometers of extension from its source in Minas Gerais to its mouth between Alagoas and Sergipe. The San Francisco River provides water for five Brazilian states: Minas Gerais, Bahia, Pernambuco, Alagoas, and Sergipe, representing an important scenario for the analysis of this nexus, since it has several hydroelectric plants for production energy in its territory, while it is also the main source of irrigation in the Northeastern semi-arid region. In this sense, the objective of the text will be to analyze governance in the hydrographic basin of the San Francisco River in its semi-arid stretch from the water-food-energy (WFE) nexus. The methodology included bibliographic analysis, documentary research technique and secondary data analysis to establish parameters to enable a diagnosis which contributes to optimizing the governance relations of this nexus in the study area.

2. Experiences in water resource management

Experiences which are based on different models of multilevel governance, have been shown to be positive and innovative practices in managing water resources. The drought that has occurred recently in recent years in various parts of the world, such as California and Australia, has brought about a change in trends. According to the Science Journal (2014), it was necessary to create some reforms involving water resources in order to reach such trends, namely: (i) water markets were well developed and allowed the trade of water to farmers with greater needs; (ii) modernization of irrigation infrastructure which increased water supply efficiency; and (iii) established water rights protecting the environment and habitats as availability decreases.

Australia's experience shows that water markets require government involvement as a meta-governor. The government interfered in the system in 2007 and inserted the environment into the market logic. Water markets cannot operate alone, they require strong government involvement to ensure environmental and social goals. In addition, the market has its limitations during scarcity, as allocation priorities are defined by other criteria which should not be purchased, such as guaranteeing access to water and its supply (Pahl-Wostl, 2019).

The impact of climate change on water resources in Brazil is expected to be more challenging, especially in the semi-arid northeast, where scarcity is currently a problem. For a country which has a region with such vulnerability, efforts should be made to map vulnerability and risk, in addition to deeply understanding their causes, sector by sector, and subsidizing public mitigation and adaptation policies (Marengo, 2011).

In the interest of plan and promote actions and decisions aimed at preventing and reducing the effects of droughts and floods, crisis teams were created by the National Water and Basic Sanitation Agency (ANA), with the objective of monitoring and making shared decisions regarding water management. This tool strengthens the participatory management of public authorities, users and civil society and contributes to solutions in crisis situations, reconciling needs from the perspective of multiple uses of water. These interactive environments emerged as one of ANA's initiatives to deal with critical hydrological events.

Since Brazil has continental characteristics, the probability of having critical hydrological events in several parts of the country at the same time is significant. The San Francisco River basin went through an adverse hydrological situation in 2012. To monitor this situation, ANA installed the San Francisco Crisis Team in 2013, which discussed measures that enabled the recovery of volumes stored in the basin's reservoirs, mainly in the Sobradinho reservoir. As of May 2019, the Crisis Team started hosting meetings to monitor the operating conditions of the San Francisco River Water System (ANA, 2020). These meetings take place at the Agency's head base and simultaneously by videoconference, enabling the attendance of several water users. They are recorded and shared with the population on ANA's YouTube channel.

There are also monitoring teams based on the same methodology, but with different objectives. The difference occurs in the analysis of priority water systems that do not integrate extreme event management or systems which have certain conditions to deal with adverse hydrological systems. The San Francisco River basin has been facing precipitation values below the historical average since 2012, resulting in a significant reduction in the inflows to the basin's hydroelectric reservoirs, which in turn leads to the lowest levels of storage ever recorded, which jeopardizes meeting the multiple uses of water. In view of the worsening of the scarcity in the basin, the ANA established the San Francisco Crisis Team in 2013, aiming at better articulation between the actors operating in the basin to mitigate the impacts.

According to Barros (2019), in critical hydrological situations, the storage stocks preservation in reservoirs placed at the headwaters of the Grande, Paranaíba, Tocantins and São Francisco Rivers plays a key role in achieving two major objectives: (i) ensuring compliance with the energy and power requirements of the SIN throughout the critical period; (ii) allowing the control of water management of bedside reservoirs for multiple water use purposes by all users. Otherwise, everyone would be harmed. In this sense, the monitoring rooms provide an environment for dialogue between the various users of the basin since there is a need to make the requirements of multiple uses of water and environmental conditions more flexible to reduce the hydraulic reservoirs inflexibilities of the National Interconnected System.

With the worsening water crisis in 2013, the minimum flows of San Francisco were gradually reduced and went from 1,300 m^3/s to 550 m^3/s in 2017, whose authorization was issued by ANA, through resolution No. 1,943.

Then, the ANA Resolution No. 2,081 of December 4th, 2017 was published with the objective of increasing water security and establishing new conditions for the operation which comprises the Três Marias, Sobradinho, Itaparica, Moxotó, Paulo Afonso I, II, III, IV and Xingó reservoirs.

The need to preserve the available water stock in the San Francisco River basin reservoirs, especially in relation to meeting multiple uses and supplying several cities, has led to actions to reduce the minimum flows released by the reservoirs. These flow reductions (carried out gradually) require systematic impacts monitoring of the level reduction in reservoirs and the river, and the necessary adjustments to maintain the fulfillment of multiple uses of water, particularly for human supply.

3. Multiple uses of water

The National Water Resources Policy established by Federal Law nº. 9,433/1977, presents the multiple use of water among its fundamentals, and complements that its management must be decentralized with the participation of the Public Power, users, and communities. In this regard, the compatibility of uses with different demands for water quantity and quality, in addition to reducing conflicts that are intensified in situations of scarcity are among the current challenges for managing water resources.

These issues became more worrying; according to the material prepared by the ANA (2020), the demand for water use in the country is growing, with an increase of approximately 80% of the total withdrawn in the last two decades. The forecast says that withdrawals will increase by 23% by 2030. As highlighted by recent studies, this increase will be followed by an intensification of the effects of climate change.

Sobral (2017) describe that the climate change scenario and the increase in extreme events of progressive water scarcity have been compromising all user sectors, which requires interdisciplinary intervention strategies worked under the focus of multiple uses.

Data from ANA (2020) also show that the main use of water in the country in terms of quantity used is irrigation. Urban supply is the second largest use of water in the country, accounting for 24.3% of the water withdrawn in 2019, and is concentrated in the territory, causing increasing pressure on water producing systems. Urban supply networks serve 92.9% of the city's population, and the rate of losses along with the unaccounted-for water portion, is close to 40% (ANA, 2020). Also, regarding the sanitation sector, the discharge of effluents into water bodies, predominantly untreated domestic sewage, is another use to be considered for making the use of water unavailable due to water pollution, which aggravates the critical situation in terms of water balance. (ANA, 2020).

Hydroelectric power generation is also an important use of water. Brazil had 1,362 hydroelectric projects in operation in 2019, including 730 hydroelectric generation plants (HGP),413 small hydroelectric plants (SHP) and 219 hydroelectric plants (HP) (ANA, 2020).

Through integration and management amid sectors and scales, a multisectoral approach can contribute to the pursuit of water, food, and energy security, as well as contradictions and gaps between sectors by providing and strengthening the synergistic relationships that exist between the dimensions that lead to sustainable development (Ferraço, 2018).

3.1 multiple uses in the San Francisco River basin

The San Francisco River extends for approximately 2,700 km, between the source, located in the Serra da Canastra, in the mining municipality of São Roque de Minas and the mouth, located between the states of Alagoas and Sergipe. Along its course, the river bathes municipalities in the states of Minas Gerais, Bahia, Pernambuco, Alagoas, and Sergipe. Its hydrographic basin includes, in addition to the aforementioned states, the State of Goiás and the Federal District. This basin corresponds to the third hydrographic basin in Brazil in relation to the area and is the only one that is entirely Brazilian (ANA, 2004).

The San Francisco River basin is divided into four physiographic regions: High, Middle, Sub-Middle and Low San Francisco (ANA, 2012). An important characteristic of this hydrographic basin is that 57% of its area is in the semiarid region, covering 218 municipalities in the region (ANA, 2004a). The main stretch of the San Francisco River has 2,696 km, while the drainage area of the basin corresponds to 638,576 km^2 (Figure 1).

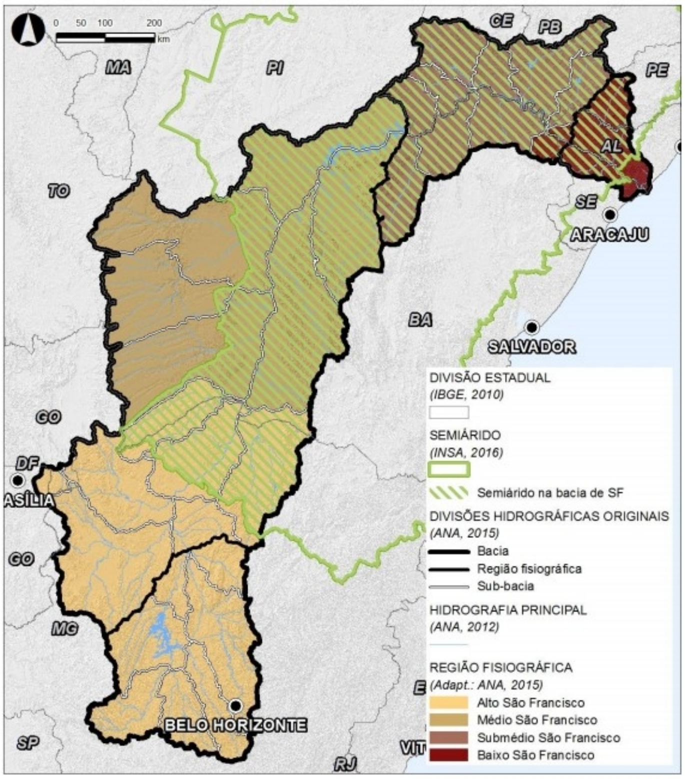

Figure 1. Hydrographic basin of the San Francisco River.
Source. ANA, 2004.

The main uses of water identified in the Basin include hydroelectricity generation, irrigation, navigation, industry, human and animal supply, effluent dilution, fishing, tourism, leisure, the maintenance of ecosystems and, in some parts, flood control reserves (Melo, 2016). Data from the CBHSF (2021), highlight that the historically priority use of navigation, which made the river known as that of "National Integration" in the second half of the twentieth century, was replaced by the generation of hydropower.

Another factor that deserves to be foregrounded in this hydrographic basin is the San Francisco River Integration Project with Northern Northeast Basins (PISF), implemented by the Ministry of Regional Development, whose objective is transferring, through the East and North Axes, waters from the San Francisco River basin to the rivers in the Northern Northeast. With 477 kilometers of extension between the two axes, the project aims to ensure the water safety of 12 million people in 390 municipalities in the states of Pernambuco, Ceará, Rio Grande do Norte and Paraíba (MINISTRY OF NATIONAL INTEGRATION, 2004; 2016). In this respect, the multiple uses considered in the management of the San Francisco basin should not compromise the flow offered to the States provided for in this project, since part of it is intended for human supply, which is understood as priority use. Table 1 presents the main uses of basins and discussions.

Multiple uses in the San Francisco watershed: main issues	
Human Supply	• The highest concentration of reservoirs for human supply is in the Northeast region of Brazil (holds 90%). • To combat the severe situation of water scarcity, since 2013 ANA, through resolution No. 2,219/17, popularly known as River Day, aims to reduce the water withdrawal from the San Francisco River in the dry period until April 30, 2018, and may be extended if there is a delay in the beginning of the rainy season in the basin. • The federal government launched the National Water Security Plan (2019). Its proposal is to list a portfolio of works, actions, and interventions of a structuring nature to ensure the supply of water for human supply and productive activities by 2035. The study showed that human water supply and river biodiversity share common risks.
Agriculture	• The Jaíba and Nilo Coelho Project stand out in the irrigation of the basin, the first refers to the state of Minas Gerais and the second to the states of Bahia and Pernambuco. In Jaíba, the total area of the project is 107,600 ha and an estimated airfield of 68,500 ha. In the irrigated perimeter Nilo Coelho, the total irrigable area is 23,486.20 ha. • In addition to these projects, there are several smaller captures along the river, especially Sobradinho and Itaparica. In this region, there is the highest production of high-quality noble fruits in Brazil, being the largest exporter of this product in the country.
Power Generation	• Historically, power generation in the San Francisco River basin has played an extremely important role in the development of the northeast region. • The uses of Sobradinho, Itaparica, Complexo de Paulo Afonso and Xingó correspond to 94% of the hydraulic generation capacity installed in the northeast. • Três Marias, in Minas Gerais, Sobradinho, Paulo Afonso and Itaparica in Bahia, and Xingó located between the states of Alagoas and Sergipe, together correspond to the generation of energy flow control. • Between the years 2014 and 2015, the reservoir Sobradinho reached its lowest storage levels in history, registering only 1% in early December 2015. • The volume of rain recorded in several basins from October/2020 to July/2021 is the lowest in the last 91 years. Currently, the region faces the worst water crisis in recent history.

Table 1. Multiple uses in the San Francisco Watershed. Source: Adapted from ANA (2020) and Castro and Pereira (2019).

4. Governance in crisis periods

Several strategies expand governance spaces and can be used daily in different spaces. However, in times of crisis they become even more necessary and urgent. Institutions play a crucial role in the pursuit of sustainability. The Sustainable Development Goal 17, described in Agenda 2030, deals with "Partnerships, and means of implementation" and in its goal 17.14 states that "policy coherence for sustainable development" must be "increased". From this perspective, the approach considering the WFE nexus becomes essential.

ANA (2020) brackets those actions aimed at promoting water security in the context of a water crisis into: (i) emergency measures which feature the immediate solution of the problem and therefore are often costly and ineffective in the long term; and (ii) measures based on medium to long-term planning objectives which are to prevent and/or mitigate future impacts arising from new crises. These measures include structuring actions both at the management level (regulatory frameworks, improvements in legislation, and in institutional and sectoral articulation) and at the level of improving a region's water infrastructure.

In this sense, this item will describe in detail how multilevel governance is related to the WFE nexus and later analyze some strategies which expand these integration spaces and have the potential to improve governance in the San Francisco River basin. Thus, the following items were chosen considering the WFE nexus for analysis: the Water Resources Plan for the San Francisco Basin, the role of the basin committee and the operation of the monitoring team for the water system.

4.1 Multilevel governance considering the WFE nexus

According to the World Bank (1992), the general definition of governance is "the exercise of authority, control, administration, government power". It is understood that "it is the way in which power is exercised in administering a country social and economic resources with a view to development," further implying "the capacity of governments to plan, formulate and implement policies and fulfill functions".

Jacobi (2012) cites other types of governance which have been used at the municipal level: good governance, that emphasizes transparency, accountability, and effectiveness as necessary conditions for the success of public policy and multi-scale governance, which has the challenge of articulating the actions of independent public actors aiming at shared objectives at different territorial levels.

The main argument of those who promote the WFE nexus, where it may include the climate, is based on the fact that different 'nexus' themes are so closely related and must be analyzed simultaneously to encourage mutually beneficial situations, avoiding negative impacts, and improving the sustainability level (Keskinen et al., 2015). In addition, a development proposal for the governance and management of water resources related to the food and economic crises is needed (Benson et al., 2015).

According to the study by Giatti et al. (2016), water governance requires a process that seeks equity with the participation of different stakeholders (community representatives, municipal and state managers, federal agencies, and companies involving the context of river basins). The nexus governance must deepen arrangements that promote arduous challenges, because it is configured in a multi-dimensional matrix in which the governance levels overlap, and a deep overview of the arrangement between the water, energy, and food sectors. Greater diversity in governance can be constituted by fragmentation, by learning spaces that dialogue with structural conceptions and by the possibility of influencing political discussions (Pahl-Wostl, 2019).

However, the challenge of the nexus should not only be seen as a new posture of integrated management; it is necessary to deepen the theme, seeking contextualization, such as the social conflicts associated with multiple uses (Cairns & Krzywoszynska, 2016). It is necessary to establish a critical and rational reflection on the nexus. It is essential to develop integrated approaches that are in quest of compensation and possibilities for synergies and increased efficiency between the water, energy, and food systems, seeking better choices based on the involvement of social actors (Giatti et al., 2016).

4.2 San Francisco River basin water resources plan

Water resources plans are one of the instruments described in the National Water Resources Policy (Federal Law No. 9.433/1997) which aim to support and guide the governance of water resources. The same law also determines that these are long-term plans, with a planning horizon compatible with the implementation period of their programs and projects.

There are the following water resources plans in the area covered by the

San Francisco River basin: (i) National Water Resources Plan, whose review for the period of 2022-2040 began in 2019; (ii) State Water Resources Plans of States inserted in the São Francisco river basin: Bahia (2004), Pernambuco (1998), Sergipe (2000), Alagoas (2011), Minas Gerais (2011), and Goiás (2018); (iii) Hydrographic Basin Plans for federal rivers; and (iv) Hydrographic Basin Plans for state rivers. Silva and Cirilo (2011) state that basin plans have generally been prepared by isolated initiatives, whether by the Federal Government or the States. However, it is necessary to have an articulated planning in case of a basin whose main river is the domain of the Union overcome the divergences that may arise to the different interests involved in a river basin.

In this perspective, Sobral (2017) state that water resource plans must be prepared by multidisciplinary teams and be approved by river basin committees that have an interdisciplinary and interinstitutional composition. This multidisciplinary and inter-institutional training is a great differential. Despite the management of water resources in Brazil currently providing the joint work of scientists, managers, users and decision makers on a given river basin, integration and planning based on what is defined in the Water Resources Plan for the basin considering several sectors (such as the WFE nexus), is still ineffective.

The San Francisco River watershed had its first water resources plan drawn up in 2004 and the review and launching of a new plan in 2016, with the main articulation of the Watershed Committee. The lack of integration between the objectives of the basin plan and other environmental policies is frequent and is enough to observe the amount of the database of the different areas which do not communicate. This can be seen in the lack of cohesion between the National Water Resources Plan, state plans and basin plans. A study by Silva and Cirilo (2011) on this aspect showed that the plans of the tributary rivers of the San Francisco often bring action in a generic way, which should be detailed due to the Plan for the Hydrographic Basin of the San Francisco River.

Regarding the need for integration, the same authors point out that a synchrony should be observed between the elaboration of a basin's plan and the plans of affluent river basins, especially when it is a river under the domain of the Union, as in the case of the San Francisco, and that could contribute to an increase in the implementation rate of water resource plans.

Unfortunately, this is a feature of several Brazilian sectoral policies, as can be seen in a study by Dulac (2017) on Brazilian policies on water resources, sanitation, and disaster risk management, who pointed out that although these policies have common objectives, their actions have been carried out in a fragmented way among the sectors.

4.3 San Francisco River basin committee

The river basin committee is an organization made up of public authorities, civil society and water users, whose purpose is to perform decentralized and participatory management of water resources in the basin with a view to protecting its water sources and contributing to its sustainable development (CBHSF, 2021). Created in 2001, the committee has normative, deliberative, and consultative attributions, and works with 62 members divided between: users representing 38.7% of the total members, public authorities (federal, state, and municipal) representing 32.2%, civil society with 25.8%, and traditional communities with 3.3% (CBHSF, 2021). This committee meets twice a year, in addition to meetings of the various technical chambers and four regional groups.

Although the committee is a participatory institution established from the top down, this is a unique opportunity for different stakeholders to come together, exchange experiences and build the foundations for a common understanding of water resources management (Koppel & Siegmund-Schultze, 2019).

A study by Kasahara et al. (2020) shows that the multiplicity of CBHSF participants seeks to ensure a balance of decisions and benefits for all areas, whether being geographic or thematic. However, given the complexity of the basin and its socio-environmental heterogeneity, the committee's performance is often inefficient and does not correspond to the most urgent needs of the basin, but rather to the desires of user groups. From this perspective, Rodorff (2015) highlights that despite implementing integrated water management through creation of a participatory committee, there is a challenging framework for its materiality and operationalization.

Although the adopted model has enabled forming participatory discussion forums, where regional interests and problems that affect and are affected by water resources are discussed and presented, one of the greatest needs currently is to increase its effectiveness, transparency, and participation of all users (Jacobi, 2019).

4.4 Monitoring team for the San Francisco water system

A long period of rainfall deficit was observed in the San Francisco River basin between 2012 and 2018 in relation to its historical average values. It rained little more than 80% of the historical average values in the first and last hydrological year of this period (2012-2013 and 2017-2018). The accumulated precipitation in the remainder of this varied period between 66% (2016-2017) and 79% (2014-2015) of the historical average (Guilhon, 2021).

This period of scarcity that occurred from 2012 onwards in the San Francisco basin pointed to the limitation of multiple uses and demonstrated the need for greater monitoring of water issues. In this context, ANA created work meetings with the various actors involved in the management of water resources in San Francisco, which later became known as the "Crisis Team", and, in 2019, it was transformed into the monitoring team for the San Francisco water system.

From this critical period onwards, ANA has used the Crisis Team expedient as an environment for governmental and non-governmental actors to meet for critical water situations. The Crisis Team aim to monitor and assess the critical event (drought or flood), to identify and plan response actions and measures within the scope of water resources management to adapt and mitigate its impacts (Mendonça, 2019). The same author highlights that the San Francisco Crisis Team was an environment of regulatory coordination created to monitor the evolution of reservoir storage and enable responses related to managing water resources for what was configured as the worst drought recorded in the San Francisco River basin.

Mendonça (2019) describes the composition of these meetings:

> *The meetings were coordinated by the ANA, and initially held monthly at the Agency's headquarters. Representatives from the electricity sector (Ministry of Mines and Energy, National Electric Energy Agency, National Electric System Operator and operators of hydroelectric plants installed on the San Francisco River – Cemig and Chesf), from the National Secretariat for Civil Defense and Protection (SEDEC), from the Brazilian Institute for the Environment and Renewable Natural Resources(IBAMA),from the state water resources management bodies of Minas Gerais, Bahia, Sergipe and Alagoas, the San Francisco River Basin Committee, the Fish Alive Agency, sanitation companies and other water users all participated. Depending on the identified needs, eventually other actors were involved in the discussions (Mendonça, 2019, p.16).*

The frequency of meetings varies by period. The meetings were previously conducted in person and then recently via videoconference, and occurred weekly at more critical moments, but in other situations they took place fortnightly or monthly. The lessons learned during this period and the advances obtained from sharing information from committee decisions showed that it was necessary to create regulations and structures in times of crisis that would support similar situations in future times. In this sense, ANA created Resolution Nº. 2081/2017 after the critical period, establishing conditions for the operation of the São Francisco River water system, which comprises the Três Marias, Sobradinho, Itaparica (Luiz Gonzaga), Moxotó, Paulo Afonso I, II, III, IV and Xingó reservoirs.

The resolution establishes parameters for the operation of the San Francisco River water system, and although it is a great advance for the standards of management of water resources practiced so far, the resolution only deals with the quantity of water and does not mention its quality. The experiences shared from the "Crisis Team" supported the creation of the water system monitoring team from 2019, as the shortage situation was alleviated.

Information from the ANA (2020) exemplifies that the monitoring team occurs in priority water systems which do not face an extreme hydrometeorological situation or which already have operating conditions in place capable of unfavorable facing hydrological periods, and do not require and implement significant changes in uses and water resource users.

The approach considering the WFE nexus is essential for coping with extreme weather events, even in times considered "normal". According to the FAO (2014, n.p.),:

> *A nexus approach provides opportunities for decision makers to engage with each other. A range of stakeholders can be involved, such as local, regional, and national governments, basin organizations, development banks and agencies, international organizations, institutes and universities, NGOs, civil society, the private sector, among others. The interaction between these stakeholders is at the heart of the nexus concept.*

The practice of governance raises constant challenges, and the discussion arena will not always reach consensus, especially when it involves several important sectors, such as the electricity and agricultural sector. Carrying out debate and the possibility of making decisions together with sectors which use common and scarce environmental resources provide opportunities for conscious decisions. From this perspective, it is important to discuss the role of all institutions that compose the Monitoring Team of the San Francisco River water system, and the lack of effective contribution from essential sectors. Examples of these issues can be observed with the performance of the electricity sector, which presents constant dilemmas with great demands from society and public authorities, especially in terms of difluence in periods of scarcity, while large agricultural enterprises that use irrigation are rarely questioned or have their grants for altered water usage. Guilhon (2021, n.p.) state that:

> *The water resources management process in the San Francisco River basin during the period of water scarcity, which involved the main actors in the basin under the coordination of ANA, underwent an improvement process and provided continuous update about the river basin, and allowed the integrated action of all these actors in decision-making without prejudice to the specific attributions of each of the participating entities. Thus, this management experience constitutes a successful case of water resources management in a participatory manner.*

In this perspective, Mendonça (2019) highlights that in addition to presenting alternatives for managing the water crisis, the crisis team has contributed to improving the quality of the Agency's decision-making process and regulatory capacity, promoting qualified participation and transparency in the decision-making process.

5. Proposals for governance considering the WFE nexus in the San Francisco River basin

Thinking about planning and management strategies which consider the WFE nexus is relevant, especially in the Brazilian Northeast where water scarcity periods are frequent and aggravated by the context of climate change.

Jansen et al. (2021) highlight that the issue of management in the territory and its different territorial levels emerges (international, national, state, and regional) from arrangements such as Municipal Associations and River Basin Committees, and the location from the municipality and the community. Interdependence, horizontal and vertical collaboration between these territorial levels is necessary for governance and integrated management processes. This process becomes viable as there is organizational and institutional structuring for its implementation which enables the participation of actors in the management network from different territorial levels and different development policies.

A study carried out by the OECD (2015) showed that formulating and implementing water resource policies are by nature highly fragmented and involve a multitude of stakeholders and authorities from different government levels and policy areas. In this same perspective, Ferraço (2018) highlight that isolation in the management and analysis of the resource is visible in Brazilian water policies, as well as delimited considerations regarding management, since the sectoral analysis disregards the implications and existing uses of the resource by other sectors, such as agriculture and energy. The same authors claim that better management of natural resources requires integrating sectoral policies, which have common elements. The WFE nexus is part of this premise (Ferraço, 2018).

The examples analyzed demonstrate that although integration and participation is a premise of the National Water Resources Policy, there are unavoidable conflicts between the different uses, what could be minimized or better understood if they were worked from the perspective of the WFE nexus and effective multilevel governance. Philippi Jr. (2019) show that governance emerges as a mechanism for democratizing and advancing shared management, minimizing conflicts between multiple users distributed across different geographic jurisdictions present in a river basin. In addition, Jacobi et al. (2015) state that although governance opens space for multiple actors, the State remains the most important. This statement was corroborated in this study mainly from analyzing the decisions of the monitoring team.

The large financial investment made in preparing Water Resource Plans for the basin does not translate into their effective application and improvements in the local socio-environmental situation, especially because the Plans operating in the same coverage area do not integrate and interact. The pioneering and successful decisions of the Crisis Team and Monitoring does not exempt it from gaps and needs for more in-depth discussions. Giatti et al. (2016) state that there are indications that certain sectors are institutionally stronger than others, and this implies that there may be difficulties in enabling equal, balanced compensation. In this sense, the present study observed that the agricultural sector is one of the most "benefited" with sectoral analyses related to water consumption in the Northeast semi-arid region. The fact that environmental agencies and water resources do not have inspection apparatus in the field, facilitated consumption of water for irrigation, including non-licensed ones.

These cases become even more relevant today with the imminent risk of an electrical crisis in the Midwest, Southeast and Southern regions, and the possible overload in the Northeast System. The reduction of runoff for a period, even if authorized in the monitoring team meetings, compromises non-priority uses in the basin. This fact may have even more consequences after starting operation of the San Francisco River Basin Integration Project in its North and East axes.

When analyzing water transposition projects in China, Chen et al. (2019) emphasize that all sectors that are listed in common projects or plans must develop decision-making processes which enable the effective participation of representatives of all sectors involved.

Climate crises show that sustainability in its ecological aspect is essential. The guarantee of multiple uses of water goes through the fundamental condition of guaranteeing adequate ecological conditions for the water body. In addition to considering this issue, the WFE nexus approach allows us to act to reduce conflicts between users, making them responsible, when necessary, but above all by integrating them into discussions and shared decision-making. In this context, to optimize multilevel governance in the San Francisco River basin considering the WFE nexus, it is recommended to:

- Carry out long-term planning based on the WFE nexus considering the specificities of the multiple uses of water resources and maintaining the environmental flow. Water resource plans need to provide for actions to recover ripe forests and recomposition of APP, together with state and municipal agencies, and civil society partnership, to improve the environmental conditions of the water body.
- ANA and state water resources agencies must act with proactive governance based on planning, and not just in crisis situations and when problems are already installed. It is essential to insert civil society in this process. In addition, extend the participation of states and municipalities in the instruments of planning and execution of integrated water resources management since the logic of the WFE nexus must be inter-scaled and encompass all federative entities.
- Expand the participation of other sectors in the discussions of the Water Resource Plans, in the execution of the proposed actions, in the basin committees and in the monitoring team meetings.
- Adopt water resource management strategies which integrate user sectors considering the WFE nexus and take joint actions, such as reducing the demand for water by certain sectors at peak times.
- Use financial resources arising from charging for the use of water resources for integration between users and optimization of watershed

recovery actions in its entirety.

- Broaden discussions, charges, and restrictions to other sectors, especially agriculture and sanitation. The agricultural sector needs greater control by the management agencies of the environment and water resources, with limitations on expansion and authorization release, in addition to increasing pressure to change more optimized irrigation technologies. Regarding the sanitation sector, it is recommended to draw up local work plans with the objective of reducing the release of untreated effluents, especially in small municipalities, contributing to improve water quality, and not affecting downstream uses.
- Greater performance by the ANA as a regulatory agent for all multiple users.
- Improve environmental inspection procedures for the diffuse use of water resources, using geotechnologies and articulation with local agencies.
- Report institutional efforts to integrate the basin plans to the various existing plans in their coverage areas, such as the Environmental Plans for Conservation and Use of The Surrounding Artificial Reservoirs and the Municipal Master Plans, and to the SDGs, as per UN guidance.
- Act to reduce institutional weaknesses highlighted in various sectors in order to ensure water, food, and energy security.

6. Conclusions

Conflicts over the use of water are intensifying in this moment, especially in Brazil. The current water crisis, which could trigger a new energy and food crisis, elevates this discussion to a priority issue for society.

Reflections on multilevel governance considering the water, food and energy nexus takes a central position in this debate. Although Brazil has advanced in its water resource management in an integrated and participatory manner, reality shows gaps that need to be rethought. The differences in the participation level and pressure among the participants of the committee decision-making bodies, such as the basin committee and the monitoring team, exemplify this issue. The strong and majority participation of the State, strongly influencing collective decisions, also deserves further analysis.

The aforementioned examples presented from the analysis of the San Francisco River hydrographic basin bring discussions at the planning and execution levels of water resource management, including in periods of water crisis. It is not intended to exhaust the topic, but to indicate issues which need to be deepened and optimized, since the interaction between the different users is not effective and has not been considering the WFE nexus. The proposals listed herein are intended to help in reflection, especially at this opportune moment for proposals, since the ANA has been coordinating an update of the National Water Resources Plan.

The period of climate change and the greater frequency of extreme events highlights the urgency of thinking about new governance arrangements based on the experiences described herein which to consider the WFE nexus in its formulation and implementation of more assertive planning and execution policies, aiming to contribute with the assurance of water, food and energy security considering the multiple users of water.

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CHAPTER 3

Instruments of environmental and productive intervention from the perspective of the nexus water, energy and food: an analysis of the context of the Cantareira Water Production System

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1. Introduction

The management of strategic resources such as water, energy and food in a segregated way is a source of conflict, reflecting inefficiency and unsustainability. Faced with a complex and interrelated reality, sector management is highly limited to contribute to sustainable development (Hoff, 2011; Olawuyi, 2020).

Recognizing this problem has motivated the emergence of new concepts that try to overcome the deficiencies in the sectoral management of natural resources. In this sense, there is the concept of nexus water, energy and food. The nexus can be understood as a theoretical-methodological approach that starts from the recognition of the interdependencies between the water, energy and food systems in order to promote more efficient and sustainable intervention instruments, aiming to reduce conflicting exchanges (trade-off) and increasing synergies between the systems (Hoff, 2011; Flammini et al., 2014).

In its applied dimension, the nexus approach aims to assess contexts, considering the instruments of interventions for sustainable development (Flammini et al., 2014). In this perspective, analyzes based on the nexus seek to provide policy makers with information for a systemic understanding of sensitive socioenvironmental contexts, supporting actions that contribute to promoting the Sustainable Development Goals (Olawuyi, 2020).

For nexus interventions have long-term impacts, they must count on adequate institutional arrangements. From said institutional arrangements, it is expected objectives that integrate the interests of different sectors (multicentric), involve multiple stakeholders (politicians, technicians and civil society), in addition to act within adjusted scales to obtain results (Hoff, 2011; Allouche et al. 2014; Flammini et al., 2014; Benson et al., 2015).

It is understood that the sectorial management is also materialized through intervention instruments used to shape the behavior of social stakeholders (Flammini et al., 2014). Thus, here the focus is placed on the integration between instruments, which promote environmental conservation, and productive development in rural areas, since these instruments are related to the water resources management, the food production and bioenergy.

From this point of view, the nexus approach was used to understand the context of the Cantareira Water Producing System. The Cantareira System is the main system that supplies water for the Metropolitan Region of São Paulo, covering a drainage area of approximately 228 thousand hectares, located partly in the state of São Paulo and Minas Gerais (Uezu et al., 2017).

In 2011, about 62% of this area was occupied by cattle ranching and eucalyptus forestry (Uezu et al., 2017). Hence, the way the soil is managed in these activities can affect the physical properties of the soil, such as water infiltration, redistribution and storage, therefore, it interferes in the recharge capacity of the water tables, and with the maintenance of continuous flow of the water in springs, streams and rivers, consequently, influencing on the regional hydrological regime (Lima, 2006).

Cattle ranching is used for meat and milk production. This activity comprises the set of economic strategies of rural families, as well as guaranteeing the supply of food at the local and regional level. Eucalyptus forestry is interrelated with livestock, as it is the first productive investment alternative to livestock. Eucalyptus monoculture is used for different purposes, but the production of firewood and charcoal stands out (Chiodi et al., 2019).

The use of nexus approach in this context consists of centralizing the environmental, socioeconomic, and political dimensions surrounding the activities that produce food and bioenergy in the region. Cattle ranching and eucalyptus monoculture are important for they occupy the soil predominantly, they promote effects on hydrological conditions, supply markets and are economic activities that make up the social reproduction strategies of a significant portion of the rural population (Chiodi et al., 2019).

In this context, this chapter identifies the main instruments that promote environmental conservation and sustainable development that affect these productive activities, aiming to discuss the perspective of integration based on the water, energy and food nexus. In doing so, it delimits the context of the study. It describes the instruments identified based on their central objectives, stakeholders involved in their implementation and scales of application. Finally, it reflects on possibilities and limits that the nexus approach allows for the management of natural resources in the context of the Cantareira System.

2. Methodology

The "context of the Cantareira System" was defined as the watersheds of its water reservoirs, or more precisely, the nine municipalities that make up 98.1% of this area, which are Camanducaia, Extrema, Itapeva and Sapucaí-Mirim in Minas Gerais, and Joanópolis, Mairiporã, Nazaré Paulista, Piracaia and Vargem in São Paulo (Figure 1) (Uezu et al., 2017).

In this context, the main intervention instruments for environmental conservation and productive development related to cattle ranching and eucalyptus planting were identified. These "intervention instruments" may be understood as formal institutions (laws, norms, policies) and actions that promote both the preservation and conservation[3] of the natural resources (forest, soil and water) as support for these productive activities. It was sought to identify the instruments to point out elements that demonstrate integration between interventions for environmental conservation and agricultural development.

The "land use and occupation" was central to the definition of the integrated elements of the intervention instruments. The integrated elements are those that aim to establish means for the conservation[4] of natural resources, not inhibiting the land use for productive activities. On the other hand, the non-integrated elements hinder the productive land use (livestock and eucalyptus) or such use negatively affects the attributes related to natural resources, compromising their functions at some level (degradation).

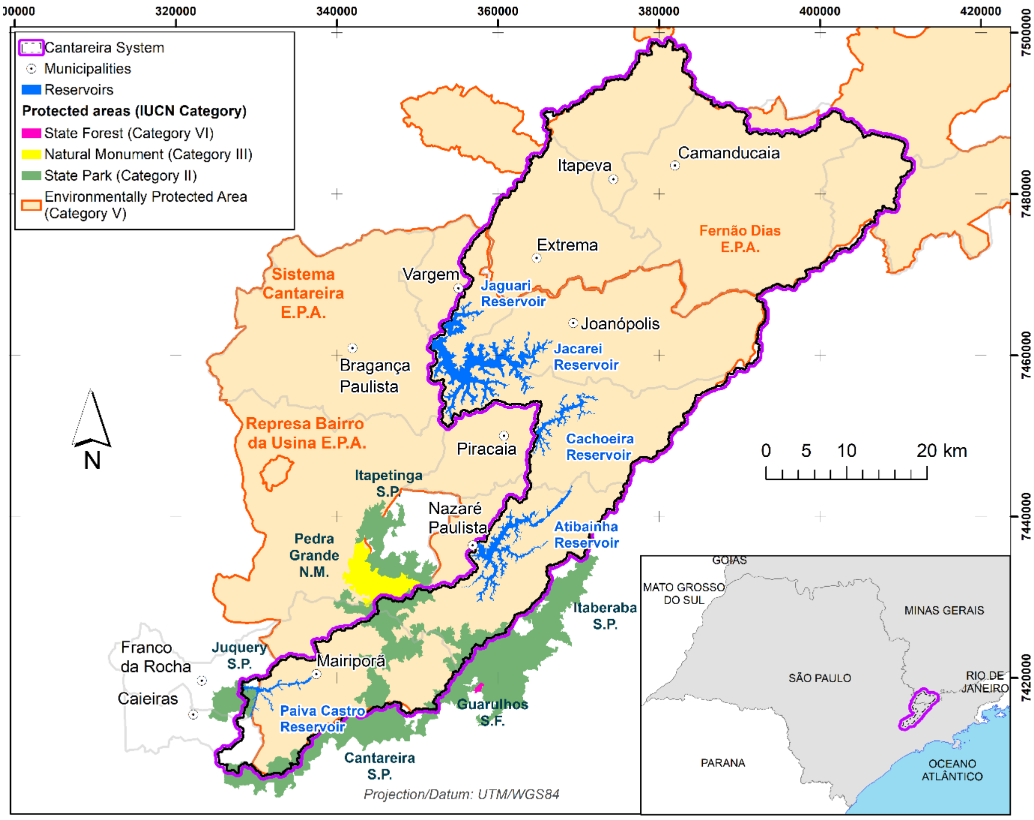

Figure 1. Delimitation of the drainage area of the water reservoirs of the Cantareira System with the subdivision of the territories of the municipalities and conservation units.
Source. Elaborated by the authors.

3 Preserving refers to the prohibition of the economic exploitation of natural resources, while conserving allows the economic exploitation of natural resources in a sustainable way.

For this study, primary and secondary data were evaluated. In the field research (primary data), the instruments were identified, and aspects of their application were captured, based on the perception of their managers. Representatives of the State Forestry Institute of Minas Gerais (SFI/MG), the Forestry Foundation of São Paulo (FF/SP), the State Technical Assistance and Rural Extension Company of Minas Gerais (STARE/MG) were interviewed, as were the Coordination for Sustainable Rural Development of São Paulo (CSRD/SP), municipal secretaries for the environment (Extrema, Camanducaia, Itapeva, Mairiporã, Joanópolis Municipalities) and the Institute for Ecological Research (IER). Altogether, twelve interviews were carried out, which took place from an open question script (Richardson, 2010) between 2017 and 2020.

Secondary data were collected in the database of the 2017 Census of Agriculture, the National System of the Rural Environmental Registry and in technical, legal and scientific documents.

3. Intervention instruments

Different instruments were identified aiming at environmental conservation and productive development. Here, the focus is on the most comprehensive ones, which were aggregated in three categories: institutions for environmental protection, instruments for forest restoration and instruments of productive incentive.

3.1 Institutions for environmental protection

The Forest Code (FC) and the Protected Areas (PAs) stand out as environmental protection institutions. Both are responsible for their applications by the state environmental agencies (SFI/MG, FF/SP and State Secretary for the Environment/SSE-SP). The partnership with the military police and, in the case of PAs, management councils composed of representatives of States, municipalities and civil society is known for its compliance with the FC.

The FC is the main environmental policy that falls on the rural property, having two central provisions: (i) that a percentage of the area of the rural property, variable for each biome, must be maintained with native vegetation as a Legal Reserve (LR); and, (ii) the obligation to maintain Permanent Preservation Areas (PPAs) with native vegetation cover, which encompass the surroundings of springs, water courses, hill tops and sloping areas (greater than 45 ° or 100%).

Depending on the physical-geographic context, PPAs impose serious restrictions on agricultural use of the soil, especially in the context of the Cantareira System. In the studied municipalities group, on average, approximately 60% of agricultural establishments had the presence of springs and water courses (Instituto Brasileiro de Geografia e Estatística – IBGE, 2017). This hydrographic network, in addition to the mountainous relief and the small rural properties predominance, sets up a scenario of strong legal impediment to land use.

When considering PAs, state parks (SP) and environmental protection areas (EPA) are noticeable (conservation unit – CU). In general, both categories have objectives related to the conservation of forests, biodiversity, and important water resources for the Metropolitan Region of São Paulo (Uezu et al., 2017).

The State Parks (SP) (Cantareira, Juquery, Itapetinga and Itaberaba) are fully protected. Since they are territories created for preservation, private properties in their interior must be expropriated to inhibit any use of the land, a fact that causes conflicts with producers in the region. As shown in Figure 1, the SPs are concentrated in the south of the Cantareira System area.

An interviewed manager reported that despite the importance of PEs for the Cantareira System, there are serious difficulties for them to be effective in protecting the territory, given the deficit of financial, human and infrastructure resources. The lack of resources to expropriate properties, the occurrence of invasions and the limited capacity to inspect the territory are factors that create conflicts when applying this instrument.

On the other hand, the Environmental Protection Area is a more integrated instrument, as it aims to make environmental conservation compatible through the sustainable use of natural resources in private properties. The Cantareira System area in São Paulo has a territory within the EPA Piracicaba/Juqueri-Mirim Area II and the EPA System Cantareira and, in Minas Gerais, the EPA Fernão Dias (Figure 1).

Although EPAs have the specific objective of promoting sustainable production, its effectiveness is limited. Through interviews with managers, it was identified that among the challenges to promote environmental conservation in the EPAs' territory, is involving very large territories, where there must be integration between public and private interests.

3.2 Instruments for forest restoration

Among the instruments for forest restoration, we highlight the initiatives of Payment for Environmental Services (PES). The PES can be understood as a transfer of resources between social stakeholders, which aims to create incentives to align individual or collective decisions on land use with the social interest in the management of natural resources (Muradian et al., 2010).

In the context of this study, the PES is materialized by the financial payment to the owners that allow conservation practices to be carried out on their properties. It is also worth mentioning the Water Conservation Project conducted by the Municipality of Extrema together with several partners, and the Water Producer Pilot Project undertaken in a partnership by The Nature Conservancy, CSRD/SP, SMA / SP, municipal governments of Nazaré Paulista and Joanópolis, among others.

Despite the financial payment having visibility, according to the manager of the Water Conservation Project, this is the means to achieve forest restoration within private properties. Thus, the PES is considered an instrument for complementary conservation to the FC (Brasil, 2012), because when promoting forest restoration, the areas will be protected by its provisions. However, such complementarity occurs at the sectoral level, as it integrates instruments for environmental preservation.

At the intersectoral level, PES initiatives invest in soil and water conservation practices, such as rainwater containment basins and agricultural terraces. These practices favor the processes of water infiltration in the soil and reduce the erosion rates, which are directly linked to the quality and quantity of water, and do not inhibit the productive use by agriculture and livestock. Thus, such practices are elements that are understood to be integrated with PES initiatives, since they promote soil and water conservation and encourage agricultural productive activities.

3.3 Productive incentive instruments

Among the instruments of productive incentive, the rural credit stands out, for it aims at the costing (finance expenses of the production cycle) and the investment (finance expenses of implantation of crops, acquisition of animals and equipment) of agricultural activities. Credit operators are public and private banks, and producers generally receive technical advice for the credit projects preparation.

In this instrument, an element that is integrated with the environmental policy is the determination that banks can only grant credit for activities that will be developed in properties which are registered in the Rural Environmental Registry (RER). Despite a relevant measure, the RER, the designated main control tool of the FC, represents a statement on the property state of use and does not necessarily guarantee compliance with the law. Therefore, there is no certainty about the real environmental counterpart on the producers' part to access rural credit.

For eucalyptus silviculture, forest promotion is an instrument to encourage the planting of the species. Forest promotion actions come from both the public and private sectors. In Minas Gerais, the SFI has an endeavor to produce and donate eucalyptus seedlings. According to a technician from the agency, about 40,000 seedlings are produced and donated annually. The seedlings are donated without proper monitoring by the technicians in relation to where to plant, therefore, there is no effective control of compliance with environmental legislation by producers.

In São Paulo, the Forest Savings Program aims to encourage farmers to plant eucalyptus as an income option, based on a public-private partnership. Suzano Company is the proponent of the program, and CSRD/SP provides technical assistance to producers in the planting process. In the program, the producer receives a package (seedlings, fertilizers, pesticides) from the company and is given the purchase of guaranteed production. Meeting the environmental legislation is a requirement of the program for the adhesion of producers. Despite this determinant, the promotion of monocultures in water sources areas is controversial, with eucalyptus being pointed out as potentially harmful in water sources (Castro & Morrot, 1996).

Among the instruments identified, the dairy production initiatives in rotated grazing systems deserve to be highlighted. These systems are encouraged by both public bodies and a civil society organization.

In the public sphere, in both states there are programs to promote dairy production. CDRS / SP develops the CSRD Milk Program and STARE/ MG executes the Minas Milk Program. These programs, through technical assistance and rural extension, support producers in converting production systems. Despite having few producers involved, these are model producers to encourage others to adhere to the rotated grazing system.

Within the scope of civil society, there is the "Sowing Water Project" of the Ecological Research Institute. According to the project coordinator, IER has been operating since 2010, supporting rural producers interested in rotated systems. Efforts continue to promote ecological management of pastures on "model" properties. Until 2020, eight properties underwent conversion processes between systems, these becoming support units for training courses for producers, in addition to being "laboratories" for studies on the environmental and economic benefits of these production systems.

Rotational management has advantages over traditional extensive grazing. This system, following the division of the area into plots and paddocks, promotes less animal trampling, and thus reduces soil compaction, which favors greater water infiltration and percolation, greater aeration and growth of the root system, and therefore less soil erosion. Consequently, such initiatives create synergies between food production and water conservation, benefiting water producers and users.

Given the above, Table 1 presents a synthesis of the instruments identified with their classification elements.

Instrument		**Sector of Origin**	**Scale**	**Integrated Elements**	**Non-Integrated Elements**
Environmental Protection	Forest Code	State-Owned	National	_	Forbit Agriculture in PPA e LR
	State Parks	State-Owned	Territory CU	_	Forbid Productive Use
	EPAs	State-Owned	Territory CU	Sustainable Land Use	_
Forest Restoration	PES	State-Owned	Hydrographic Basin	Soil Conservation Practices	Forest Restoration
Productive Incentive	Rural Credit	State-Owned and Private	Rural Property	To Posses RER	Conventional Production
	Forestry promotion	State-Owned and Private	Rural Property	Environmental Adequacy	Monoculture
	Rotational Grazing	State-Owned and Civil Society	Rural Property	Soil and Water Conservation	Monoculture

Table 1. Intervention instrument, sector of origin, scale of intervention, integrated and non-integrated elements in the context of the Cantareira System, in 2019.
Source. Elaborated by the authors.

4. Discussion

All the identified instruments come from or have the participation of state agencies (state or municipal level), a fact that demonstrates the role of the State as a formulating and executing agent for environmental conservation and productive development instruments. Although noting the participation of civil society and private sector, the centrality of state action raises questions regarding the forms of State organization as fundamental to the nexus water, energy and food.

All the instruments express the sectorial character of state origin, since the environmental protection institutions and the instruments of forest restoration start from environmental agencies, which act within the scope of environmental policies, and the instruments of productive incentive come especially from rural credit policies and technical assistance, and rural extension services.

This result alludes to the sectoral organization of the Brazilian State in the context of the formulation and implementation of public policies. Sectoral structures are characterized by the existence of isolated government agencies, by spatially and functionally limited jurisdictions, by restrictive financing mechanisms, and by legislative and regulatory barriers that impose obstacles to the perspective of integrated confrontation of socio-environmental issues (Allouche et al., 2014).

Understanding the sectoral arrangement from which interventions emerge is the starting point for reflecting on the possibilities of the nexus approach. However, the alternatives to overcome this obstacle are open within the scope of the nexus. The question that arises is: to activate nexus governance and intervention processes would it be necessary to build new institutional arrangements, or would it be feasible to induce efforts to adapt the pre-existing ones? (Flammini et al., 2014).

It is agreed here with Mercure et al. (2019), that it is not essential to create ministries, secretariats, integrated bodies, or even a Nexus government department, but to improve the science-political interface in governance institutions to make them specialists in the nexus. For the authors, the assistance of nexus experts (policy analysts, technical experts, legal experts) with policy makers and interested parties can lead to the transmission of their views and knowledge, which may favor adjustments in their action strategies. Thus, the bridge between science and politics should be used continuously so that the nexus approach can be assimilated within each sector.

Furthermore, the delimitation of a spatial scale is equally relevant to guide nexus intervention processes, since each system works under different scales (Flammini et al., 2014). In the studied case, the instruments for environmental conservation intervene at different scales: national, territorial, municipal and watershed; those for productive development focus on rural properties. For Leck et al. (2015), this dimension adds complexity to the nexus due to issues related to the possibilities of synchronizing interventions within existing regulatory and administrative systems.

Even recognizing that multiple scales emerge as obstacles to the nexus approach, it is necessary to highlight rural property as a common scale. The FC is an institution of national application, but it provides for rural properties; PES initiatives are designed from the hydrographic basin, yet their actions fall on private properties; and, although EPAs have wide territories, there is a need to generate effects on private property.

In this way, the performance guided by a common scale gives meaning to the participation of the stakeholders by contextualizing the interrelated problems (Benson et al., 2015). The ideal scale of intervention depends on each reality, and in the context of analysis, there is a fine scale in rural private property to synchronize interventions with a focus on the nexus, allowing it to be integrated with other scales of interest to water security. This perspective can be extrapolated to the national level, since around 64% of the Brazilian territory (543 million hectares) is already being declared as a private domain (Cadastro Ambiental Rural - CAR, 2020).

However, pointing out an ideal nexus intervention scale does not solve the problem of the effectiveness of interventions. In the context of the Cantareira System, private land ownership imposes itself as a formal institution that limits the effectiveness of instruments for environmental conservation. The dependence on rural property to generate income and the sense of absolute usufruct over private property, largely explain scenarios of non-compliance with the provisions of the Forest Code (Chiodi et al., 2013).

In the field of possibilities of the nexus practical effectiveness, it is opportune to bring the comparative perspective of participatory and integrated water resources management (Benson et al., 2015). In Brazil, it took shape with the National Water Resources Policy (Law 9.433 / 1997). Social participation in the space created by the Hydrographic Basin Committees (HBC) was shaped by calling for the participation of the public sector, users, and the community with a view to establishing priorities and making decisions for a consensual management of water resources. Thus, integrated management was proposed to contemplate the multiple uses made by different sectors of water resources.

After 24 years of the model, although recognizing relevant advances, the gaps for integrated management are still clear. The study context is privileged for such an appointment, since it is one of the most advanced in its effectiveness. If, on the one hand, the creation of HBCs (Piracicaba, Capivari and Jundiaí) enabled shared water management spaces, on the other hand, these spaces present problems. It starts with the exclusion of important stakeholders, such as small rural producers. The dominance practiced by the state segment in formulating the agenda and conducting discussions also limits the active participation of other sectors (Alvim et al., 2008). And, precisely at a crucial moment to carry out integrated management, that of the water crisis between 2013 and 2015, the model was disfigured by the centralizing and technocratic action of state sectoral stakeholders (Puga, 2018).

Therefore, in addition to the challenge of achieving greater coherence between sectoral policies (Mercure et al., 2019), what the trajectory of integrated water resources management can show to those applying the nexus approach is how these policies materialize. It is noticed that even with an institutional arrangement set up to promote integrated and participatory management, characteristics such as authoritarianism, centralized action and exclusion emerge to distance the possibilities of full integrated management. In view of these challenges, it is understood that the nexus approach offers little in the way of overcoming these issues.

In any case, it was identified that non-integrated sectoral elements are linked to the central objectives of the analyzed instruments. The FC aims to protect forests in private areas, SPs to inhibit any productive use in their territory and PES initiatives to restore forests. Instead, rural credit, forest promotion and rotational grazing systems foster monocultures. Thus, it is assumed that forest protection and restoration inhibit productive uses and monocultures cannot be considered as sustainable systems in areas of water sources.

This result refers to the dilemma between privileging environmental conservation or agricultural production in the context of public interventions. In addition to this dilemma being the basis of the perspective of sectoral intervention, therefore, generating socio-environmental conflicts, it is configured in the original problem that the concept of sustainable development proposes to overcome.

Contrastingly, when focusing on integrated elements, they clearly assist the central objectives of the instruments. The FC may make exceptions for the recovery of PPAs and LRs with sustainable practices for family farming, the PES initiatives combine soil conservation practices, rural credit, and forestry promotion by requiring the Rural Environmental Registry to induce the environmental adequacy of the property rural to the FC.

However, it is understood that such a degree of integration between the instruments is less than expected for the nexus approach, since this part of a deep understanding of the interdependencies between water, energy and food, these resources being perceived within interconnected systems (Mercure et al., 2019).

5. Conclusions

In the context of System Cantareira, the nexus water, energy and food refer to the interrelations that occur in the context of land use, especially between the production of bioenergy and food and dimensions of regional water security. These systems are influenced by different intervention instruments, which are materialized in environmental protection institutions, forest restoration instruments and productive incentive instruments.

Such instruments are strongly associated with state intervention, clearly expressing the sectoral characteristic based on their objectives, the executing stakeholders and the scales of intervention. If the sectoral management of nexus resources is precisely the starting point for changes towards greater integration, the trajectory of combined management of water resources demonstrates obstacles for a nexus model to materialize effectively.

The perspective compared to the integrated management of water resources provides lessons for the application of the nexus approach in the Brazilian context. Obstacles such as authoritarianism that emerges in instances of said management, centralizing actions by the state sector and the exclusion of central actors for the administration of natural resources are placed ahead of the realization of nexus governance. In this sense, even the search for the improvement of the science-politics interface in governance institutions does not allow us to understand that these obstacles can be easily overcome by applying the nexus approach.

Furthermore, as the advance of occupation of the Brazilian territory through the domain of private property is identified, another challenge is to promote the sustainable management of nexus resources based on such a scale. In this sense, in addition to the search for the development of instruments that integrate environmental, productive and socioeconomic objectives, these will need to be effective inside private properties.

It can be considered that the identified intervention instruments are positioned at a starting point of what is understood as an integration process capable of suppressing conflicts of interest. The integrated elements identified are clearly ancillary to the instruments' central objectives, which reveal themselves to be deeply sectoral. As part of the analyzed instruments having national application, the configuration of the studied context may, to some extent, also reflect a national reality.

If the nexus approach opens up new opportunities to improve political, economic and social processes towards the Sustainable Development Goals, the carried out analysis shows that a huge distance has to be covered for the realization of such perspective.

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CHAPTER 4

Governing Food-Water-Energy Nexus using Green and Blue Infrastructure (GBI) in Brazilian Cities

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1. Introduction

Food, water, and energy (FWE) are interacting systems, crucial to not only human survival but also for the socio-economic development, particularly in urban areas, which import most of the natural resources to carry out their daily activities. Inadequate management of FWE systems that are affected by policy choices may lead to negative trade-offs. Cities need to explore the nexus between food, water, and energy (FWEN), to increase efficiency and security of their FWE systems. Innovations in Green and Blue Infrastructure (GBI) can provide important alternatives to improve the FWEN in cities by delivering key ecosystem services (ES). Therefore, understanding urban ES dynamics is a key requirement for the adequate planning, management, and governance of urban GBI that impacts food, water, and energy systems. This is particularly relevant for Brazil, where cities have grown haphazardly, without proper planning, and have to tackle insecurity in the FWE systems due to environmental challenges, such as the severe drought that hit São Paulo in 2015, affecting the city´s water supply and energy generation based on hydropower. Water and energy shortage problems in the country remain a concern in 2021 and are expected to increase due to climate change. To help overcome these challenges and mitigate the consequences, cities around the world are innovating in GBI initiatives. An analysis of innovative urban GBI experiences, particularly those in Brazil, can support alternatives to improve synergies in the FWE nexus and tackle environmental issues throughout the country.

In this chapter, we evaluate the results of the research project IFWEN - "Understanding Innovative Initiatives for Governing Food, Water and Energy Nexus in Cities" (a global research project financed by FAPESP with support of the Belmont Forum and JPI Urban Europe). We focus on initiatives in Brazil and present in more details the case of urban agriculture in Florianópolis. We start with an analysis of the interactions between GBI and FWE systems and how the international literature has studied the benefits of GBI provided to the urban FWEN. Then, we examine the innovations in GBI in international literature focusing on Brazil, and present the case of Florianópolis, where Urban Agriculture (UA) was integrated into a city-wide system of composting organic waste. Finally, we conclude with reflections on how these initiatives have affected the FWEN and environmental policies in the city.

2. FWE and GBI Interactions in the International Literature

Aiming to understand and analyze how urban GBI can affect the FWEN, Bellezoni et al. (2021) applied automated content analysis to gain an overview of the topics in the literature. The authors developed a conceptual integrated framework with the main links between GBI and FWEN in the urban environment (Figure 1). First, the main links are by the repetition of their appearance in the studies assessed in a GBI-FWEN literature review. Figure 1a (left side of Figure 1) shows the effects of GBI on individual FWE resources and their respective ecosystem services (ES), according to the literature; the thickness of blue arrows represents the number of articles in a given topic (relevance of the pathway). Most of the identified topics in the literature represent urban ecosystem services, which have effects (positive or negative) on people's well-being. The most discussed ES (or topic) for each FWE resource is highlighted (small blue arrows). Black dashed arrows represent the main negative effects of GBI on FWE ecosystem services. Also known as ecosystem disservices, these unintended negative effects can arise, for example, the contamination of urban agricultural production by the reuse of wastewater (health impacts), or even from falling leaves or trees that cause damage to urban infrastructure (logistical and/or economic impacts). White arrows show the links each FWE-related eco-services (box) have to different GBI. The thicker these arrows are, the more varied the types of GBI that influence that type of ecosystem service, which makes this information useful for indirect effects analysis under the FWE nexus approach.

This framework is then coupled with the well-known nexus framework (Hoff, 2011; FAO, 2014). Within city boundaries, Figure 1b presents how different types of GBI can affect different components of the FWE nexus, according to the literature. These are known as indirect and in-boundary effects. The cross-sectoral FWE interactions are also expected to occur in all cities at different scales (Haase et al., 2017; SEI, 2018; Newell et al., 2019).

Transboundary effects occur beyond city's territory and should be the focus of broader (regional and or national) policies for FWE systems. Figure 1c summarizes the indirect effects of GBI on regional FWEN (trans-boundary effects). Modules for socioeconomic, biophysical and socioecological systems are presented as external factors that have influence on urban GBI and FWEN, which should be considered when evaluating best suited choices to local characteristics. Although conceptual (and not exhaustive), this framework draws attention to the indirect and transboundary effects of GBI decisions taken at the

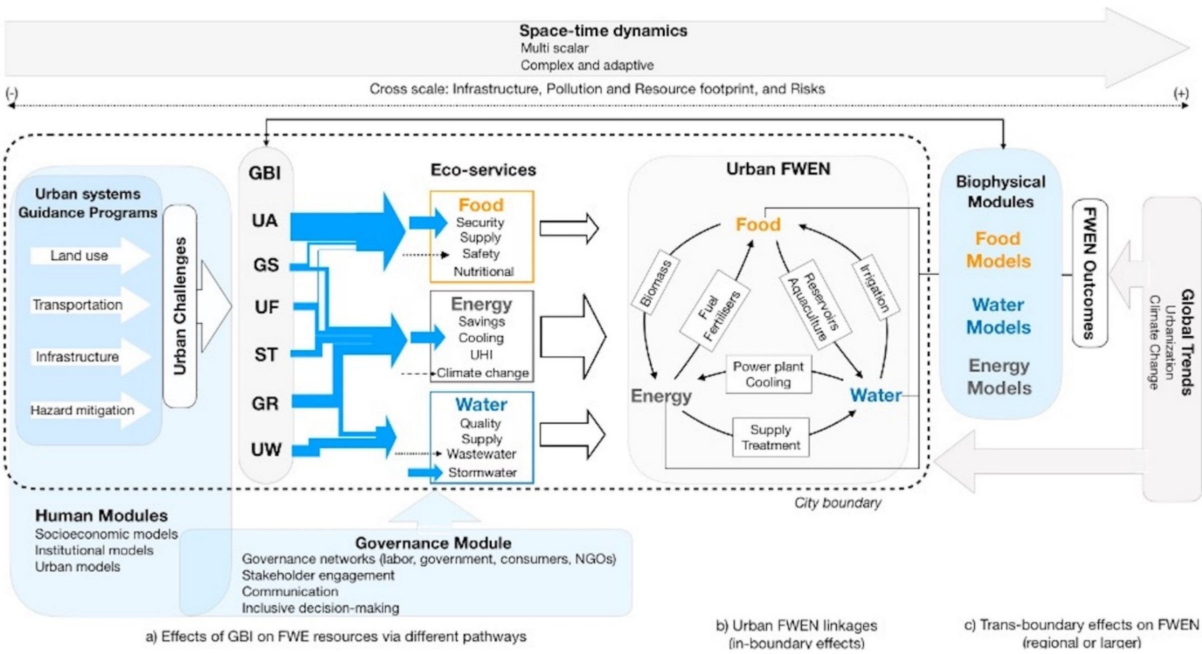

Figure 1. Conceptual framework for the effects of GBI on the FWE nexus in cities, depicting the importance of further understanding of the sociotechnical system (development of governance, human, urban, and biophysical modules).
Note. UF: Urban Forest; GS: Green space; ST: street trees; UA: Urban agriculture; GR: Green roofs; UW: Urban wetlands.
Source. Bellezoni et al. (2021), based on Hoff (2011), Bazilian et al. (2011), Ramaswami et al. (2012), and Newell et al. (2019).

local scale and can be an important tool for different groups in society and at different scales. Identifying indirect impacts and dependence on neighboring areas can help cities with integrated and more sustainable decisions for FWE systems.

The international literature depicted in Figure 1 allows us to make some initial arguments. Urban demands for FWE have effects that go beyond the city boundaries. Transboundary effects are therefore influences of decisions taken locally and their possible outcomes on processes elsewhere, whether nearby (regional, e.g., water use in river basins) or not (global, e.g., emissions). This calls for more integrated actions between local and regional governments; as urban governance plays a key role in promoting greater representativeness, public participation in planning and decision making, and bottom-up policy design. On the other hand, top-down actions increase the capacity of cities to solve their own problems by providing them with policies, targets, financial mechanisms, etc. (Homsy et al., 2019).

GBI of different scales can play a key role in cities to decrease internal demands for FWE (UN-ESCAP, 2019). Bottom-up actions for GBI can promote creative solutions, knowledge co-production and civil society engagement. Participatory approaches should thus be encouraged to promote better connection with and among decision-makers for GBI and FWE policies. This contributes directly to the development of institutional, political, and community capabilities that are fundamental for knowledge transfer on issues that require participation of groups with different interests.

Understanding the relationships between GBI, their effects on the urban FWEN and how these effects translate into trans-boundary demands becomes critical to local and regional urban planning. Consequently, the application of biophysical, socioeconomic, institutional, and governance modules (or models) is highly recommended to further detail, understand, and anticipate the effects (positive and negative) of different urban GBI on the FWE systems. Therefore, complementary perspectives for the integrated planning of FWE systems can contribute to the identification of trade-offs and synergies, highlighting the importance of local actions and policies (bottom-up) focused on local potentials (and demands) to inform the planning of supply on a larger scale (top-down).

3. Analysis of the Innovations in Urban GBI in Brazil

Understanding the links between FWEN and GBI, our research analyzed the innovations in Green and Blue Infrastructure in the Global South, including Brazil (Macedo et al., 2021). To identify relevant articles to our analysis, we used the Web of Science (WoS) database, and conducted a search based on a list of terms classified in three different categories: "urban", "green and blue infrastructure" and "innovation". The search terms in each category were selected in an iterative process, based on GBI concepts used in papers of the relevant fields, and with input from fifteen researchers. We screened only peer-reviewed articles in journals published in English, between 2015 and 2019, excluding journals on unrelated subjects. The search produced a total of 1,693 results, brought down to 283 relevant publications after an initial screening, of which 24 were about GBI cases in Brazil. The abstracts were then coded, read and analyzed.

The results of the analysis show that the number of articles about GBI in Brazil varied significantly between 2015 and 2019. The research found 24 articles between 2015 and 2019 (see list in Table 1). However, 2019 was the year with the most articles published, indicating a growing interest in urban GBI in Brazil (Figure 2). Furthermore, it was found that urban GBI-related studies in Brazil were concentrated in the two largest cities: Rio de Janeiro (29.2%) and São Paulo (20.8%), followed by medium sized cities and state capitals (see Figure 2).

Title	Year	Journal	Authors	City	Issue	GBI Typology
Environmental and economic assessment of a pilot stormwater infiltration system for flood prevention in Brazil	2015	Ecological Engineering	Petit-Boix, Anna; Sevigne-Itoiz, Eva; Avelina Rojas-Gutierrez, Lorena; et al.	São Carlos	assessment/ evaluation	stormwater management infrastructures
Estimating the Willingness to Pay for Improvement of an Urban Park in Southern Brazil Using the Contingent Valuation Method	2015	Journal Of Urban Planning And Development	Brandli, Luciana Lander; Marques Prietto, Pedro Domingos; Neckel, Alcindo	Passo Fundo	assessment/ evaluation	urban park
Multi-Temporal Patterns of Urban Heat Island as Response to Economic Growth Management	2015	Sustainability	Gusso, Anibal; Cafruni, Cristina; Bordin, Fabiane; Veronez, Mauricio Roberto; Lenz, Leticia; Crija, Sabrina	Porto Alegre	assessment/ evaluation	green space
Retrofitting Housing with Lightweight Green Roof Technology in Sydney, Australia, and Rio de Janeiro, Brazil	2015	Sustainability	Wilkinson, Sara; Feitosa, Renato Castiglia	Rio de Janeiro	experiment	green roof
Revealing Curitiba's flawed sustainability: How discourse can prevent institutional change	2015	Habitat International	Martinez, Joyde Giacomini; Boas, Ingrid; Lenhart, Jennifer; Mol, Arthur P. J.	Curitiba	assessment/ evaluation	green space, water body
Urban Floods in Lowlands-Levee Systems, Unplanned Urban Growth and River Restoration Alternative: A Case Study in Brazil	2015	Sustainability	Miguez, Marcelo Gomes; Verol, Aline Pires; de Sousa, Matheus Martins; Rezende, Osvaldo Moura	Rio de Janeiro	planning	urban river
A catchment scale Integrated Flood Resilience Index to support decision making in urban flood control design	2016	Environment And Planning B-Urban Analytics And City Science	Miguez, Marcelo G.; Verol, Aline P.	Rio de Janeiro	index	stormwater management infrastructures, urban river
A multifunctional green infrastructure design to protect and improve native biodiversity in Rio de Janeiro	2016	Landscape And Ecological Engineering	Herzog, Cecilia Polacow	Rio de Janeiro	planning	green infrastructure, coastal vegetation, urban forest
Improving Acceptance of More Sustainable Technologies: Exploratory Study in Brazil	2016	Journal Of Urban Planning And Development	da Rocha, Cecilia Gravina; Sattler, Miguel Aloysio	Feliz	assessment/ evaluation	green infrastructure
Decentralized management of public squares in the city of Sao Paulo, Brazil: Implications for urban green spaces	2017	Land Use Policy	Benchimol, Juliana Furlaneto; do Nascimento Lamano-Ferreira, Ana Paula; Ferreira, Mauricio Lamano; et al.	São Paulo	assessment/ evaluation	green space
Green Infrastructure in Informal Settlements through a Multiple-Level Perspective	2017	Water Alternatives-An Interdiscipli-nary Journal On Water Politics And Development	Diep, Loan; Dodman, David; Parikh, Priti	São Paulo	framework	green infrastructure
Influence of Air Pollution and Soil Contamination on the Contents of Polycyclic Aromatic Hydrocarbons (PAHs) in Vegetables Grown in Urban Gardens of Sao Paulo, Brazil	2017	Frontiers In Environmental Science	Amato-Lourenco, Luis F.; Saiki, Mitiko; Saldiva, Paulo H. N.; Mauad, Thais	São Paulo	assessment/ evaluation	urban gardens

Learning from the operation, pathology, and maintenance of a bioretention system to optimize urban drainage practices	2017	Journal Of Environmental Management	de Macedo, Marina Batalini; Rosa, Altair; Ferreira do Lago, Cesar Ambrogi; Mendiondo, Eduardo Mario; Borges de Souza, Vladimir Caramori	Unspecified	experiment	stormwater management infrastructures
Food security and edible plant cultivation in the urban gardens of socially disadvantaged families in the municipality of Vicosa, Minas Gerais, Brazil	2018	Environment Development And Sustainability	de Medeiros, Natalia Sant'Anna; do Carmo, Davi Lopes; Priore, Silvia Eloiza; Silva Santos, Ricardo Henrique; Pinto, Carina Aparecida	Viçosa	assessment/ evaluation	urban gardens
Potable Water Savings in Multifamily Buildings Using Stormwater Runoff from Impermeable Paved Streets	2018	European Journal Of Sustainable Development	Thives, Liseane Padilha; Ghisi, Enedir; da Silva, Natalia Mattos	Flo-	assessment/ evaluation	stormwater management infrastructures
Best management practices as an alternative for flood and urban storm water control in a changing climate	2019	Journal Of Flood Risk Management	Moura, N. C. B.; Pellegrino, P. R. M.; Martins, J. R. S.	São Paulo	comparison	stormwater management infrastructures
Diffuse pollution monitoring and modelling of small urban watershed in Brazil Cerrado	2019	Water Science And Technology	Tsuji, T. M.; Costa, M. E. L.; Koide, S.	Brasília	modelling	stormwater management infrastructure, waterbody
Green and socioeconomic infrastructures in the Brazilian Amazon: implications for a changing climate	2019	Climate And Development	da Silva, Jose Maria Cardoso; Prasad, Shivangi	Unspecified	mapping	green infrastructure
Influence of drainage network and compensatory techniques on urban flooding susceptibility	2019	Water Science And Technology	Caprario, Jakcemara; Rech, Aline Schuck; Tasca, Fabiane Andressa; Finotti, Alexandra Rodrigues	Curitiba	assessment/ evaluation	stormwater management infrastructures
The role of air pollution and climate on the growth of urban trees	2019	Science Of The Total Environment	Locosselli, Giuliano Maselli; de Camargo, Evelyn Pereira; Lopes Moreira, Tiana Carla; et. al.	São Paulo	assessment/ evaluation	urban trees
A framework to support the urbanization process on lowland coastal areas: Exploring the case of Vargem Grande - Rio de Janeiro, Brazil	2019	Journal Of Cleaner Production	Miguez, Marcelo Gomes, Aline Pires Veról, Bruna Peres Battemarco, Lilian Marie Tenório Yamamoto, et al.	Rio de Janeiro	framework	stormwater management infrastructures
An integrated quantitative framework to support design of resilient alternatives to manage urban flood risks	2019	Journal Of Flood Risk Management	Miguez, M. G., Raupp, I. P., & Veról, A. P.	Rio de Janeiro	framework	stormwater management infrastructures
Integrating conventional and green roofs for mitigating thermal discomfort and water scarcity in urban areas	2019	Journal Of Cleaner Production	dos Santos and SM; Silva and JFF; dos Santos and GC; de Macedo and PMT; Gavazza and S	Caruaru	experiment	green roof
Main Greenhouse Gases levels in the largest secondary urban forest in the world	2019	Atmospheric Pollution Research	da Silva and CM; da Silva and LL; Souza and TD; Dantas and TC; Correa and SM; Arbilla and G	Rio de Janeiro	assessment/ evaluation	urban forest

Table 1. Articles on GBI Innovations in Brazil.
Source. Elaborated by the authors.

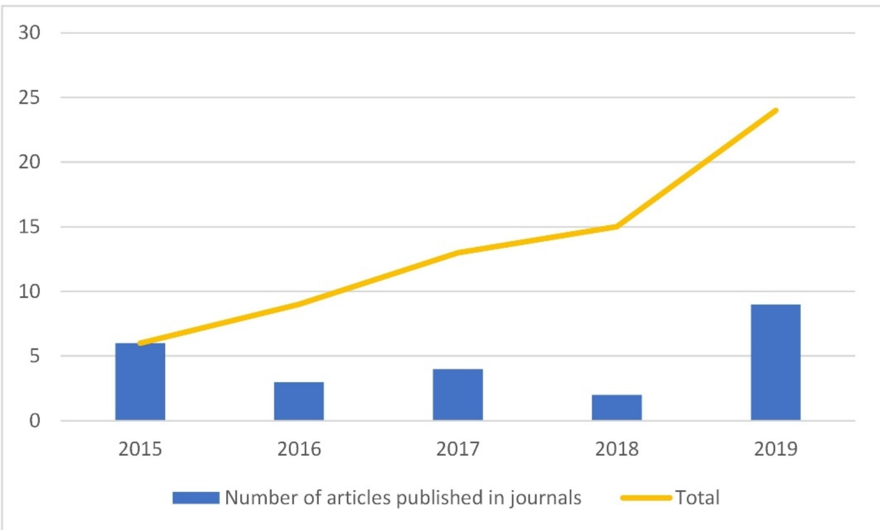

Figure 2. Infographic: GBI articles in Brazil.
Source. Elaborated by the authors.

There were not many urban GBI experiences on the ground described as a new approach in the Brazilian context. Most of innovations were replication of initiatives that existed elsewhere. The three papers that address innovation refer to a proposal of a multifunctional green infrastructure designed to protect and improve native biodiversity in Rio de Janeiro (Herzog, 2016), a Multi-Level Perspective (MLP) framework to identify opportunities and overcome barriers on urban GI implementation (Diep et al., 2019), and a critique about Curitiba´s reputation as a leading sustainable city (Martinez et al., 2016). There is also an article on a very small-scale experiment in green roof retrofitting in Rio de Janeiro, concluding that it could lower the energy demand for cooling (Wilkinson & Feitosa, 2015). The remaining articles refer to assessments or evaluations of the benefits, viability, consequences and/or perceptions about GBIs.

In the examined sample we found that the most mentioned urban GBI typology overall is "green space", and the nomenclature is often used interchangeably with green infrastructure (GI). Next, the most cited GBIs are more specific: first, green roof, followed by urban agriculture – which included peri-urban agriculture, urban farming and urban gardening – and then urban forest (see Table 2).

While none of the abstracts explicitly mentioned blue infrastructure, it is equally studied in Brazil, but not framed as such. Nonetheless, there is a clear focus on stormwater management infrastructure, including for instance, rain gardens, urban drainage, stormwater ponds, permeable pavement, and bioswales. The blue infrastructure typologies with the most citations were water bodies (including lakes and ponds) and urban rivers (including creeks

	GBI Typologies	Articles	%	total GBIs
Green Infrastructure	Green infrastructure or space	7	24.1%	29
	Green roof	2	6.9%	29
	Urban agriculture (including urban farming, peri-urban agriculture, urban garden, urban gardening)	2	6.9%	29
	Urban Forest	2	6.9%	29
	Urban Park	1	3.4%	29
	Urban trees	1	3.4%	29
	Living or green wall	0	0.0%	29
	Urban greening/Greenery	0	0.0%	29
Blue Infrastructure	Stormwater management infrastructures (rain gardens, urban drainage, stormwater ponds, permeable pavement, bioswales)	9	31.0%	29
	water body (including lakes, ponds, wetlands, etc..)	2	6.9%	29
	urban river (including creeks and streams)	2	6.9%	29
	Coastal vegetation (mangrove, saltmarsh, seagrass)	1	3.4%	29
	Blue infrastructure	0	0.0%	29
	Total GBI	20	100.0%	29

Table 2. Articles by different GBI typologies.
Source. Elaborated by the authors.

and streams), but to a lesser extent. In sum, all GBIs were somewhat evenly distributed among all cities, with no predominating typology in Rio, São Paulo, or any other medium-sized city. None of the following GBI types were found in the sample: greenway, urban greening, green belt or wetlands. In contrast, international literature assessed by Bellezoni et al. (2021) demonstrated that the most popular topic was urban wetland (for nutrient removal) in North America (41 percent of all water-related studies), Asia (27 percent), and Europe (18 percent).

The GI typology cited in the Brazilian sample corroborates findings about the trends in the Global South and Latin America verified by Macedo et al. (2021). In their analysis, green spaces, green infrastructure, urban agriculture, and green roofs are among the top GIs addressed, in line with the international literature on GBI-FWEN (Bellezoni et al., 2021). Accordingly, the most cited blue infrastructure in the Brazilian sample, urban drainage, matches the findings about Latin America and the Global South. Sponge city, a terminology used in China, was considered here as urban drainage. Overall, findings about Brazilian urban GBI trends are consistent with those of Latin America or the Global South.

It is important to note that in Brazil, stormwater management infrastructure is the most studied GBI typology, more than GI and green space combined. By comparison, based on data for the Global South and Latin America from Macedo et al. (2021), stormwater infrastructure and related typologies appear in far less articles than green space, green infrastructure, and urban agriculture taken individually. This suggests that stormwater management infrastructure is important in Brazil, especially to tackle severe flooding in large cities such as São Paulo and Rio de Janeiro. Based on the studies from the Brazilian sample, this kind of infrastructure is often used to solve problems of runoff management and flood control.

The most common linkages between GBI and FWEN investigated in the Brazilian sample were "food supply" for food, "stormwater runoff and flood control" for water and "climate change, carbon footprint and storage" for energy. However, only green infrastructure/green spaces, including Urban Agriculture (UA), explore the combined Nexus sectors. Other GBIs addressed one or two of the Nexus sectors, with an emphasis on water, as demonstrated by the number of studies on stormwater management infrastructures, followed by energy. Considering the FWE nexus, Food was the least addressed sector, and mostly in urban agriculture. Interestingly, the scope of articles on stormwater management infrastructures is limited to research on water, overlooking the linkages with other sectors. This gap could be explored in future research about stormwater management infrastructure in Brazil. In the Florianópolis case, we describe and analyze urban agriculture as a response to community sanitation needs by combining food, water and energy elements to address waste management and health concerns.

4. Urban Agriculture and Waste Management in Florianópolis, Brazil

Florianópolis is the capital of Santa Catarina state in the South region of Brazil. As a touristic city mainly located in an island, it has an estimated population of 508,000 inhabitants in 2020, and despite its 96.21 percent urbanization rate, about 30 percent of its territory consists of environmentally protected areas. Since the early 2000´s, Florianópolis ranks amongst the top 10 cities with the best quality of life in the country, according to official data (IBGE, 2021); its Human Development Index (HDI) of 0.847 has been steadily increasing since 1991 and is higher than the national HDI of 0.765 in 2019 (PNUD Brasil, 2021). Living in Florianópolis implies paying a high price in terms of ecological footprint elsewhere: the city imports 65 percent of the water from neighbor cities, energy is generated outside the city, most of the food comes from the metropolitan area in the mainland, outside the city´s territory, and 90 percent of the waste is taken to Biguaçu landfill, 25 miles away, by truck (PMF, 2021a).

However, despite its high HDI, like most cities in Brazil, Florianópolis has high levels of inequality, and many poverty-stricken areas where the lack of access to basic public services aggravates the residents´ vulnerable conditions. In 2018, it was estimated that 16 percent of the population lived in subnormal housing, most of which in the city´s 64 favelas (shanty towns), totaling approximately 51,000 people[2]. One of these informal settlements, the Chico Mendes favela in the Monte Cristo´s neighborhood cluster became well-known for an innovative sociotechnical experiment, the Bucket Revolution (in Portuguese, Revolução dos Baldinhos). In 2008, as the community expanded, inadequate organic waste disposal and limited availability of municipal collection services led to critical public health problems. Following the death of two residents due to leptospirosis transmitted by rats, a local movement

2 We found no accurate information on the number of informal settlements, precarious or subnormal housing and inhabitants living in these areas. The news website that quotes a public official in 2016 can be accessed at https://www.nsctotal.com.br/noticias/mais-de-50-mil-pessoas-vivem-em-64-comunidades-irregulares-de-florianopolis

mobilized efforts to address the issue. With the help of an NGO working with community agriculture (Centro de Estudos e Promoção da Agricultura de Grupo - CEPAGRO), residents managed to organize a system to collect their organic waste and transform it into fertilizer to use it in local food production (Abreu, 2013). Unlike countless other projects, which were discontinued by following governments, the Bucket Revolution continued beyond different administrations, benefitting 200 families and recycling 5.6 tons/month of organic waste (Bonatti, 2019). It has since expanded and inspired many other similar initiatives, both in Florianópolis and in other Brazilian cities. Besides the composting methodology itself, the engagement of community members with several other stakeholders, including the municipality, was key to the initiative´s success; in spite of significant limitations, the Bucket Revolution became a model of community waste management and sociotechnical innovation, garnering national and international support.

Building on this experience combined with other local initiatives, Florianópolis launched a city-wide policy to promote urban agriculture and sustainability, having waste management and health as the principal drivers. The Urban Agriculture Program (PMAU) was established by municipal decree in 2017, to foster agroecological production of food and medicinal plants using organic compost. It was amended in 2018 and 2020 to include sustainable use of natural resources such as the use of rainwater, production of solar energy and use of recycled materials (PMF 2020; 2021b).

The PMAU involves municipal services, and organizing community actions such as cleaning up, composting, and implementing community gardens. Civil society engagement includes setting up work groups and associations, partnering with NGOs and the Federal University of Santa Catarina (UFSC) to provide training and capacity building. There are 117 community gardens mapped by the city, in Basic Health Units (UBS), Educational Units (UE), Social Assistance Reference Centers (CRAS), Psychosocial Assistance Centers (CAPS), green leisure areas, and in municipality's community spaces. They are managed by volunteer residents and city staff, with technical support from partners such as NGOs and the Federal University of Santa Catarina. Vacant public lots are also used as community gardens and composting facilities, thus avoiding waste dumping and contamination in residential areas (PMF, 2021c).

An interesting aspect of this particular case is how the GBI initiative evolved as a collaborative action, from grassroots movements in the poorest communities of the city to a municipality-led city-wide program that includes other neighborhoods, regardless of social and economic status. The involvement of different institutional partners (CEPAGRO, UFSC, the municipality, particularly the waste management authority) fostered knowledge sharing between the participants. For instance, some residents that migrated from rural areas had experience in planting, researchers improved composting methodologies, health workers and students could instruct the community on medicinal plants and nutrition. The city also provided operational support and land for composting, a fundamental element in the urban agriculture cycle (Abreu, 2013). City officials and technical staff are also key agents, acting as catalysts or boundary-spanners, by taking on multiple roles and often being personally involved. However, local political issues still challenge implementation and there is controversy about changes in the sociotechnical methodology after the city became the leading agent in the system (personal communication). Nevertheless, according to official reports, results are encouraging: from 2017 to 2021, 59 thousand tons of dry and organic waste were diverted from the landfill, avoiding emissions of 157,000 tons of carbon equivalent (PMF, 2021d).

By early 2020, municipal senior management had gradually increased the city´s role by systematizing activities, many of which were originally bottom-up, culminating in an umbrella governance structure established by the new decree, that centralized administration and operations and limited civil society participation in decision-making. The PMAU decree amended in June 2020 establishes a steering group composed of municipal departments, with the Superintendence of Fisheries, Mariculture and Agriculture, under the Environment Secretariat acting as the administrative coordinator, the Capital Improvement Authority (COMCAP) acting as the operational coordinator, the Municipal Environment Foundation (FLORAM), the Municipal Health Secretariat and the Municipal Education Secretariat as technical coordinators. The multistakeholder consultative body, Forum Cultiva Floripa including civil society organizations, academic and neighborhood associations, amongst other institutional stakeholders is also coordinated by the municipality.

Changes in the administration brought about by mayoral elections in October (2020) also affected the balance of power, despite the mayor´s re-election for another 4-year term beginning on 01 January 2021. A “mini administrative reform” in February 2021 rearranged leadership and positions in some departments, and also impacted the program. Due to restrictions imposed by the COVID-19 pandemic, activities in community gardens of public schools were almost completely paralyzed, although there were a few cases in which teachers and municipal employees maintained the community gardens voluntarily to help providing food to poor community members (PMF, 2021c). The medicinal gardens in health centers continued to be maintained as part of a community health program that includes unconventional treatments, such as phytotherapy and acupuncture. And while activities on the ground suffered due to the pandemic restrictions, the city government remained committed to implement its waste management policies and launched the Zero Waste 2030 program, aiming to expand the door-to-door collection of segregated waste, increase the fleet of garbage collector trucks, and reduce waste transportation costs from the city to the landfill site, by increasing compost (Table 3). The city already gained R$9.9 million/year from the recycling program, between 2017 and 2020, and is expected to increase this amount to R$ 55 million by 2030 (PMF, 2021d).

A follow-up survey in August 2021 found that UA activities in the community health centers were gradually being reestablished and some interviewees expressed enthusiasm about the new governance structure and prospects for the PMAU´s continuity. The Municipality reported revitalizing vegetable gardens in public schools, such as the Mateus de Barros Municipal Children's Education Center, in Monte Cristo, one of the early initiatives participating in the movement (PMF, 2021d).

Type of waste	2020 current gains	2030 targets
Organic	4.6 thousand ton/year = USD 234,3 thousand gain	66 thousand ton/year
	= USD 140.8 thousand savings in landfill cost	= USD 2.28 million-gain
	= USD 98.8 thousand in income generation from shavings and compost donated to urban agricul-ture	
Recyclables	12 thousand ton/year = USD 1.7 million gain	54 thousand ton/year
	= USD 351.45 thousand in landfill savings	= USD 1.49 million-gain
	= USD 1.33 million from the sale of materials donated to 7 associations of sorters, benefitting 370 families	
Waste	188,000 ton/year	88 thousand ton/year
	= USD 5.76 million – cost with landfill	= USD 2.69 million-cost

Table 3. The Floripa Zero Waste 2030 targets.
Note. exchange rate 01 Aug. 2021: USD 1.00 = R$ 5.12
Source. Elaborated by the authors, adapted from PMF (2021d).

5. Conclusions

Overall, there is no energy production without water, no water supply without energy, and no food production without these key resources. This interdependence between FWE sectors is universally applicable. The literature on GBI clearly highlights several socio-environmental benefits of such infrastructure, which include, among others, more extensive urban food production (Pitman et al., 2015; Russo et al., 2017). In fact, UA offers benefits through the reuse of urban waste and wastewater, increased urban biodiversity, and may also contribute to improved air quality, depending on the scale of production. Moreover, UA contributes to an overall reduction of the environmental impact on the food production chain, given reductions in demands for transportation, storage, processing, packaging and refrigeration (Orsini et al., 2013). Depending on the scale, changes in local food demands caused by UA activities affect the urban FWEN through the food entry point and can be connected to different sectors and city services, as in the case of Florianópolis, where UA interacts with the waste management system by using compost from organic waste. In 2020, Florianópolis launched the Zero Waste by 2030 program, highlighting the connection with the Sustainable Development Goals and establishing ambitious targets (PMF 2021d). The plan is to increase recycling, composting and waste reduction from 8 percent organic and recycled waste in 2020 figures to 60 percent by 2030 (Table 3). These changes in the food component will affect trans-boundary food supply (Figure 1c), indirectly affecting the urban FWEN, also in terms of water and energy requirements (Figure 1b). As in other parts of the world (Oliveira & Ahmed, 2021), a good governance of UA was key for the expansion and improvement of the program. Finally, UA demands will directly affect UA supply and be indirectly affected by both local and regional demands for food.

Brazilian cities can benefit from understanding innovative initiatives in FWEN using urban GBI, being implemented around the globe, including those in Brazil. Interest in the international literature about Brazil is growing, but there are lessons to be learned from studies developed worldwide, particularly in the Global South, where innovations are showing promising results (Macedo et al., 2021). Innovating in GBI and integrating GBI initiatives to city-wide services can reduce the risks of insecurity in the FWE systems faced by Brazilian cities, as the impacts of climate change confirmed by IPCC scientists in the AR6 become more frequent and intense (Allan et al., 2021).

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CHAPTER 5

The water-energy-food nexus in local urban planning strategies: the case of São Paulo, Brazil

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1. Introduction

Cities play a pivotal role in the pursuit of sustainable development. Currently, 55% of the world's urban population lives in cities (United Nations, 2016), with an expected increase of 68% by 2050. Urban settlements demand a significant set of goods and natural resources to ensure water, energy and food supply, adequate housing, transportation and other basic services. As a side effect, this results into a substantial production of GHG emissions, solid waste and pollutants. Moreover, modern cities were planned and designed as if urban life were disconnected from rural life and natural environment (Barthel & Isendahl, 2013). On the other hand, empirical studies highlight that urban areas can also play an important role in addressing the environmental and climate crises (Bulkeley, 2010; Seto et al., 2010), promoting transformative urban processes with sustainable measures that potentially deliver multiple economic, social and environmental benefits (Broto, 2017; Romero-Lankao et al., 2018).

The Water-Energy-Food nexus (WEF nexus) approach emerged in the last decade as an attempt to address the complex interrelationships between water, energy and food resources with the aim of building synergies between sectors and minimizing trade-offs to ensure more efficient, equitable and fair use of natural resources (Bazilian et al., 2011; Hoff, 2011). Research often sees growing urbanization as a central issue for the security of the nexus elements considering its impacts on land use, population distribution, urban infrastructure and resource flows (Artioli et al., 2017). As a consequence, the urban dimension of the nexus has gained increasing attention, although scholars endorse the need for a more critical perspective on the nexus applicability to address major challenges in urban environments (e.g., Williams et al., 2014; Cairns & Krzywoszynska, 2016; Dalla Fontana et al., 2020).

While there is a growing recognition that the close interconnection between water, energy, food and materials supply systems in the urban context asks for integrate planning and resource management, and provide an opportunity for a "policy nexus" (Daher & Mohtar, 2015; Lehmann, 2018), the nexus approach has not been commonly adopted in urban planning (van Gevelt, 2020; Urbinatti et al., 2020). Hoff and Kasparek (2016) argue that one way to facilitate the inclusion of the nexus perspective in decision-making processes would be to broaden and give visibility to public policy analyses that enable more integrated actions. While there are examples of studies in this field focused on supranational policies (e.g., Venghaus & Hake, 2018;

Venghaus et al., 2019) and national policies analysis (e.g., Paim et al., 2020), there is still an underrepresentation of studies that conduct similar analysis at the local level (Wahl et al., 2021).

The nexus approach can make a contribution to urban sustainable development as long as policy-makers pay attention to critical aspects, including: (i) adopting a coherent macro development pathway planning; (ii) optimizing infrastructure spatial planning; (iii) and supporting other auxiliary interventions (e.g., financial incentives, promote awareness) (Fan et al., 2019). Concerning the first aspect, master plans are understood as overarching strategic plans, and communicative policy acts that provide a vision of how a city wants to develop and be in the future (Norton, 2008). Because they may address different flows in the city such as water, energy and food, but also waste, traffic, green infrastructure and other materials, master plans are critical instruments to determine areas that need integrative planning, identifying possible synergies and conflicts (Zengerling, 2019).

Starting from the hypothesis that the nexus could be integrated into existing local strategic plans and policies rather than applied as a dedicated approach or a new policy domain, we provide an insight into if and how nexus elements and principles are (or not) instrumental in urban strategic planning in the city of São Paulo, Brazil. We thereby aim at contributing to the question of how to link WEF nexus and local policy, municipal strategies and plans (Wahl et al., 2021; Hoff & Kasparek, 2016). From this perspective, this chapter aims to contribute to this direction by proposing an analysis of the 2014 Strategic Master Plan of São Paulo (SMP – São Paulo, 2014), through the lenses of the WEF nexus. This can therefore help identifying gaps and space for improvements to optimize policies and adapt existing government arrangements, considering local environmental, historical and regulatory aspects (Hoff & Kasparek, 2016; Venghaus & Hake, 2018; Weitz et al., 2017).

2. The case of São Paulo

2.1. Main features to understand the local context

Like other megacities in the Global South, São Paulo struggles with socioeconomic inequalities, lack of modernization of infrastructure networks and logistics, environmental and urban problems (Di Giulio et al., 2017; 2018). São Paulo has the largest national GDP (~ US$ 142 billion) and the largest urban population in Brazil, close to 12 million people (SEADE, 2018). However, 15% of its population lives in precarious settlements, with about 25,000 homeless residents (SMADS, 2019), revealing the extreme inequalities that exist in its territory.

While this global city can be a source of innovation and lead transformative processes (Di Giulio et al., 2018), recent analyses indicate a set of challenges that still seriously affect communities' quality of life, such as river and soil pollution, lack of sanitation, changes in microclimates (e.g., urban heat islands), loss of biodiversity, impacts on precipitation and water production and storage capacity by reservoirs, among others (Jacobi, 2006; Bonduki, 2011; Franco et al., 2015). These challenges are closely related to the inability of local governments to develop public policies and implement urgent actions to sustain the city's growth process and to carry out the most appropriate territorial planning (Di Giulio & Vasconcellos, 2014; D'Almeida, 2016).

2.2. Urban policy and the Strategic Master Plan of São Paulo

The Strategic Master Plan of São Paulo approved in 2014 by the Law 16.050 (São Paulo, 2014), which revises the previous plan of 2002, is based on the 1988' Federal Constitution and on the 2001' Federal Law 10.257 (Brazil, 2001), known as the City Statute, which established the parameters for the elaboration and implementation of the national urban policy. The master plan is the main instrument for the deployment of urban development and expansion policy in the City Statute, and it is mandatory for all municipalities with more than 20 thousand inhabitants, for cities located in metropolitan regions or urban agglomerations, and other specific cases with fewer inhabitants (Brazil, 2001). The master plan aims to identify urban problems of the municipalities and propose solutions, with a wide set of guidelines, strategies and measures, through a public participation process (Franco et al., 2015; Piérola & Almeida, 2016; Andrade, 2017).

The SMP was designed to integrate urban development and environmental protection with an ecosystem approach, seeking to enhance the areas that provide environmental services (Sepe & Pereira, 2015). Other guiding components include the right to the city, the right to an ecologically balanced environment, sustainable and balanced urban development, the social function of the city and rural property, social and territorial inclusion and equity (Andrade, 2017).

3. Methodology

In concordance with Norton's arguments (Norton, 2008), who demonstrated that content analysis (Bardin, 1977) is a suitable tool for assessing the symbolic content of a local master plan, data used to inform this chapter is based on an objective, systematic, and critical description and analysis of the content of the SMP with its 393 articles, through the lenses of the WEF nexus.

Thorough a systematic reading of the document, we identified for each article whether and how the elements of the nexus were addressed. By adopting an inductive approach, the articles of the SMP were submitted to multiple rounds of analysis and iterative coding. In the first round, the articles were coded according to the categories: water, energy and food. Articles that did not fit these categories were no longer considered. The coding was then refined in subsequent rounds, leading to the identification of specific categories. Information found for each element was separated into specific tables in Microsoft Excel, which allowed us to identify how many articles were mentioned for each of the categories and organize the content of the identified articles in a systematic manner. A critical interpretation of the results also enabled us identify venues of integration and a common ground between water, energy and food.

During the analysis, it was possible to understand that water, energy and food are not always addressed explicitly, but also implicitly. For example, articles that address soil-sealing issues were considered in the analysis for the indirect effects of this process on the hydrological cycle. Therefore, we consider an article to explicitly treat water, energy and food when these are clearly stated and spelled out and there is no room for confusion. On the other hand, we also consider an article to implicitly treat water, energy and food when they are not clearly stated and spelled out, but the content of the article implies possible effects on the three elements.

4. Results

4.1. Water, energy and food in the 2014 Strategic Master Plan of São Paulo

In general terms, our results highlight how water, energy and food are critical elements in the strategic planning of the city of São Paulo. After a

SECTOR	CATEGORY	DESCRIPTION
Water	Basic Sabitation	The focus here is on the production of water for the city, the supply system, the wastewater collection, treatment system and the drainage infrastructure. The issue of water is explicitly addressed, and the main concern is the improvement and universalization of environmental sanitation.
	Protection	Water is considered a resource to be protected through measures of protection, conservation, recovery and preservation of nature. The issue of water pollution is a directly addressed issue. Soil contamination is also addressed, considering its indirect effects on water sources.
	Use of the resource	This category includes articles that consider the need to improve the use of water by the population, promoting rational use and reuse.
	Transport	Networks of rivers, dams, lakes and canals are considered for their potential to function as a transport infrastructure (e.g., waterways).
	Leisure	Water bodies and surroundings are considered as a space for leisure.
	Extreme Events	The SMP places the need for actions to protect the population, the infrastructure system and the territory from extreme events such as floods, soil erosion and slides that result from the combination of extreme weather events and social factors related to the occupation of the territory. Issues such as soil sealing, poor drainage systems and small plant cover can also be cited for their impacts.
Energy	Mobility	Urban mobility is a central topic in the SMP and it implicitly addresses the energy issue, for example in terms of: promoting the use of bicycles; control of less efficient modes of transportation; orienting real estate production to areas located along public transportation axes etc. Although these actions are more explicitly aimed at reducing air pollution and improving urban mobility, we argue that their implementation would also affect the city's energy consumption.
	Infraestructure	This category covers issues such as the installation, maintenance and extension of electric power, gas and public lighting networks.
	Use of the resource	Issues such as rational energy use and energy efficiency are here considered.
	Production	This category covers articles that encourage the use of cogeneration systems, alternative energy sources and renewable energies, and identify sites for the installation of energy utilities.
	Climate and Atmosphere	Although we acknowledge that emissions are not only a product of the energy sector, we have identified an implicit relationship between the energy issue and some topics addressed in the SMP, such as the reduction of air pollution emitted by transport systems and the mitigation of greenhouse gas emissions.
Food	Production	This category includes articles that address the rural areas of the municipality for their agricultural characteristics and their importance for food production. Measures to maintain and strengthen local food production are also here considered.
	Protection	Articles that consider areas characterized by agricultural activities for their role in the protection and preservation of vegetation and water springs are considered in this category.
	Organic Agriculture and Agroecology	Articles are focused on the production of healthy food in sustainable ways through the promotion of organic agriculture and the agro-ecological transition.
	Urban and Peri-urban agriculture	Articles tackle the need to support and encourage peri-urban and urban vegetable gardening.
	Food Security	It encompasses articles that deal with guaranteeing food security and social right to food.
	Land Regularization	The category covers the regularization of agricultural properties, which guarantees greater protection for agricultural producers, food production and the environmental compatibility of agricultural activities.
	Agritourism	It considers agricultural production activities for their potential to tourism.
	Organic Waste	Articles that address organic waste management are considered to treat implicitly the food (waste) issue.

Table 1. Description of how water, energy and food are treated in the 2014 São Paulo SMP.
Source. Elaborated by the authors.

first round of analysis, we identified 125 articles related to water, 50 articles related to energy and 47 articles related to food. However, water, energy and food are not treated uniformly, and different perspectives can be identified for each of the elements in further refined rounds of analysis. The categories in Table 1 summarize the different perspectives on water, energy and food that we identified, and they show how these elements are considered and described in the SMP.

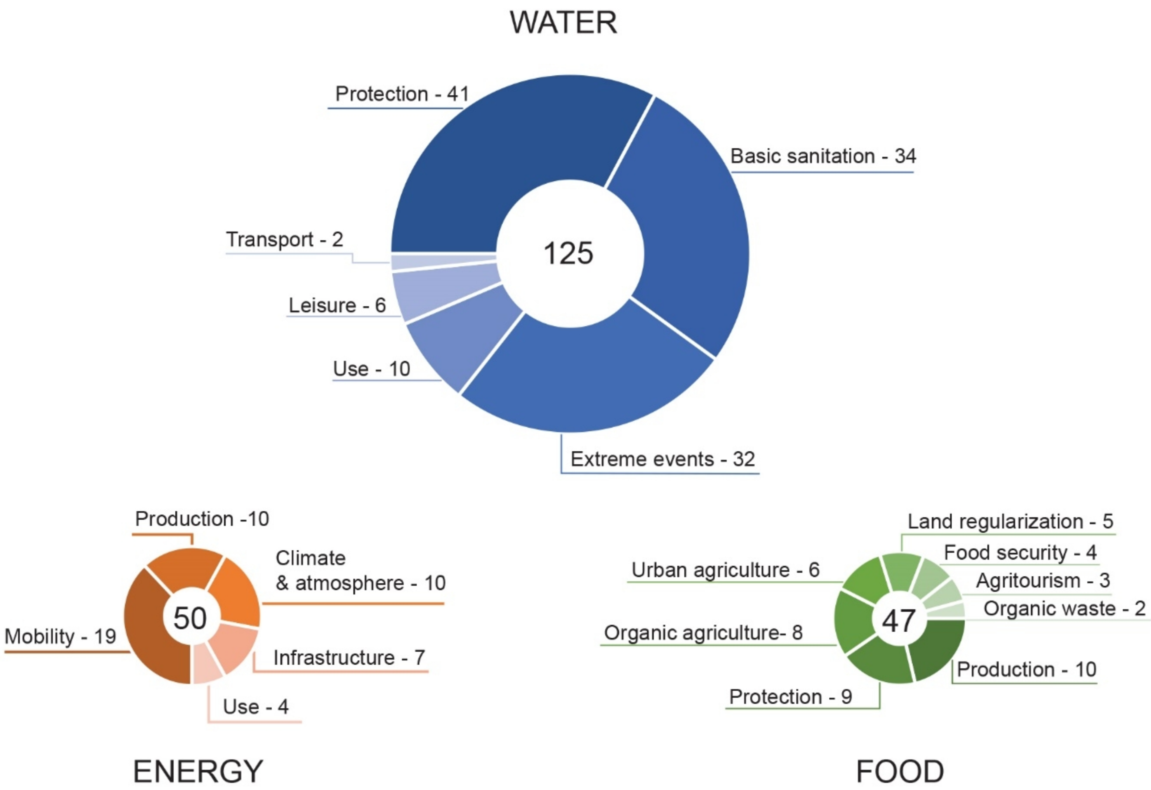

Figure 1. Number of articles in the 2014 São Paulo SMP dealing with water, energy and food.
Source. Elaborated by the authors.

After identifying the categories, it was possible to provide an overview of how the articles were distributed among such categories (Figure 1).

The water element, in its various perspectives, is central to the document and clearly predominant if compared to energy and food. Figure 1 shows the greater attention given to measures of protection, conservation, recovery and preservation of water bodies and the water resource (41 articles). Basic sanitation issues, such as water supply, wastewater collection and treatment are also often mentioned (34 articles). On the other hand, it is observed that water can also cause material and human losses, due to the combination of extreme weather events and land occupation (32 articles). Other topics are less considered.

Regarding energy, most of the articles deal with the issue of urban mobility (19) and emissions of air pollutants and greenhouse gases (10 articles). These articles are here considered for the possible impacts of these questions on the municipal energy system. In addition, 10 articles evoke the issue of energy production from alternative and renewable sources, while others are more focused on the infrastructure and the energy distribution system (7 articles).

For the food element, we identified 10 articles that address the issue of incentives for local agricultural production (in the rural area of the municipality). The topic of preservation of agricultural areas is developed in 9 articles, while the support for organic agriculture and agroecology is addressed in 8 articles. Other articles are less considered.

4.2. A common ground for water, energy and food: land use

The issue of land use planning is considered to be particularly innovative in the 2014 São Paulo SMP, and the analysis reveals that land use is in fact recurrently evoked when water, energy and food are addressed.

It is important to note that the SMP divides the territory into smaller parts, including macrozones, macroareas and special zones (Figure 2 a, b and c, respectively) according to their characteristics, priorities and designated uses. Furthermore, unlike the previous master plan (São Paulo, 2002), the current SMP delimits and identifies the rural area of the municipality, and clearly distinguishes it from the urban area (Figure 2 d). This new division is largely influenced by water and food resources, considered key components to define the limits of rural areas, which are seen as a multifunctional part of the territory, providing ecosystem services, such as water supply, food production, biodiversity maintenance, protection and conservation of natural areas, leisure and ecotourism (São Paulo, 2014). The analysis showed that both elements are often addressed with environmental protection, urban sprawl containment, sustainable use, and agriculture issues – all central elements in the SMP. The water element is here addressed mainly in the form of protection and recovery of water sources (see “protection” category in Table 1), and universalization of environmental sanitation through the expansion of the water and sewage network (see “basic sanitation” category in Table 1).

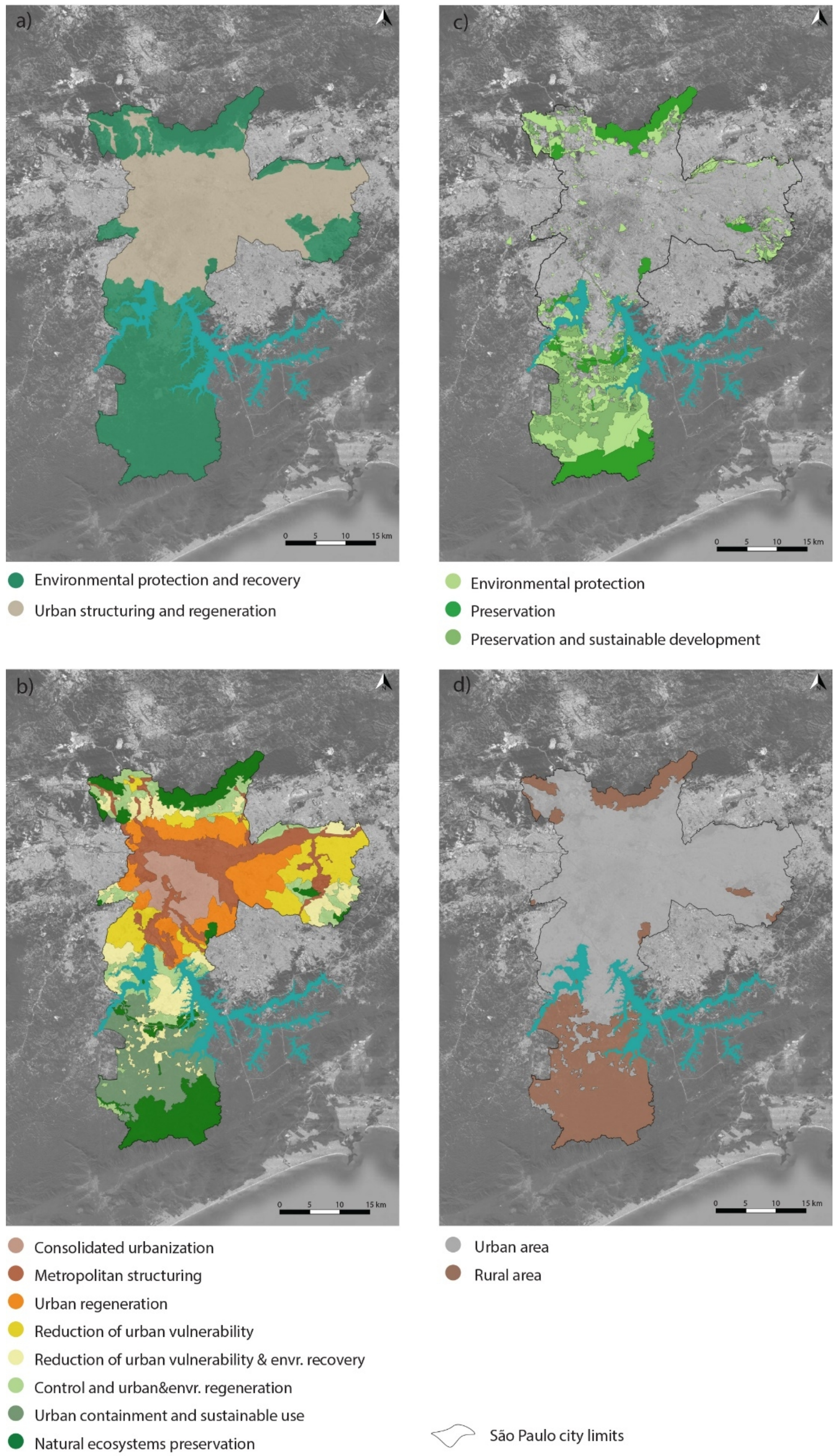

Figure 2. Maps of the: (a) macrozones; (b) macroareas; (c) special zones; and (d) urban/rural limits in the SMP.
Source. Elaborated by the authors, based on Ligue os Pontos, 2020.

Some special zones proposed by the SMP are clearly defined by activities focusing on environmental protection and recovery, and maintenance of natural resources (i.e., Special Zone for Environmental Protection; for Preservation; for Preservation and Sustainable Development - Figure 2c). Once again, water element emerges as a critical aspect in the definition of the zoning schemes, considering, for example, parameters and mechanisms related to rainwater drainage, which avoid network overload and flooding; soil occupation parameters related to geological, geotechnical, and hydrological aspects; implementation of activities that require the use of groundwater or interference with the water table; and water sources protection areas. Food is considered a central element as well, particularly in the definition of preservation and sustainable development zone in the territory. In this specific area, landscape preservation must be carried out through the implementation of economic activities (agriculture and tourism) that are understood as compatible with the maintenance and recovery of environmental services (see "protection" category in Table 1).

Land use also comes into play in the sections of the SMP that deal with water in relation to extreme weather events (see "extreme events" in Table 1). Land changes are critical to cope with urgent urban problems, such as floods, soil erosion and landslides, that can, to some extent, be linked to soil sealing, inefficient drainage systems, deforestation, and poorly organized land occupation (Travassos et al., 2020).

In addition, while it is not a major topic in the SMP, it is worth noting how the regularization of agricultural land (see "land regularization" category in Table 1) is considered to be an important measure to safeguard farmers, and consequently to guarantee food production, sustainable agricultural practices and environmental protection.

The analysis shows that energy is also connected to land use planning. In fact, we found that energy issues are, for instance, implicitly addressed in the SMP section called "Urban Transformation Structuring Axis", which aimed to stimulate housing policies to areas located along the public transport axes, improving the interactions between public and private spaces, and reducing travel times and distances. Furthermore, measures such as maximum standards for parking spaces are proposed to discourage the use of private cars in favor of public transport. Guidelines to stimulate the use of cogeneration systems in specific areas and the use of equipment that share electricity, wind, solar and natural gas, especially in large facilities are also included, however concrete measures in this direction are not foreseen.

5. Discussion

The analysis reveals that all three elements of the nexus are addressed in the 2014 São Paulo SMP in different ways and with different intensity. However, water has a central and explicit role in the document, while energy and food remain marginal. This is in line with the previous SMP of 2002, in which water was also considered a steering element for the development of local public policies (Sepe & Pereira, 2015). Three main issues related to water are addressed in the SMP and can therefore be considered priority concerns in the urban agenda of the city.

First, water is considered a precious resource that must be protected and preserved, which reverses the position of past public policies that privileged its consumption and considered it an inexhaustible resource (Ramos & Pollachi, 2019). Second, there is great emphasis on the maintenance and future development of the water supply system and universalization of wastewater collection and treatment. In this sense, the 2014-2015 water crisis has increased the concerns to improve the water supply system. Moreover, the deficit in wastewater collection and treatment has been an historical issue that has not yet been solved and it should be a strategic priority (Buckeridge & Ribeiro, 2018). Third, while water is a resource to be preserved, it can also be a destructive force when extreme weather events are combined with inadequate infrastructures and poor spatial planning (Travassos et al., 2020). That is why the SMP places a great emphasis on measures to protect residents, infrastructure systems and the territory from floods, landslides and similar events.

Our results show that the energy issue does not get as much attention as the water issue. We argue that this is related to the fact that, in Brazil, the energy sector is largely regulated on a federal level through the National Electric System Operator, which results in limited initiatives from municipalities. Furthermore, there is an existing dispute between the cheaper and more abundant national energy production and the local systems. Therefore, local energy strategies are less attractive, including the development of small solutions based on renewable sources that cannot stand the competition with the national production (Collaço, 2019). Despite the SMP providing some guidelines to stimulate the use of renewable energy sources in buildings, industries and municipal public bus system, other efforts have been made in the urban mobility sector with an implicit effect on the São Paulo energy matrix.

The definition of the rural area in São Paulo is a sign that food, or at least food production, is a key component for the strategic development of the city. Other nuances of this issue are related to guaranteeing food security for all, supporting (peri-) urban agriculture, and encouraging the transition to agroecology, which reflects not only a concern for the socio-economic effects of these activities, but it still denotes an environmental awareness. An interesting fact is that agricultural activities are also recognized for their critical role in preserving the rural and natural landscape of the city, which is very rich in water springs and biodiversity (Ligue os Pontos, 2020).

At first glance, the analysis shows that, although water, energy and food are addressed in the SMP, there is no mention to the nexus or similar integrated approaches, and the nexus elements still seem to be considered in a sectoral way. Despite the fact that we did not perform a structured analysis of the synergies and tradeoffs between the elements of the nexus, the content analysis has proven to be sufficient in shedding light on the fact that the SMP does not address these issues systematically. However, while we can say that there is currently unused potential for a more integrated approach in the SMP of São Paulo, we cannot guarantee that nexus-type solutions are not included in sectoral plans or in policies developed by other local or supra-local authorities.

On the other hand, as our analysis demonstrates, the nexus elements are implicitly connected through issues of land use, environmental preservation and reorganization of urban development. For example, we identified the category protection for both water and food, which indicates that these two elements are, to some extent, linked and play together a critical role in the environmental protection and urban development strategy of the city. While water and water source areas are considered something to be protected, agricultural activities, mainly in the rural area, play a critical role in the local biodiversity protection. In addition, our analysis highlights that the SMP, in fact, supports organic agriculture, transition to agroecology, agritourism and other activities related to food production as important strategies to contain urban sprawl and to create a sustainable buffer to protect and preserve natural, vegetated and water-rich areas. We argue that water and food can create synergetic effects, driving the development of some particular areas, where environmental preservation is crucial to guarantee the provision of ecosystem services. This is particularly true in the case of the south zone of the city, where the largest portion of the environmental protection and recovery macrozone - the rural area - concentrates the most important remnants of Atlantic Forest, biodiversity, and water sources (including the Billing and Guarapiranga reservoirs, which are still used for water supply and energy production). The preservation of these areas and their environmental services are key for ensuring water quality, supply and food production, as well as air quality and carbon sequestration, mitigating urban heat island effect, with potential effects beyond the city limits to the entire metropolitan region (Franco et al., 2015; Sepe & Pereira, 2015). While the incentives to the rural area are critical to preserve the city's green belt, they also are helpful to avoid the horizontal expansion of urban agglomeration, which is in line with the conceptualization of a compact city (Piérola & Almeida, 2016). Ultimately, the SMP explicitly recognizes the social function of rural property according to rational use and resource conservation parameters, which favors the well-being of its owners and the workers of these properties (Andrade, 2017).

Through our analysis, we recognize that land is also of great importance in the way the SMP deals with energy through the mobility issue. The urban expansion in the city of São Paulo towards the peripheries and the substantial increase in the vehicle fleet per inhabitant have led to increasing daily commuting between home and work. This resulted in increasing greenhouse gases emissions and air pollutants, and an urgent demand for non-renewable fuels, particularly for municipal public bus system (Di Giulio et al., 2018; Saldiva, 2018). It is no coincidence that the mobility strategy advocated in the SMP takes into account the influence of existing public transport infrastructure of high and medium capacity, such as subways, trains and buses, improving the urban development and increasing the density along these axes (D’Almeida, 2016), and also stimulates the use of public transport, biking and walking. The reorganization of urban development from a mobility perspective has the potential to improve the well-being of the population and the environment. Moreover, urban planning strategies are also very effective for energy savings and GHG emissions reduction (Collaço, 2019).

We recognize that, particularly in the context of large cities in the Global South, the disarticulation between sectoral policies hinders the integrated development of urban space (D’Almeida, 2016). The subdivision of responsibilities within municipal bureaucracies is a critical aspect, and frequently causes difficulties for effective collaboration, information sharing and coordinated action among municipal staff (Di Giulio et a., 2017; Jacobi et al., 2015; Aylett, 2014). The internal fragmentation, combined with the vertical and horizontal dimension of urban governance beyond their administrative borders, can limit the possibilities for cities to implement integrated or nexus approaches in strategic planning.

6. Conclusions

This chapter presented a content analysis of the 2014 Strategic Master Plan of the city of São Paulo through the lenses of the WEF nexus. Identifying land as the connection point between the nexus elements in a strategic planning instrument of a megacity such as São Paulo can both contribute to enrich the nexus literature and give insights on the role of local authorities in the nexus governance. Our findings add to other studies that identify land as the missing element to be added to the nexus approach (e.g., Ringler et al., 2013; Sharmina et al., 2016; Janssen et al., 2020). The nexus can be considered a starting point for including a broader set of resource interactions (Fan et al., 2019), and there is great potential to link the nexus with sustainable urban planning by acting on land use to simultaneously address water, energy and food. Furthermore, the option of tackling the nexus by acting on land can give agency to cities in those contexts in which local authorities are responsible for land use regulation management. Land can therefore be an entry point for local authorities to strategically operationalize the nexus. Moreover, the results show that identifying how water, energy and food are addressed in urban planning strategies can help to: (i) recognize and fill gaps in the local urban agenda; and (ii) suggest alternative paths of development in a cross-sectoral fashion.

We indicate that more studies should be carried out in different cities, investigating how integrated public policies and actions can potentially deliver multiple economic, social, and environmental benefits, which help cities to achieve sustainable outcomes. Future research is also needed to look at the implementation stage of policies covering water, energy and food as well as explore if synergies and tradeoffs between these elements are addressed in sectoral policies and plans at different government levels, since without this broader view, many disputes and interactions can be left aside or not fully understood.

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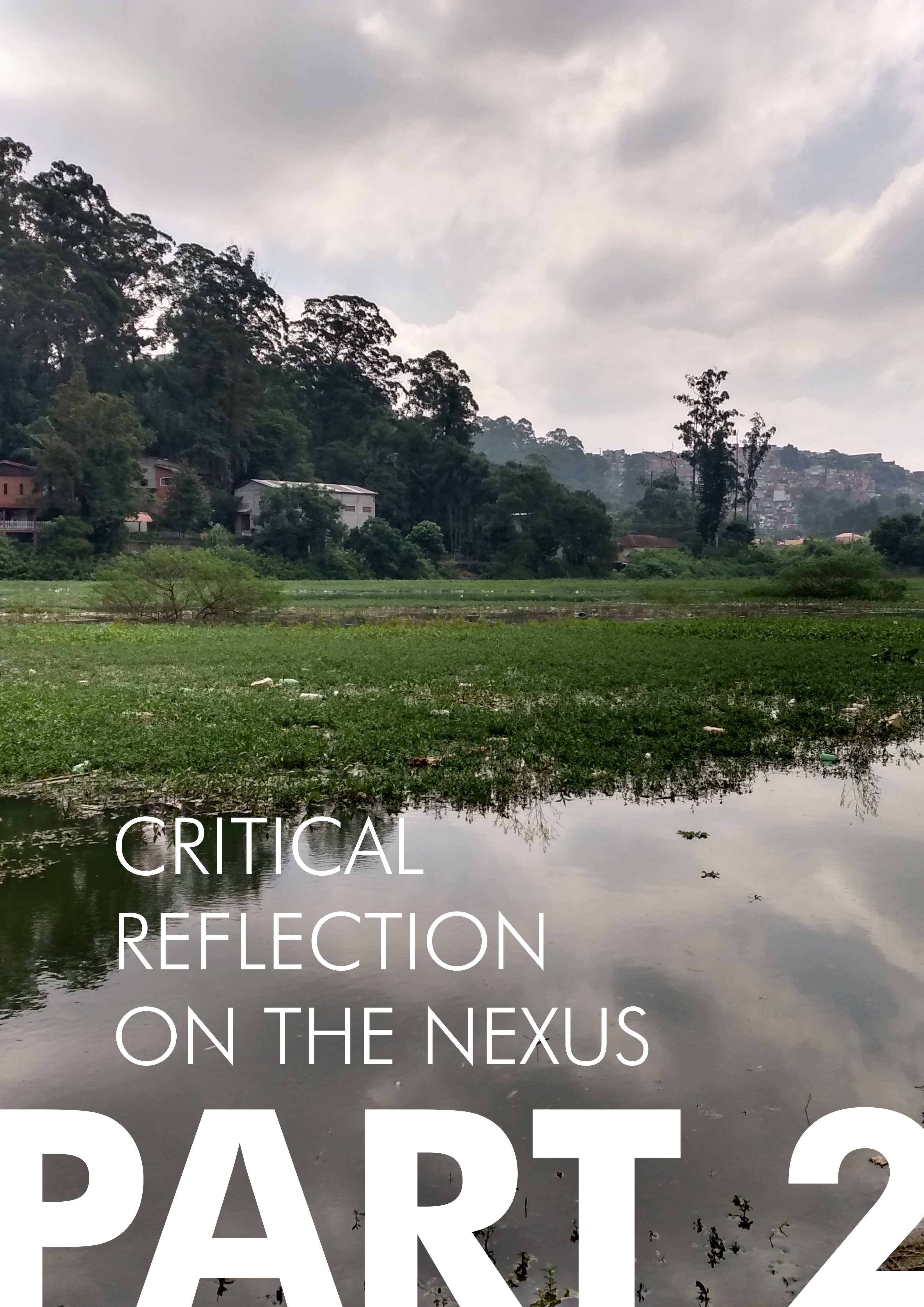

CRITICAL REFLECTION ON THE NEXUS

PART 2

CHAPTER 6

Situating the subject on the WEF nexus research: insights from a critical perspective

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1. Introduction

Once we came across the water-energy-food (WEF) nexus literature, our attention was drawn to its calls for synergies between these sectors in support sustainable transitions considering the vulnerability of people and systems (Hoff, 2011). Working as researchers in psychology/social sciences and following closely public interventions proposing to establish more integrative and sustainable use of natural resources, we found a different approach to increase visibility of the resources interdependencies affecting environmental transformations at the local level. Nonetheless, as a "buzzword" (Cairns & Krzywoszynska, 2016), the nexus has also revealed some blind spots on the subject's accounts. A growing body of literature has shown that the nexus is not a homogeneous framework, but has been widely associated to techno-managerial, apolitical discourses, presuming that a range of multiple actors –institutions, policymakers, local communities – are amendable to decision-making tools which are capable of integrating water, energy, and food sectors (Wiegleb & Burns, 2018; Allouche et al., 2019; Williams et al., 2019; van Gevelt, 2020). Likewise, emphasis on managerial solutions tends to ignore people's lived experiences and communities rooted in a multiplicity of contexts built upon historical exclusions. Indeed, our experiences of empirical research on Brazilian agrarian reform areas informed us of more contradictory realities than those dominant assumptions supposed. We have argued elsewhere (Melo et al., 2020) that socio-environmental transformations related to water, energy and food interactions in these areas are not promulgated by managerial solutions. Instead, they are contested fields involving multiple subjects, subjectivities, territorial-specific tensions and persisting systems of inequities.

While these blind spots resonate a depoliticized interpretation of the nexus, Allouche et al. (2019) point out that claimed technical protocols to address the nexus interactions also overshadow the role of subjects in contesting or resisting changes. The focus on natural resource scarcity unravels the economic rationality, placing the nexus into neoliberal narratives and reproducing socio-environmental inequalities. The authors argue that what is needed is to acknowledge politics, power, and justice as the key processes through which critical social science engages an alternative perspective of the nexus. Taken together, these engagements in co-creating knowledge and solutions sensitive to livelihoods, structural inequities and non-negotiable rights, point toward challenging directions for both theoretical and practical work of the nexus.

Is such orientation to politics, power and justice enough for critical nexus research in Brazil? In many respects, this inquiry reflects Dalla Fontana et al. (2019) analysis of the nexus research in the Brazilian context. Though emerging yet marginal literature is concerned with socio-political challenges in issues like urbanization and poverty, the authors argue that the human dimension and local concerns remain superficially addressed in the nexus research, even by social sciences. As they suggest, one of the potential contributions of critical studies is to incorporate more empirical analysis on the nexus in Brazil, which has been essential to consolidate alternative perspectives. However, it seems to us that the links between the critical nexus research and human dimension are rarely discussed, not only by the lack of empirical evidence but also by insufficient lenses that fail to unpack the way the subjects have been conceived in sustainable development discussion, often blinded by individualized rationalities.

We argue in this chapter that critical scrutiny of the subject is needed to make sense of such blind spots in the WEF nexus research in Brazil. Situated in critical sociological/ psychological (Bourdieu, 1996; Gaulejac, 1997; 2004; Barus-Michel, 2004; Dardot & Laval, 2016) and feminist/postcolonial perspectives (Haraway, 1988; Spivak, 2000; Federici, 2011; Brown, 2015), we draw on the social subject as the concept foregrounding the fundamental relationality of our existence entangled with the other, which cannot be understood separately from the ontological lenses that guide both hegemonic and alternative nexus perspective in the nexus debate. In revisiting two interrelated but opposite conceptions – the entrepreneurial and the collective subject – we seek to explore how subjects are understood in the nexus framings, in which ways particular relationalities are mobilized, and whether there is or not space to think about justice in the nexus agenda. In other words, by investing in a deeper reading of the subject, this chapter aims to contribute to answering a fundamental question brought by Williams et al. (2019) for the nexus critical research: how things (and people) are connected and with what consequences. We also dialogue with our empirical research experiences from Brazilian agrarian reform areas as part of this conceptual reflection. Here, we do not analyze cases, but we draw on these territories to provide initial insights on the subjects that simultaneously grapple with entrenched injustices and exclusionary politics related to water, energy, and food, but also struggle to remake their socio-material, environmental conditions occurring every day.

The text proceeds as follows: the first section situates the concept of social subject and why we should scrutinize it to address some theoretical and methodological challenges posed by a critical nexus research; the second section unpacks the neoliberal rationality and the entrepreneurial subject to discuss how these modes of reasoning underly three key problems of dominant techno-managerial nexus: the de-politicization of nature, naturalization of injustices and disengagement of collective interests. And the third section proposes to rethink the nexus and the struggles for justice through the lens of the collective subject.

2. Why the subject?

> *It is not, however, a question of opposing the objective and the subjective, the quantitative and the qualitative, but of joining them together for a better understating of social actors – one that is closer to their lives, their feelings, their emotions and their singularities (Gaulejac 1997, p. 187).*

When sociologist Vincent de Gaulejac delineated the concept of social subject, he and other psychosociologists (Barus-Michel, 2004) were contesting essentialist, deterministic views on individuals that can solve problems by personal efforts alone or that passively incorporate the others' rules and domains. Inspired by a range of disciplines – sociology, anthropology, psychoanalysis and history - these authors argue that one cannot think about the subject as it defines itself exclusively by an organic substrate. Rather, the subject is defined by a reciprocal relationship between psychological, social (resulting from political and economic relations) historical, and cultural forces. As being domains underpinned by particular rules, the question of the social subject is to grasp the "dialectical circularities" (Gaulejac, 2004) connecting structural relations (and the contradictions they produce) with the concrete practices and singular responses of individuals in attempting to position themselves as subjects of their history. Subjects outline collectives with history, knowledge, practices and ways of organizing relations, as well as identities that produce and reproduce a contingent intersubjective space. In other words, the social subject conceptualizes the actors as an enduring articulation between oneself and the other, enacting within an intermeshed world of power relations, circumscribed by hierarchies and inscribed daily.

Drawing on this concept and its characteristics (multidimensionality, intentionality and transformative potential) we understand that techno-managerial recommendations cannot merely envisage people as background actors, who are target population of public policies. Instead, subjects conjoin common projects to the praxis, co-producing multiple worldviews, practices and meanings in a changing and unpredictable social life. When thinking about these imbrications on water, food and energy interactions, we argue that a social and politically informed discussion of the nexus, including its theoretical and methodological challenges, implies serious regard of the subject. Considering that the ways of living together, simultaneously singular and collective, are informed by norms; values systems and current technical knowledge expressing dominant worldviews, they can also reshape the subjects' subjectivities, asking who they are, their relationalities, experiences, ways of thinking, everyday relationships, conflicts, and constraints, which can provide a useful lens to critical nexus approach.

We are joining similar critical scholarship appeals for greater concern with people in the Brazilian nexus research. When studying participatory approaches to the nexus in the metropolitan area of São Paulo, Carvalho (2021), Börner (2021) and Kraftl et al. (2019) advocate for an engagement with the citizens' protagonism that enables us to think about fairer and more equitable territories. Comparably, Jacobi and Giatti (2017) argue for a nexus rationality that recognizes people and local interests. This rationality, they say, is faced with the challenge of reconnecting everything that has been excluded and treated independently in the modern context. Urbinatti et al. (2020) have conceptualized similar concerns focusing on the framework of "nexus of humility" – a set of dimensions that explore the hybridity of perspectives – to enable more plural and democratic knowledge for the nexus.

Along with this scholarship and building on the concept of the social subject, we argue that another fundamental challenge is to go beyond the limits of methodological manuals that prescribe broad-spectrum formulas to deal with unique realities. When we shift our lenses to the subject, we reconcile efforts towards the artisanal construction of leading us to know the other's logic and, in a dialogical sense, allow them to know ours. This task of unfolding the lived experiences of the nexus through the subject's perspective requires an encounter of complex realities. In the Brazilian case, it is an encounter with diversified expropriations over life and territories, which means concomitantly facing subjects, as Spivak describes, constituted by "specific modes of exclusion from markets, political-legal representation, and the possibility of full membership in dominant social strata" (Spivak, 2000, n.p.). As such, Bourdieu (1996) argues that it is a field of asymmetrical power relations in which researchers and practitioners, holding certain types of symbolic capital, draw on the prerogative to define, propose, and control the game's rules. Framing knowledge through supposed objectivity, researchers often naturalize power asymmetries. Contesting this position is recognizing the existing asymmetries through dialogic, as they relate to distinct experiences that people carry with them. By performing a “spiritual exercise” of “mentally putting ourselves in their place” (Bourdieu, 1996, p. 22), we can face, and make visible, both asymmetries and interferences produced in this interaction, and establish a non-violent communication. Moreover, it is to refuse the researchers’ “god trick” (Haraway, 1988, p. 581) and ambition to see ourselves apart from a situated, embodied relationship with a common world. What emerges from this theoretical and practical exercise, whether the “situated knowledge” (Haraway, 1988), the “learn to learn from below” (Spivak, 2000), or the “reflexive reflexivity” (Bourdieu, 2004), must be a researcher's concern regarding the subject.

These theoretical and methodological understandings of the subject call attention to the crucial role that Humanities and Social Sciences can play for the nexus approach in planning and imagining research practices that reflect the complex realities of where we work. Essential, in this respect, is the consideration of the “politics of knowledge” (Allouche et al., 2019, p. 9) underlying rationalities guiding transdisciplinarity when approaching the nexus. For example, our empirical experiences supporting sustainable development interventions have shown that social scientists are often requested not to embrace the subjects' perspectives as valid knowledge about decision-making over resources. Instead, an accessorial contribution to softening conflicts is expected, which may become disposable as soon as the uncomfortable knowledge confronts these asymmetries. As Allouche et al. (2019) alert, this refusal renders the risk to perform a supposed transdisciplinarity that reaffirms established knowledge rather than a transformative one.

Another example of such challenging horizontal dialogue with the subject has also emerged from our empirical experiences. It refers to how to face, in practice, the obstacles posed by polysemic categories that are crucial to understand people’s livelihoods, difficulties and possibilities they have for the nexus. When studying the agrarian reform areas, we came across different representations of health-disease, quality of life, agroecology, environment. Again, such accounts tell how different subjects, carrying vast experiences and life trajectories, attribute different meanings to things in the world. Given the high-priority role of Brazil's agrarian reform areas for social and environmental change, it was crucial to understand the social representations of agroecology while analyzing the discourses and practices of the local population, government officials and academics involved in sustainable development projects. By unpacking these, we understood the origin and reasons for dissensions that hindered the agents' organizing process and the implementation of sustainable economic practices in the territory. Connections between Agroecology (as a scientific discipline), agroecology (as a more sustainable and resilient solution to climate change) and agroecology (as a traditional agricultural practice) are neither automatic nor established like a magic trick. Instead, they require indefinite time and a lot of insistence from all stakeholders so that various agents conjoin distinct ways of understanding and viewing the same object. Obviously, in addition to time and insistence, this process depends not only on the urgency to meet the subjects' vital and material needs, but also on the culture of each place, which can facilitate or undermine the nexus synergies towards the dialogue between knowledge of a scientific, technical and popular nature.

These are just initial insights on how explicit attention to the subject can enrich critical nexus discussion, especially those that seek to explore terrains through which more plural, ethical and local perspectives can be enacted. On the other hand, as the next section suggests, an account of the subject also helps to expose the rationalities of techno-managerial framings that, as Leese and Meisch (2015) suggest, might confirm structural injustices rather than transformative change.

3. Techno-managerial nexus and the entrepreneurial subject

If the subject is the expression and synthesis of multiple dimensions – of thinking, desiring, acting – this is because they do so through their involvement and social practices in a network animated by modes of conduct, accepted practices and justifications. As such, subjects are inextricably linked to the technical-scientific knowledge, norms, values, imaginaries, rationalities shaping the nexus governance. But a problem of dominant nexus thinking in disregarding such dynamics is to disguise the rationalities they co-constitute. As Brazilian geographer Carlos Walter Porto-Gonçalves (2006) observes, we cannot see environment and related technocratic discourses independently of an intersubjective reason far from being neutral. Instead, it reflects rationalities that have won and to which it is committed. As such, we must ask to what extent the water-energy-food nexus discussions are built upon rationalities that frame individualistic, utilitarian views on the subject that justifies inequities.

This section argues that we cannot grasp the nexus complexities if we omit how neoliberalism broadly shapes human worlds - subjects, institutions, modes of governing - and the implications of these rationalities to the nexus. Drawing on critiques of dominant nexus consistency with neoliberal logic (Cairns & Krzywoszynska, 2016; Williams et al., 2019), we found a helpful concept in the entrepreneurial subject to work on these articulations. Extending Foucauldian approaches, Brown (2015) and Dardot and Laval (2016) have contributed towards broader understanding of how neoliberalism is not only an ideology and socioeconomic model, but a rationality that catalyze the subjects' experiences to become entrepreneurs of their own lives alongside the marketization of every sphere of life. As a synthesis of self-reliant subjectivity, social relationships, and worldviews that pressure competition everywhere, the entrepreneurial subject can demonstrate how techno-managerial perspectives are built upon ontologies that obfuscate fundamental politics and contradictions of the nexus. We turn to this concept to contend specifically with three key issues raised by critical scholarship about the current nexus framing: the de-politicization of nature, legitimation of injustices and disengagement with local realities.

By tracing the nexus foundations through sustainable development debates post-2008 crisis, Allouche et al. (2019) elucidate that the early arguments on resources scarcity and global crisis were strongly connected to market-led solutions and rational-efficiency framings. Thus, by opening new territories for policy reforms and supporting state-private sector collaborations, the nexus approach intended to reduce trade-offs, provide more efficient use of resources, and integrate water-energy-food-systems. Moreover, the call for securitization of natural resources fuelled arguments to break down institutional barriers and to promote large-scale, beneficial solutions, such as land deals allocated to grains and biofuels production. In addition to the risk arguments, these competitive pressures on resources were adjusted to what policymakers claimed to be the "eradication of inefficiencies" (Williams et al., 2019, p. 14) and the need for an integrative, sustainable management of tensions between water, energy and food production, while not losing sight of global economic imperatives for growth in these sectors. As these and other authors demonstrate (Monstadt & Coutard, 2019; Moss & Hüesker, 2019), these assumed logics resonating the nexus hegemonic narratives overlooks the different, intricate politics, contradictions, scales, subjects and materialities of the nexus. These suggest an apolitical vision of nature mediated by optimal measurements to reach a 'perfect equilibrium' of the nexus and eliminate external threats. What is deemed a threat, however, is a vague notion that opens space to the nexus becoming a discursive tool amendable to powerful narratives (Cairns &

Krzywoszynska, 2016), tying resources governance to the safeguard of market interests, dismantling of rights and leaving untouched structures of unequal access and resources distribution in many locations.

Whereas we come to understand the existence of such compelling arguments in terms of the capital's remaking nature, we also need to trace them alongside a dominant rationality that, as Brown suggests, figures “human beings exhaustively as market actors” (Brown, 2015, p. 31 [emphasis added]). It reminds us that the interplay of neoliberal rules – precarity, deregulation, competitiveness, high technical and social requirements – co-constitutes intersubjective domains shaping the everyday, so as the solutions to fundamental issues related to water, energy and food. Subjects will make sense of their lives through the neoliberal rationality that regards humans and nature as businesses to be managed and optimized by major market innovations. Bhattacharyya (2015) adds how neoliberal rationality encompasses the reshaping of state's role from arbiters and providers of services to the guardian of individualized choice. Indeed, Dardot and Laval (2016) argue that neoliberalism responsibilizes subjects to manage to their own expense the access of common goods as a matter of strictly private decisions and consequence of personal trajectories. For Brown (2015), it means that no matter how vulnerable, impoverished, or without resources people are, it is always up to the entrepreneurial subjects. They must account for rights as merits that feature winners and losers, to the extent that inequities become legitimated.

These combined aspects of neoliberal rationality might explain how discourses on more efficient solutions can reinforce the prevailing common sense that there are no possible means for integrating the nexus without austerity politics while blaming subjects for putting pressure on the resources and provision systems. Indeed, it is easier to justify the privatization of essential water and energy services, arguably more efficient, by forging a supposed consensus when it involves “producing individuals who will decreasingly be able to count on forms of mutual aid from their local milieus or public mechanisms of solidarity.” (Dardot & Laval, 2016, p. 663). When thinking about water, energy and food interactions through a purely economic and technical perspective, it is not difficult to see that such rationality disguises the intricate relationship between winners and losers embedded in the production and provision of natural resources (Allouche et al., 2019). Amaral et al. (2021) analysis of the São Paulo Macrometropolis offers a rich empirical study that unveiled how the environmental inequalities in the metro area responsible for 33.9% of Brazil's GDP feature winner and loser populations concerning the WEF nexus.

While neoliberal rationality writes off politics from nature and legitimizes the injustices of the nexus, democracy misplaces political valence and venue for the subjects. For Bourdieu (1998), the individualization of structural problems is the outcome of one of the most visible dimensions of neoliberalism: the fragmentation of the subject's collective dimension. The appealing of techno-managerial perspectives might reflect the disengagement with local realities and the very fracturing of collectives by neoliberal reason. As Brown (2015) reminds, by combining elements of devolved authority with individual responsibility, the participation promoted is not equivalent to effective democratization engaged with the protagonism of vulnerable localities and their concerns in the public debate. Deemed as human capital, subjects are included to support proposed solutions by experts, but not to make decisions, exercise power, or other ways of organizing social institutions that contest control over resources and disguised forms of injustices.

Moreover, competition and utilitarian expectations regarding the subject create a short-term and speculative tendency of politics without considering the long-term effects for local communities. Not surprisingly, vulnerable social groups are the first to suffer from budgets and socio-environmental impacts. In our experiences in Brazilian agrarian reform areas, we witnessed the implementation of sustainable development projects in highly degraded areas where families arrived in extreme poverty conditions after spending years under precarious occupations. To restart life, residents accessed meager resources lost by the lack of infrastructure and appropriated inputs to provide energy for water, and water for food, hindering the managing of poverty. In addition, initial investments for food production did not engage people's motivations and abilities.

In part, these dynamics suggest how dominant ontologies of the entrepreneurial subject can underly techno-managerial perspectives of the nexus frontally opposed to those that acknowledge the human-environment relationalities through the lens of fair and equal protection. The focus on politics and justice issues thus challenges us to interrogate how the vocabulary of neoliberal rationality reproduces and naturalizes systemic environmental inequities, eliminating the political character of social struggles and conflicts in the nexus. It is worth remembering that, as Porto-Gonçalves (2006) says, these dynamics are nothing natural except for the powerful actors that see their domination as a work of nature itself. Likewise, contesting the hegemony of entrepreneurial rationality in dominant assumptions of the nexus invites us to rethink rationalities and ways of living beyond the privatization of life.

4. Rethinking the nexus and the collective subject

While the concerns about such techno-managerial dominant framings are increasingly emerging in the critical literature, imagining fairer and ethical terrains for the nexus approach remain a challenge. Allouche et al. (2019) suggest a constructive engagement to understand better the local realities of resources availability and styles of organizing towards a plural democratic perspective. Swyngedouw (2019) argues for a new socio-physical and socio-ecological reality that requires repositioning politics through sustained action and organization. Throughout this chapter, we have argued that an account of the subject is critical to these tasks for the inescapable intersubjectivity connecting people, politics and environment unfolding the nexus. Likewise, if the nexus is to be a transformative concept that relies on the subjects as crucial and active participants in the politics of the everyday, we should look not only to the collective possibilities for contesting systemic injustices but to people's contradictory ways of relating with the material world.

In Brazil, communities formed by distributive policies in collective proprietary regimes, such as some agrarian reform areas in sustainable model, have resisted against the global commodification of land and environmental resources. These experiences demonstrate relevant examples of how collective claims for the right to land have transformative socio-environmental effects, reconfiguring the nexus at the local level and creating new meanings for land and environment. At the same time, the subjects also bring marks of colonial expropriation and exclusion, reproducing neoliberal conditions that undermine their reproduction and livelihoods. In this section, we argue that to assert the socio-political perspective of the nexus must reflect on these contradictions. The concept of collective subject and feminist/postcolonial approaches to the common have provided useful insights into thinking about the emergence of collective struggles reclaiming rights and resources vis-à-vis the everyday realities of material social, political and cultural vulnerabilities.

The collective subject is not a universalizing force. It is produced by a composition of diverse subjects politically acting on a shared desire, and collectively responding to the challenges at hand (Callahan, 2012). Scholars that advocate the common as a principle that keep away natural commons such as land, water, air and food, from any logic of appropriation and reserving it for collective use, do also analyze the collective subject as inextricably co-related to such radical democratic praxis (Dardot & Laval, 2017). Feminist and decolonial scholars assert the common as a logical and historical alternative to disentangle our livelihood from neoliberal's attempts to subordinate every form of life. Contesting autonomist accounts of the common, Federici stresses the fundamental need for a material basis for constructing "a common subject" (Federici, 2011, p. 7). Similarly, Tola and Rossi stress that the common say little about colonial dispossession of many social groups, "including the dispossession of ways of relating with the material world that do not entail a binary distinction between active subjects and inert resources" (Tola & Rossi, 2019, p. 261).

When centering our analysis to the most vulnerable in the nexus discussion, the struggles for power and justice cannot be understood as a theoretical or finished abstraction in the real world. Collective subject expresses a historical and social construction that puts shared action in constant tension with the everyday inequities. For example, our experiences in agrarian reform areas illustrate a contradictory reality: the subjects created a powerful political strength to challenge the local agribusiness power and claim rights through land occupations. At the same time, they become politically fragile in the face of capital and state's constraints along the organizing process. Once brutally crushed by historical land dispossession, unemployment, precariousness, lack of access to formal education and constant migration and cultural uprooting, the subjects found in the land occupations less of a political strategy to carry out Brazilian agrarian reform or sustainable projects and more of a need to overcome extreme poverty. These particularities barely allowed people to voluntarily adhere to proposals for collective organization and use of resources in the occupied territories. However, it was possible to identify new ways of organizing the territory and social relations, built upon informal solidarities of kinship and neighborhood, which served as a starting point for the construction of the collective subject. Yet, the collective solution did not survive as a political project, especially when subjects faced bureaucratic conditionalities with supporting food production and water access. Since 2016, with the far-right's rise in Brazil's political scenario and elites' reclaiming commons from the state, successive attacks against the project to implement the agrarian reform policy have been taking place. Subjects have been struggling to recreate and reappropriate the collective organization to grapple with the ongoing uncertainties and more deepening inequalities in the face of the Covid-2019 crisis and federal government's denial of pandemic, which aggravated the food insecurity throughout Brazil. The strategies show that the environmental change produced by these subjects in the area has been the way to articulate new meanings for place and nature, as well as to create new food networks with civil society resources. Financing collective agroecological food production, agrarian reform areas have been distributing fresh food to other vulnerable populations and community kitchens in surrounding urban areas.

We learned from these contradictions that taking the subjects' life experiences as a starting point for socio-environmental changes was not enough. It was also necessary to ensure socio-material conditions, public policies, institutional arrangements, and the necessary time to learn and co-create the rules of coexistence and sharing common resources. At the same time, these experiences point towards "instituent praxis" (Dardot & Laval, 2017, p. 889) of a concrete, collective subject with desires, limits and burdens that weave together water, energy and food, but also facing persistent inequities on social reproduction. With this in mind, we assert that a critical perspective of the nexus must always be attentive to the structural, political and cultural particularities of each territory and the different forms of dispossession (crosscut by race, class and gender inequities) that challenge the construction of a collective subject, strong enough to carry out projects of social justice and sustainability. Converging solutions towards an engaged nexus perspective with local concerns and other ways of organizing then requires grapple with these different faces and contradictions of the subject.

5. Conclusions

In this chapter, we proposed a critical scrutiny of the subject to add insights to the nexus approach. We argued that constructing a critical framework for the nexus brings the ontological debate around the concept of the social subject, giving expression to both social, political and justice domains of the nexus regarding local realities and vulnerable groups in the Brazilian context. Moreover, an account of the subject can add insights to the increasing concerns of critical scholarship of the nexus to engage with more plural, democratic knowledge.

By situating the subject into both dominant and alternative framings of the nexus, we revisited two opposites but interrelated concepts – the entrepreneurial and the collective subject. We suggested that the entrepreneurial subject expresses the neoliberal rationality that points to the generalization of characteristics, permanently invisible, but structuring the dominant techno-managerial framework in different scales of everyday life. The subject disappears amid managerial explanations that frame apolitical discourses about nature, blames the subjects and makes social and environmental injustices invisible, as well as disengages other forms of thought and organization that would enable political action in the face of inequities. Nonetheless, studies and different conceptual lenses reaffirm the importance of the collective subject throughout this process. The collective subject gives expression to an institutional praxis through which people struggle for justice and experiment with new ways of organizing social relations and the nexus, as we learned from empirical experiences in agrarian reform areas. Moreover, we must contest essentialist views that can make the ongoing forms of dispossession and the subjects' material conditions invisible when conducting sustainability projects.

Finally, we suggest that an account of the subject sheds light on the challenges of nexus studies in equating the classic dichotomies between subject and society, subject and environment, society and environment. The continuous unfolding of the subject is relevant to understanding what is deemed acceptable by underlying rationalities of both dominant and critical approaches. It can also help extend the conceptual lenses that consider the realities of the nexus in the global South countries. A critical nexus approach in the Brazilian context then requires understanding subjects, subjectivities, livelihoods and everyday relationalities tying neoliberalism and its ongoing renew of colonial structures of exclusion.

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CHAPTER 7

Youth knowledge and perceptions about the water-energy-food nexus: challenges and learning gained from interdisciplinary research on education for sustainability

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1. Introduction

This chapter is a reflection on results from the process of researching the knowledge and perceptions of Brazilian youth about the water, energy and food nexus, carried out by a multidisciplinary research team from Brazil and the United Kingdom between 2016 and 2019. The main objective of this chapter is to highlight that realizing the diversity of ways that young people understand and experience water, energy and food, as well as the nexus between them, can help to identify significant gaps in education for sustainability as a whole and point out some paths for enabling people to understand sustainability and trying to reach it.

The collaboration between these researchers had its inception through another project. In 2014, two independent research groups of UK social scientists and Brazilian Engineering researchers were introduced by a common acquaintance, a Brazilian researcher who had noticed that the expertise of each group could be mutually beneficial. Both groups felt the need to incorporate new elements aiming to characterize their objects of study to advance in methodological terms. This was the origin of the Sharing Futures research project (www.sharing-futures.com), an interdisciplinary project funded by ESRC (UK), which focused upon sustainable urban planning concerning the water-energy nexus. There was a good synergy between the two groups and their different approaches proved to be complementary:

> *The Brazilian team comprised of mechanical engineers, water resources engineers, electrical engineers and geologists with technical research expertise in energy and water resources management. By contrast, the UK team were qualitative human geographers interested in everyday experiences and interactions with built environments, primarily informed by qualitative, participatory and ethnographic research principles. Both groups of researchers began from a point of openness to knowledge sharing and stepping out-side disciplinary "comfort zones". For the Brazilian team, this was articulated in terms of the importance of bringing social, cultural and environmental subjectivities into the modelling, analysis and verification of inherently complex, dynamic, uncertain real-world systems, to better support technical, political and institutional decisions around sustainable urbanism. For the UK team, the project was seen as an opportunity to develop skills in working with scientific peers in order to generate theoretical and methodological tools for understanding complex physical systems that could improve community participation and education about sustainable urbanisms (Hadfield-Hill et al., 2020, p.5).*

The research project '(Re)connect the nexus: young Brazilians' experiences and education about food-water-energy - RCTN (www.foodwaterenergynexus.com) was developed from the Sharing Futures project. It was proposed to the RCUK-CONFAP Research Partnerships Call, which was aiming to fund interdisciplinary research about the water-energy-food (WEF) nexus carried out by researchers from the UK and Brazil. As Kraftl et al. (2019, p. 300), the project was designed to

> *… directly respond to calls for both a more detailed conceptual development of the term "nexus" (and its attendant focus on "connection") and for "bottom-up" research with key stakeholders, and especially of people's engagements with water, energy and food in non-professional, everyday and/or domestic settings (Allouche et al., 2014; Leck et al., 2015; Schwanen, 2018).*

The project sought to identify young Brazilians' knowledge, perceptions and experiences of the water, energy, food nexus. It mainly aimed to examine children and young people's (aged 10-24) understanding, experience and participation in the WEF-nexus to verify whether their knowledge and experience about the WEF-nexus in their everyday lives could guide public policies or education for sustainability.

The case study region selected for the RCTN project was the Metropolitan Region of Paraíba do Sul River Basin and São Paulo State North Coast (whose acronym in Portuguese is RMVPLN). This region has some relevant characteristics for the study: (i) a population of circa 2.4 million (5.5% of São Paulo State population); (ii) it is in a strategic location between the most important Brazilian metropolitan areas, i.e., São Paulo and Rio de Janeiro; (iii) a significant economy for the State and country as a whole; (iv) the presence of towns and cities of different sizes and economic scenarios of highly urbanized, rural populations and traditional communities. There are previous works on this region that explore its socioeconomic and environmental aspects (Santos et al., 2016; Santos & Balestieri, 2018) and the impacts of urban expansion on water security (Paiva et al., 2020).

The project sought to follow a different path from the majority of previous studies, which have focused either on technological issues that aim to support integrated management of water, energy and food, and/or on using mathematical models to support decision-making about them, as in (Al-Ansari et al., 2017), and/or on the WEF-nexus from the point of view of governance in broader, top-down terms by considering larger-scale flows of food, water and energy (e.g. Beck & Walker, 2013; Walker et al., 2014).

It was decided to start by recognizing the need to understand people's point of view (the end-users of water, energy, and food resources) about the nexus. This understanding makes it possible to address crucial issues, such as (un)equal access to the nexus, resilience to pressure on resources and the role of education in fulfilling the needs and aspirations of different communities. A key aspect was the decision to listen to youth about their daily and practical experiences because this age group is still quite significant in the Brazilian population composition – the stratum between 0 and 24 years old constituted 35% of the population in 2019 (IBGE, 2019). Moreover, older children and young adults are generally the main targets of the Education for Sustainability (EfS) and are considered likely to have greater capacities to engage in and reflect on the nexus than younger children.

Therefore, this chapter considers reflections present in other manuscripts as starting points (Hadfield-Hill et al., 2020; Kraftl et al., 2019). It shares difficulties and learning processes from this interdisciplinary collaboration and presents some results obtained from two of the research project components: one survey and one qualitative multi-method research carried out with children and young individuals aged between 11 and 24 years. The highlighted results have been selected due to their usefulness to reflect on how to incorporate the concept of the WEF-nexus into sustainable development and education in Brazil.

2. The RCTN project

Three sets of research questions were addressed by the RCTN project, which has potential for both academic applications and societal impacts. In the first set, possible variations in young peoples' understandings, experiences and participation in the WEF-nexus have been analyzed in terms of their diverse geographical (urban or rural) and socioeconomic status (focusing on age, gender, education and ethnicity). The second set of research questions were posed to establish priorities and identify the everyday choices that young people typically make about water, food, or energy. The third set was about education for sustainability and the extent to which learning about the WEF-nexus can support young people's understandings, experiences and engagement.

The research comprised four components: a global video contest for groups of young students; a set of semi-structured interviews with professionals working in companies, government agencies and non-governmental organizations linked to the production or governance of water, energy and food; a baseline survey applied to children and young individuals aged between 10 and 24 years; one qualitative research involving multiple methods and 48 children, and young individuals of the same age range mentioned above, which was composed of initial and follow-up interviews, a task of recording activities using a smartphone app and Google maps, production of graphic representations of visual webs of “their own nexus”. This chapter is focused on the results of the latter two components of the project.

Children and young individuals were sampled in the survey and mixed methods of qualitative research, to ensure good representativeness of the RMVPLN area, particularly in terms of age, gender, education, type of educational institution (public or private) and geographical location (subregion; urban or rural). In all aspects of the project, guidance from schools, colleges, universities, youth organizations, community groups and non-governmental organizations (NGOs) supported the project group in ensuring the appropriateness of the sampling strategy, ethical procedures and research materials. Such local expertise assisted in assessing the potential vulnerability of participants and their capacity to consent.

A baseline survey comprised of a quali-quantitative questionnaire was answered by 3,705 young individuals (aged 10-24) living in diverse communities of the case study area (RMVPLN) through a web-based form developed using Sphinx iQ2® software. The questionnaire was composed of four sections: (i) the respondent profile; (ii) knowledge and experience concerning water; (iii) knowledge and experience regarding food; and (iv) knowledge and experience concerning energy. Two pre-tests were applied to students of UNESP, Guaratinguetá campus, to ensure the adequacy of survey questions.

The qualitative research involving young individuals comprised a total of 76 interviews of 1-3 hours each. This component of the project resulted in a far more detailed understanding of how the youth of today derive gains from participating in the WEF-nexus project, and so acquire knowledge about it. It comprised a series of activities: (i) an initial semi-structured interview called "my life with water-energy-food”, about their everyday routines and engagements with food, water, and energy; (ii) an app-mediated task during which young individuals and children recorded and photographed key aspects of the food/water/energy nexus in their neighborhoods; and (iii) a follow-up interview (‘visual web exercise and mapping’) through which they created visual representations of their own nexus based on the app-mediated task, in addition to a mapping exercise where geotagged photos/entries from the app were visualized on Google Earth.

The hardest challenge was to organize the visits aimed at data collection, mainly to schools due to the dependence on third parties and their respective schedules. Flexible planning of the trips was required along with choosing the quickest route and adjusting to institutions' timetables with a contingency plan in the event of an unexpected situation. Another issue was the bureaucracy required to get authorizations and book the visits to some organizations. Those negotiations have been frequently facilitated by the organizations' high level of interest in receiving research findings. Data collection allowed researchers to have a rough idea about the research participants' living conditions and their interaction with the WEF-nexus elements.

3. Discussion / Reflection

3.1 Multidisciplinary teamwork in two countries

The research project group was mostly composed of engineers and social scientists, but it also included physicists, biologists and geologists. Recurring conflicts and typical difficulties have arisen whilst carrying out multi and transdisciplinary teamwork (Russell et al., 2008; Klein, 2004). Among difficulties to be overcome, the most essential was the need for mutually familiarizing with distinct notions of the meaning of methodological correction and rigor. The success of collaborative work depended on facing the difficulty of gaining familiarity with the terms and references of other areas, which always implies discomfort since it is beyond one's field of expertise. On the other hand, such effort brought rewards for expanding conceptual horizons and enriching the perspectives of researchers who are engaged in this dialogical effort.

In addition to the personal growth achieved by the researchers involved, the multidisciplinary decisively facilitated the project progress. Researchers in the physical and engineering sciences were more familiar with research methods involving a quantitative approach, mathematical modelling and technical aspects of production and distribution of water, energy and food. According to their perspective, social scientists – at least those involved in this project – were more conversant with qualitative and hybrid approaches and more attentive to the particularities of behavior and perceptions of social actors about production processes and consumption of these elements. Such a wealth of experiences facilitated the use of multiple qualitative and quantitative methods, which characterized the study. Specifically, it was reflected in the development of tools and procedures for collecting and processing data.

For example, the project team prepared an elementary questionnaire for conducting the survey in this sense. It was mostly based on a qualitative approach from the point of view of socio-cultural aspects. Its initial version has been analyzed, criticized and revised from a perspective that provided the most extensive and technical knowledge about energy generation and distribution, water collection and distribution, basic sanitation, among others, in the region. The tool that was created from this collaborative struggle was certainly richer, more extensive and adequate to the complex reality of resource and environmental 'nexuses' than if it had been developed by only one of the groups.

Even greater gains have been brought through efforts to interpret and analyze results. Encounters, meetings and events (face-to-face and remote) are challenges to be faced in the search for interpreting and synthesizing the obtained data. These are moments of confrontation of interpretations, provocations, questionings, dialogues and learning, together with the natural understanding of what is thought of the reality of Brazilian children and youth by the English, and how this is reflected in the research development. On the other hand, Brazilian participants have diversified the ways of evaluating data obtained through the common mastery techniques of English colleagues.

For researchers in the field of physical and engineering sciences, it meant more than just becoming accustomed to new procedures and methodological requirements that belong to the realm of qualitative research, but it was also an opportunity to concede to possibilities created while focusing on what interviewees and respondents have to say. By focusing on the fact that interviewees or respondents have significant interpretations regarding the nexus elements based on their life experience has enriched the understanding that had been only previously supported by mathematical or logical criteria of correction or meeting technical requirements.

3.2 The approach to the WEF-nexus in question

The use of concepts related to the WEF-nexus while conducting the research project has highlighted multiple possibilities to address the issue of the search for sustainability. The WEF-nexus concept highlights mutual dependencies between basic elements such as water, energy and food, as well as between decisions regarding their production and consumption. The WEF-nexus approach represents some of the complexity inherent in understanding what sustainability truly means, in addition to that implicit in initiatives to find ways to produce, consume and live sustainably (Cai et al., 2018; Pahl-Wostl, 2019; Schlör et al., 2021). By highlighting these mutual dependencies and intricate consequences of decisions regarding the ways to produce and consume these elements, this approach can create a robust benchmark for education and management.

For the project group members who are engaged in the training of engineers, the virtues of the nexus approach are particularly evident. If the intention is to train engineers capable of meeting the challenge of promoting sustainable ways of living, it is essential to develop young people's abilities to understand and deal with the inherent trade-offs in the choices between different alternatives of technologies, models, location of enterprises, among others. Thinking from the nexus perspective, it provides a novel and effective approach for training engineers with a better understanding of sustainability in the face of its ambiguity and the compound environmental and social problems that face different social groups in different places.

From a dialogue with the youth and children who participated in the survey or interviews, it was found indications that education for sustainability can benefit from the inclusion of the concept of the WEF-nexus, as a way of translating part of its inherent complexity. Young people were able to 'ground' themselves (to some extent) in nexuses of water, food, energy and more, enabling them to understand and articulate what is often seen as abstract, large-scale processes that seem to be the domain of academics and policy-makers. Moreover, the nexus inclusion into educational processes could assume the role of an interdisciplinary axis endowed with meanings, concepts and elements that, currently, are dispersed in curriculum blocks that can have little or no articulation between them. Such dispersion certainly does not foster a more elaborate understanding of reality by young individuals.

However, the project prompted reflection upon the clear weaknesses in the WEF-nexus approach. While processing responses to numerous survey questions, there was a limited understanding by the youth and children about basic issues regarding the origin of food, energy or water consumed in their homes. In turn, this meant that some young people were not able to articulate all or any aspects of the WEF-nexus and, in particular, connections and trade-offs between different elements. This revealed the fact that, before dealing with the WEF-nexus, it is imperative to better acquire knowledge about the conditions to make food, energy or water available with a certain quality and in sufficient quantities for daily consumption. Some interviews and responses to the questionnaire also revealed that the respondents had an understanding of the consequences of decisions related to governance concerning the elements of the WEF-nexus in their daily lives, such as the provision of poor-quality water, the inexistence or inadequacy of urban water drainage systems, as well as food insecurity. However, it was found through the survey that ignorance about the various spheres of governance of the WEF-nexus elements is very frequent. Overcoming such issues seems to be prerequisites for the effectiveness of the WEF-nexus approach.

Another important limitation of the WEF-nexus approach to sustainability, particularly in the case of Brazil, is that it lacks the development of more explicit links with biodiversity conservation. One cannot think about education for sustainability without emphasizing the importance of biological diversity and initiatives to develop ways of living that do not reduce it, or that contribute to its restoration. Although it is more immediately linked to the issue of food production through different means, biodiversity conservation is strongly related to the generation and consumption of energy, as well as with the capture and use of water from rainfall and the possibility of occurrence of extreme events related to them.

In several of the interviews, it was evident that the WEF-nexus approach might be insufficient to achieve education for sustainability – in particular, to prepare people to participate in decision-making processes about sustainability – Therefore, a more integrating dimension would be necessary which ought to favor the development of competencies and skills, not only of a technical-scientific nature but mainly concerning social sciences and participatory politics related to the search for strategies and the development of public policies. This can be evidenced by the fact that several youth interviewees mention issues related to the marked inequality that characterizes Brazilian society and economy. They mentioned, for example, aspects of inequality regarding access to adequate drinking water or food. References to unsafe housing in the face of flooding were also frequent. Education for sustainability based only on the WEF-nexus approach which is restricted to material, technical and technological issues could assist in masking the inequalities faced and experienced by them.

Under Brazil's actual conditions in which the acquisition of participatory citizenship is an unfinished and constantly threatened task, the nexus approach can be extremely useful, once it is understood as a subsystem of a larger and more complex system. If the nexus itself implies an interdisciplinary approach, understanding it as a subsystem would mean having a transdisciplinary approach, in which historical, cultural, ethical and aesthetic dimensions are comprised. Experience from this project confirmed the advantages of the nexus approach, but it also highlighted that it must be included in education for sustainability aimed at society as a whole and aimed to make substantive social changes. In short, the project group realizes the need to frame the nexus approach in a broader theoretical framework, which includes explicit evaluative elements, such as the expansion of rights, commitment to justice, rescue of freedom and preservation of dignity.

3.3 Research Contribution to discuss the WEF-nexus in Brazil

There are issues regarding the method and results that can contribute to carry out other studies or formulate public policies in general, specifically concerning educational actions. One of which has been highlighted previously relating to the composition of the multidisciplinary group and its difficulties and advantages. However, the presence of professionals who are acknowledged and experienced educators of children and adolescents would have certainly made a difference.

The second methodological issue worth mentioning is that the exploratory nature of the research aiming to identify the perceptions of groups of individuals about the nexus has required multiple methodological tools. In retrospect, it is now evident that the adoption of this set of methods has ensured a wealth of perspectives which each of the elements alone would be unable to provide. The attempt to allow stakeholders to voice their concerns using multiple tools proved to be very effective.

As for the results, there are various contributions. It was possible to establish a diagnosis of young individuals' understandings and perceptions about the elements and the nexus itself in the Metropolitan Region of Vale do Paraíba and North Coast. Generalizations about other youth groups from other metropolitan regions of Brazil can only be carried out more carefully, but there are hypotheses yet to be verified. There are certainly some specific historical and cultural features of the region that influence their perceptions; therefore, it is necessary to take into account that the data collection was carried out before the economic crisis worsened in the country and the pandemic of covid-19, which has been affecting the emotional, mental, physical, social and economic health of most families to which interviewees belong.

Given these caveats, the first set of results allows concluding that there is no such thing as a homogenous profile of young people in the region. Data processing has shown that knowledge and perceptions regarding the WEF-nexus are highly dependent on socioeconomic variables. The demographic strata comparison has shown sensitive nuances. The most significant differences explored so far are: (i) between rural and urban youth; (ii) among students from public and private schools; (iii) between levels of education; (iv) between cities with a greater or lesser deficiency in water supply; (v) among the youth from different microregions according to different regionalization criteria.

The second set of results reveals that perceptions, knowledge and attitudes towards the nexus are adopted from multiple sources and influences. Parents, siblings, teachers, school assignments, social media, media, newspapers and magazines are the main sources of information. Yes, there is greater or lesser importance of one or another element, depending on the stratification of the sample; but none of which can be considered irrelevant to any strata. The implications of these results seem significant, given that a wide range of social actors must be considered and influenced, and not just the school community itself, for any strategy adopted towards education for sustainability to be moderately effective.

The third set of results prompts the conclusion that there is a serious lack of knowledge and interest in the WEF-nexus amongst youth. At least 40% of young people, on average, consider their knowledge about the production of the nexus elements to be "negligible" or "inexistent". Another 10%, at least, say they are not interested in matters related to issues concerning the WEF-nexus. These results are difficult to generalize to other social and geographical contexts, but they can serve as comparison parameters. Moreover, they indicate the magnitude of challenges inherent to the planning of public policies oriented towards education for sustainability.

3.4 The RCTN Project Developments

As the project progressed, there was a growing concern by the Brazilian team about what education for sustainability was like at the University where its members work. Questions have arisen about the state of research and extension projects concerning sustainability issues. The sensitivity and personal experiences of group members revealed that present research and extension projects would not fulfill the current needs and that they can and should be improved. Then, three Discussion Sessions were organized to which people who could enrich the debate have been invited.

What mostly mobilized teachers, students and technical-administrative staff participating in the Discussion Sessions was the desire to improve the training of the next generation: the desire that graduates ought to be decisive in promoting the various dimensions of sustainability. There was also an expectation of establishing collaborative spaces for various majors within the scope of sustainability, whether in teaching, extension projects and research, but particularly in the teaching-research-extension integration. There was also the conviction that it is of utmost importance to create novel and more effective channels of communication and collaboration with non-university publics, especially regarding social actors who are most affected by socio-environmental crises and compelled to act in a sustainable manner (including especially marginalised young people).

From the Discussion Sessions, the "Open Letter to the Unesp Community: on the urgency of improved and better education, research and extensions for sustainability" was written by the Brazilian group involved in the project, which has also been signed by other participants in the Sessions. Based on the content discussed, the letter analyzes the current scenario by highlighting the socio-environmental crisis extending throughout the globe, although the sense of urgency about the situation that countries, institutions and the university itself find themselves in is not fully perceived. The document indicates that sustainability should stop being a common theme like any other, but instead become a central theme articulating different, overlapping, but pressing topics. A nexus perspective may be an important – although not standalone – element in articulating such an approach to education for sustainability, as long as it is cognizant of the challenges, opportunities and broader contexts within which nexuses operate.

Given the above, the letter lists a series of proposals to be debated by the entire university, among which: (i) greater incentive and valorization of integrated research-extension-teaching projects aligned with sustainability themes; (ii) creation of Sustainability Offices at UNESP university campuses; (iii) strengthening partnerships with sectors directly affected by socio-environmental crises; (iv) intensification and deepening of conceptual debates and the search for new interpretative syntheses that better fit the present moment; (v) promoting an understanding of sustainability in its various dimensions (territorial, environmental, economic, social, cultural and political-institutional), thus avoiding its conceptual trivialization; (vi) a restructuring of courses by a valorization of knowledge and the development of competencies and skills related to sustainability and responsibilities of technical activities and their impacts on society. Although conceived considering the UNESP reality, these proposals may be debated by other Universities, due to their adherence to the United Nations' Sustainable Development Goals and citizenship formation.

A third development of the research project was an extension project carried out in partnership with the Municipality of Potim (SP). It aimed to improve the training of City Hall's technical staff as decision-makers, and the representatives of the municipality's educational system as opinion-makers, to act during the formulation of the city's master plan, particularly regarding issues related to water and energy. Potim offers excellent opportunities for action research projects considering the receptivity of the City Hall representatives for interaction with the University, and the need for improvements in water treatment and distribution. Results of this partnership are under development and point out to the support of the research group in future WEF-nexus actions' implementation in schools.

4. Conclusions

The concept of the WEF-nexus has been developed from multiple approaches. In the research reported in this chapter, it was deployed to allow youth to voice their concerns and provide them with a chance to express their knowledge, understandings and perceptions about each of the elements, as well as their own nexus. Thus, the concept was used to attempt to identify elements that would support discussions about education for sustainability in Brazil.

A decisive aspect for the success of the research was the structuring of a methodological framework in qualitative and quantitative terms, in which social, as well as physical and engineering sciences techniques, have been used. The exchange of experiences in the application of different approaches strengthened the research group and provided participants with greater personal and professional proximity. There was an increase in empathy while exploring professional issues. Regarding the approaches, the researchers experienced what they sought to capture in their research involving the youth: an exchange of knowledge and perceptions in a multidisciplinary and multicultural way.

Among the developments that have not been covered by the project, the researchers' self-questioning about their own practices, which emerged during the Discussion Sessions, stands out. This was identified through a reflection on how the local university community and the University as a whole have been addressing the issue of sustainability.

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CHAPTER 8

Qualitative and participatory research experiences on social-ecological attributes of the water-energy-food nexus

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1. Introduction

The growing demand for resources to promote social inclusion and reduce the vulnerabilities of extensive disadvantaged population contingents faces the current condition and very worrying forecasts of the limits of the earth system. There are no simplifying and massifying solutions to global problems when analyzing and mitigating them from varied local contexts, where different needs confront limited resources.

Although there is a synthesis language and rationality for understanding urgent global issues, their impacts and mitigation possibilities can be very different at lower organizational levels. For example, the assumption of greenhouse gases raising, and related global warming can convert regionally in sea level rising or savannization of rainforests, scarcity of defrost water or even decrease of temperatures. It is vital to recognize complexities and distinct chains of causes and consequences across different organizational levels in this sense. These distinguishable environmental changes can have different unfoldings related to the plural territorial contexts, social vulnerabilities, productive systems and globalizing processes. There is a demand for plural adaptive capacities and new rationalities on interdependent scarcities in the face of the multiplicity of possible and critical scenarios.

The water-energy-food (WEF) nexus can help discuss and cope with the environmental crisis and scarcities (Hoff, 2011), offering more robust ways of thinking and acting on intertwined issues, which are dependent on socio environmental constraints and capacities, and with the nature of being transversal through multiple sectors and organizational levels (Artioli et al., 2017; Boas et al., 2016; Pahl-Wostl, 2019). In the context of climate change, the nexus approach emphasizes that understanding the trade-offs within these multiple sectors is important not only to ensure sustainable management of resources but also to avoid future conflict by the competitive uses of them (Lazaro et al., 2021). The nexus approach to policy making is presented as a "nexus governance" proposal, searching for coherent and integrative governance and reflecting on the need for dialogue among various sectors and actors to seek and identify solutions for natural resource management (Lazaro et al., 2020).

Furthermore, the WEF nexus implementation and operationalization outcomes can help the Sustainable Development Goals (SDG) realization. For that, we can argue on intrinsic pertinence to: SDG 2 - zero hunger, SDG 6 - clean water and sanitation, SDG 7 - affordable and clean energy, with its relationship with SDG 1- no poverty, SDG 5 - gender equality, SDG 8 - decent work and economic growth, SDG 12 - responsible consumption and production, SDG 13 - climate action, SDG 14 - life below water, and SDG15 - life on land. Thus, the nexus approach has become crucial policy alternatives and planning tools to improve intersectoral interactions and resource management possibilities (Lazaro et al., 2021). Still, on the challenging Agenda 2030, the institutionalization of the nexus thinking must occur from high-level political forums, easing the cross-sectoral and multi-level understanding about trade-offs mitigation and possibilities of synergies. This process must encompass varied social actors, representatives from different sectors and from lower organizational levels, making connections and alternatives from bottom-up processes possible (Boas et al., 2016).

The essential transversality of the nexus requires innovations and reconnections between subsystems that are inevitably dependent on external resources. From this perspective, cities are vital analytical cut-offs for applying the nexus thinking when considering their magnitude of demands. The conception of urban nexus can be a pathway for reconnecting urban sustainability through synergies between the resources that mostly come from outside. As for this, Artioli et al. (2017) propose three hypotheses for urban policies and actions to integrate the nexus. The first one deals with cross-sectoral integration as a possibility of incorporating the nexus into urban management, which can occur through collective actors advocating for resource management, efficiency and distribution. The second one refers to the possibilities of reorganizing relations between the State and private capital in urban governance, counterbalancing risks that the search for efficiency may be reduced to a neoliberal logic that simplifies its real potential. The third hypothesis considers the nexus operationalized by propositions of smart cities. Under this perspective, integrative properties of new technologies and digital participation can contribute to holistic relationships of interest to the convergence of different sectors.

The nexus thinking must be studied and managed through systemic and collaborative approaches (Pahl-Wostl, 2019; Wahl et al., 2021). Thus, socio-political dimensions of the nexus must be seen as very relevant to avoid the reductionism of technical and managerial directives (Artioli et al., 2017; Cairns & Krzywoszynska, 2016; Dalla Fontana et al., 2020). Considering these prerogatives, we argue that the nexus must be understood in the background of Social-Ecological Systems (SES), with self-organizing properties and complexity as fundamental characteristics. The current critical conditions associated with the realization of the Anthropocene makes sense for adopting SES by the recognition that environmental and social dimensions of sustainability are undeniably systemic and intertwined (Biggs et al., 2021).

In SES, the ways to cope with disturbances will be obligately plural and composed by the interaction of the diversity of capacities related to environmental conditionings, socio-political competencies, organizational skills, moral values and knowledge, technologies, infrastructure, and economic assets (Folke et al., 2010; Walker et al., 2004). The range and capacity to adapt to disturbances, the resilience to maintaining integrity, or the disruption of transformability of SES can be explored or enhanced through narratives. On the relevance of exploring depth, diversity, and the breadth of narratives on adaptive capacities of SES (Kay et al., 1999), we argue on the potential and relevance of qualitative and participatory research approaches.

Considering the challenging interdependencies on resource scarcities and complex systemic interactions, we aim to explore narratives on the water-energy food nexus considering social-ecological features through qualitative and participatory research approaches. For our analysis, socio-political attributes are focal. Thus, we explore the nexus starting from vulnerable urban communities and investigate the engagement of social actors' discourses in productive systems.

We analyze the experiences of two qualitative research approaches held in Brazil. That is a convenience sample based on recent research experiences of our group. It represents good insights and different possibilities for exploring nexus issues and searching for descriptive details and possibilities related to socio-political dimensions of a SES. Due to deep social inequities, environmental injustices, intense and unplanned urbanization, strong economic dependence on natural resources and conflicts involving ecosystem services, we consider that Brazil can provide compelling cases for exploring the challenges associated with the nexus (Daniel, 2020; Facchini et al., 2014; Nobre, 2010; Rajão et al., 2020; Rigotto & Augusto, 2007; Santos, 2013). To represent some of this diversity of situations and challenges, we will deal with two distinct situations: firstly, a study on the nexus in a vulnerable urban community; secondly, an investigation of the governance of the bioethanol production chain. We consider that the Brazilian context and respective contradictions on natural resources and demands for human development offer an exciting frame for exploring the nexus through qualitative approaches. However, we expect to promote discussions concerning contexts related to global challenges, contributing with cross-sector and multi-level understandings to broaden knowledge and to enable the search for synergies on the water-energy-food nexus.

This chapter is composed of this introduction and four other sections. The first and the second describe the research experience of the ResNexus project[3], carried out in a vulnerable urban community in Guarulhos city, Metropolitan Region of São Paulo. We explore in the first section an ethnographic approach within the urban nexus. In the second section, we describe applying a participatory research approach in the same project in Guarulhos. In the third section, we present applications and potentialities of discourse analysis on extensive textual data from different social actors, exploring the permeability of the nexus concerning governance in the Brazilian agro-industrial sector of bioethanol. In the fourth and final section, we discuss the importance of qualitative research as a component for the necessary democratization and hybridization of knowledge for boosting nexus transformations in SES.

2. Approaching the nexus in an urban vulnerable community

Guarulhos has around 1.2 million inhabitants, being the municipality with the second largest population in the State of São Paulo. Its urban area is conurbated with other municipalities of the Metropolitan Region of São Paulo; however, Guarulhos is bordered by an important preservation area of the Atlantic Rainforest in its northern portion. The study site was on this boundary, the Novo Recreio neighborhood, with characteristics of socio-environmental vulnerability, difficult access, poor urban transport, precarious public water supply, and lack of sewage collection.

A qualitative approach in Novo Recreio/Guarulhos constitutes the primary reference (Giatti et al., 2019) for understanding how the water-energy-food nexus can be understood from the perspective of scarcity and difficulty access to resources. The initial conception of the research is that despite vulnerabilities, the disadvantaged urban population creates and reproduces alternatives to dialogue with challenges, developing social practices and specific knowledge (Magnani, 2002; Nicolini, 2011; Schatzki, 2015). The research team proceeded with an urban ethnography through shadowing method by home visits, semi-structured interviews, direct observation and use of records in field notebooks, investigating social practices (Bartkowiak-Theron & Robyn Sappey, 2012; McDonald & Simpson, 2014). The investigation focused on synergies or contradictions in association with the interdependent scarcity of sectors of the nexus.

3 https://bv.fapesp.br/en/auxilios/92515/resilience-and-vulnerability-at-the-urban-nexus-of-food-water-energy-and-the-environment-resnexus/

Therefore, synergies constitute social practices that refer to meeting the local need for resources and mitigating trade-offs between water, energy, and food chains. For example, when the community's water supply was intermittent (day on, day off), the practice of storing rainwater for less noble purposes (such as washing clothes or flushing toilets) entailed a synergy. Also, with the potential to contribute to reducing trade-offs, it was found that several residents carried out the practice of collecting and selling recyclable materials to intermediaries. Likewise, even if in small quantities, food production in the community also indicates synergies since it optimizes resources required for cultivation, such as water and inputs (locally produced organic fertilizer).

Since the neighborhood was verified as a food desert, the acquisition of fresh and healthy food stood out as an essential element in the research. Thus, it was realized that the nexus thinking could contribute to both equate synergies and provide access to better quality food, while reducing the high consumption of ultra-processed food.

On the other hand, the need to travel outside the neighborhood to buy food represents a contradiction regarding the nexus, as individual transport is for the minority of the inhabitants and public transport is precarious. Moreover, it is assumed that transport represents one of the most significant demands for energy in the urban environment, thus making the burden of such practice associated with a trade-off with energy. Another contradiction identified within the nexus, i.e., exacerbation of trade-offs, is related to the theft of electricity and water. There were records of clandestine connections to access these resources in the neighborhood, a practice that relates to indiscriminate use and, generally, high waste of resources.

In comparison, a study using the same shadowing approach was conducted in Kampala, Uganda. In even more precarious and more impoverished urban communities where there is no access to water or energy at home, the nexus was also analyzed through social practices, including what it is concerned to general aspects of quality of life and nutrition. In the studied communities in Kampala, difficulties in access to water caused severe limitations and risks of contamination and the spread of diseases. Evidently, there were also difficulties to access food. However, accessing energy for cooking configured the central and strongly limiting issue. The predominant source of energy in homes was charcoal, whose scarcity can limit the practice of boiling water before consumption or, on the other hand, could favor the choice of foods with lower protein value because they were easier to cook – for example, choosing to cook bananas instead of beans (Mguni et al., 2020).

Considering the Guarulhos' case, an essential conclusion of the study is that synergies related to social practices in local contexts of vulnerability do not happen through reflections. Instead, the local mindsets focus on surviving, not necessarily connecting it with the nexus or global environmental crises, such as water resources scarcity, deforestation, and climate change. In part, this occurs within the constant search for subsistence and facing local difficulties by people in social and cognitive exclusion conditions – there is no correspondence and dialogue between popular knowledge and public administration or academic knowledge (Santos, 2007; Santos, 2009). With this, the authors identify the occurrence of a nexus of exclusion, which represents "an abysmal frontier that disconnects peripheral residents from sustainable and healthy choices and interaction with other organizational levels" (Giatti et al. 2019, p. 8).

Researching the nexus from poor urban communities allows us understand that there is a need to make connections among local social practices and a demand for appropriate alternatives in reducing trade-offs. However, the synergies that come from poor urban communities making a nexus through the access to resources cannot allow conceiving that the solutions are good enough just because of the self-organizing capacities of surviving. Actually, it is necessary to learn from and integrate such positive feedback into better and dynamic actions and public policies. For that, it is essential to overcome the lack of dialogue among local governments and vulnerable people.

3. Participatory Research for synergies

The ethnographic study reported in Guarulhos served as a facilitator for applying a participatory action research methodology - PAR[4] (Baum et al., 2006; Thiollent, 2011) on the promotion of synergies in the context of the water-energy-food nexus at the local level. The action targeted was based on the legitimate wishes of local social actors through the implementation of a community garden in the backyard of the municipal school located in the Novo Recreio neighborhood. Therefore, community members engaged with health issues, education professionals, and primary health care professionals were associated with researchers in the process of collaborative construction of agricultural knowledge, democratic planning of actions, and the necessary work to carry out this initiative (Honda, 2018).

4 In analogy, we consider PAR as an approach similar to ´pesquisa-ação´ (Portuguese), most known in the Brazilian tradition of Freirian participatory research methods (Thiollent, 2011).

The subjects were involved collaboratively through cycles of interactions fulfilled in workshops using participatory research tools, such as the river of life (Wallerstein et al., 2017) and the construction of talking maps (Toledo & Giatti, 2014). A workshop was also held with the application of the CBPR model, which consisted of a collaborative dialogue on the local context/ problems, possible partnerships and collaborations, implementation of joint actions and reflection on expected or intended results (Wallerstein & Duran, 2010). From the workshops, manual and cooperative work actions were planned and executed, as for the construction of flowerbeds, planting and care procedures for growing vegetables. In addition to local social actors, interactions were also promoted with municipal public managers from different municipal secretariats, for which workshops happened with the application of the world café (Fouché & Light, 2011).

Dialogical interactions provided by participatory research can aggregate several possibilities through the collaborative construction of alternatives to sustainability and health issues. Through them, it is possible to empower vulnerable communities, promote and strengthen partnerships, optimize resources, and enable hybrid and adaptive knowledge. Furthermore, it is also worth mentioning the potential of dialogue between local social actors and municipal government managers, who are usually active at other organizational levels. This approach is of great importance for building bridges between actors who often do not dialogue, and in the case, contributing to collaborative solutions legitimized in the communitarian ways of life, values and knowledge of vulnerable people (Giatti, 2019; Wallerstein et al., 2017). Within these perspectives, the community garden was implemented in one year and this was also made possible by the achievement of fundamental partnerships established through dialogue. For example, through interaction with local government managers and neighborhood traders, it was possible to acquire basic materials to construct flowerbeds for growing vegetables (Honda et al., 2021).

Identifying the importance of food by its association with the urban nexus in Novo Recreio allowed the recognition of the potentiality of food production on a local scale. Thus, the implementation of the community garden was understood as a possibility for various synergies regarding the nexus. This means, for example, optimizing the use of resources (water, energy, local inputs) for the production and local supply of fresh and healthy food. Furthermore, it is noteworthy that the participatory research approach has also expanded hybrid knowledge and dialogue horizons between the community and municipal managers. Indeed, the absence of dialogue prevails among distinct levels, and it also relates to the nexus of exclusion concept mentioned above. Therefore, participatory research approaches carried out in a multi-level process represent an important innovation to promote synergies within the nexus from communities to higher organizational levels. It can be worthy for integrating local initiatives and public policies through different territorial scales.

For Wahl et al. (2021) participatory approaches represent a small minority among studies on the urban nexus. Conversely, participation should be considered a vector for cross-level synergies regarding the nexus, as well as making it possible to establish and strengthen multi-level networks among communities, municipal agencies, authorities and others. A vital issue for nexus-oriented implementations in urban contexts is to integrate it into municipal strategies and plans. For this reason, there is relevance in making public staff learn from relationships with communities, propitiating legitimate pathways for integrating social actors from different levels, and making possible to engage adaptive alternatives from bottom-up flows. Participatory approaches are notably recognized by the potential of integrating different social actors in dialogical interactions, with the empowerment of the disadvantaged and with building of trust in more symmetrical relationships (Christopher et al., 2008; Wallerstein et al., 2017).

4. Discourses of social actors on production systems

As already mentioned regarding the multi-level nature of the nexus, it is also worth noting that it is necessary to seek researching alternatives which focus on the dialogue between social actors operating at higher organizational levels. In this sense, it is possible to investigate cross-sectoral interactions between official governmental discourses (such as from different ministries), media, non-governmental organizations (NGOs), and discourses produced from productive industrial sectors.

Every day humanity produces an enormous amount of data, which covers almost all areas of our activity. "Approximately 80% of electronic data is in text format. It has created a significant demand for new powerful tools to turn data into useful knowledge", to analyze the responses of stakeholders to certain issues, and mainly for the analysis of public policies (Lazaro et al., 2018).

For example, the study by Lazaro et al. (2020), explores the discourses of social actors - government, media, companies from the bioenergy sector, NGOs in order to show how these discourses influence policy and how the analysis of such narratives can improve our understanding of what interests, what are prioritized, and the themes that are neglected. The data corpus was of large amounts of textual data obtained from governmental and business documents, Brazilian newspapers, and the bulletins of non-governmental organizations over the last ten years. For examining it, it was combined an unsupervised probabilistic latent Dirichlet allocation (LDA) model with sentiment analysis.

The authors showed that the expansion of crops for ethanol production, even with several positive elements in GHG emission reduction, has been emptied from the debate of some concerns regarding the links and interdependencies between water resources, land use, food production and energy. One of the main findings of this study was the low interest in the water issues regarding other themes such as climate change, land use, energy and food. It is explained by the persistent narrative of the abundance of water in Brazil. As a matter of fact, the assumption of abundance of water, land and territory was convenient to support the growth and expansion of bioenergy and agribusiness. Within the dominant conception that water is an abundant resource, there has been an absence of awareness and inaction around water conservation and management. Thus, the nexus approach provides an innovative framework to analyze the synergies, trade-offs, and interrelations between sectors to transcend traditional sectorized governance in our natural resources.

In another example, Lazaro, Giatti & de Oliveira (2021) applied the latent Dirichlet allocation method to analyze extensive textual data of the sustainability reports of Brazil's largest bioenergy companies. The study demonstrates that, despite the company's efforts to minimize impacts, the bioenergy firmly neglects the nexus thinking in many aspects, such as in the interactions amid food security, water scarcity and working conditions. The study emphasizes that the nexus security and management should lie at the heart of the nexus approach. However, nowadays, decision-making is based on linear causalities, classical management theories of forecasting, planning, organizing, leading, and controlling. This way of managing no longer fits into the solutions required for our "wicked problems", which demand other alternatives, other ways of doing business and managing finite resources. According to the authors, the nexus approach can be used as a management and policy tool to offer real potential ways to address global change and modify development trajectories and outcomes, and the energy, water, land/soil, and food need to be looked at as a "system."

In another study, Lazaro et al. (2021), by mixing latent Dirichlet allocation algorithm with co-occurrence and network analyses, exam large scientific literature, documents and sustainability reports from sugarcane ethanol companies to build a qualitative model to analyze the water-energy-land-food nexus in ethanol production. This analysis contributes to understand how both scientific production and institutions are dealing with the complexity associated with sugarcane production within the nexus framework. The study also demonstrates the usefulness of the qualitative model in assessing the development, outlook, and progress of biofuels within the nexus by incorporating relevant influencing factors such as policy, governance, innovation, and labor. The main conclusion of this study is that a qualitative model can be used to evaluate the interfaces between science-policy and businesses within the biofuels nexus. The presented model was able to identify how to best integrate the development of policies, governance, and stakeholder actions to support cost-effective decisions for optimal resource management and regulatory processes while enabling better integration of scientific insight and policy-making.

5. Hybrid knowledge and nexus transformations in SES

By definition and evolution of concepts, SES are understood through its composition involving human and ecological inseparable dynamics. SES can assume six key features of Complex Adaptive Systems (CAS): "(1) CAS are constituted relationally; (2) CAS have adaptive capacities; (3) CAS behavior comes about as a result of dynamic processes; (4) CAS are radically open; (5) CAS are determined contextually; and (6) novel qualities emerge through complex causality" (Preiser et al., 2018).

From these features, it is possible to assume converging characteristics inherent to the search for coordination and governance within the water-energy-food nexus, as appointed by Pahl-Wostl (2019). Nexus governance can be built through self-organizing processes among social networks related to ecosystem services provision. Also, nexus governance is expected to make transcendence among sectors and scales – referring to the property of open systems. Thus, polycentric governance systems can balance necessary interactions through bottom-up and top-down flows within multi-level and through lateral (inter-sectoral) pathways. Also, nexus governance can benefit from adaptive capacities and inherent diversity of possible collaborative models that arise from integrating different framings and social learning processes and participatory management (Pahl-Wostl & Hare, 2004). Sustainability transformations cannot be achieved without interrelations among sectors; thus, systemic nexus analysis can make relevant contributions for optimizing the challenging search for the SDGs (Pahl-Wostl, 2019).

A diversity of methods can be applied to empirically study SES for the relevance of social actors associated with the provision of ecosystem services; an alternative can be applying network analysis and agent-based modeling. Also, some studies can focus on the dynamic interactions that constitute the complexities in relation of humans with the environment (Vos et al., 2019). Regarding the qualitative studies presented in this paper, the ethnographic and participatory approaches in the vulnerable urban community (Giatti, 2019; Giatti et al., 2019) corroborated to the understanding of dynamics of access and synergies among scarce resources. It helped to account for SES´ relational and context-dependent nature (Vos et al., 2019). On the other hand, the studies exploring extensive amounts of textual data for discourses on the biofuels industry (Lazaro et al., 2020; Lazaro, Giatti & de Oliveira, 2021; Lazaro et al., 2021) illustrate the possibility of verifying the permeability of nexus at a high organizational level, also contributing with systemic analysis and potentialities to address such intertwined issues of access the resources (Biggs et al., 2021; Preiser et al., 2018).

In the research in Guarulhos and in the case of bioethanol, we found ways of exploring narratives that are important to understand the dynamics of networks of actors' interactions concerning the nexus. With this, we argue on the pertinence of qualitative research for such challenging issues related to the search for sustainability. Both the ethnographic and the study of textual data allow relevant systems descriptions. Looking at these descriptions through nexus lenses allows us to understand about lack of integration among sectors or even the current opportunities to strengthen synergetic actions. For instance, in Guarulhos, many social practices provide learning from the local management of scarcity. Thus, it shows relevant possibilities to stimulate the local government´s cross-sectoral actions, like boosting local fresh and healthy food acquisition. Within studies on bioethanol production, the discourses exhibit a strong centrality in the association climate and energy among the companies (Lazaro, Giatti & de Oliveira, 2021). Identifying the fragmentation between sectors in the nexus, in this case, contributes to understanding relevant systemic information that can contribute to the planning of cross-sectoral actions.

However, given the desire for better governance of the nexus, we must assume that participatory approaches such as PAR and action research represent very relevant gains. The promotion of participatory processes is strongly recommended to broaden dialogues and interactions, in order to build polycentric governance structures. Furthermore, the interactions between different actors, the search for the construction of hybrid knowledge and the strengthening of new cooperation in the creation of alternatives diversity and changes constitute premises for transformations to sustainability (Scoones et al., 2018). Figure 1, from the study of Urbinatti et al. (2020), presents a model of layers conceived from the literature on nexus-oriented scientific and political decision-making interrelations. Following this model, the conventional knowledge application refers to a close down technocratic decision-making; knowledge integration brings the assumption that there must have general dialog between different sectors of science, policy and society; finally, knowledge transformation calls attention to a necessary opening up through co-creation of opportunities, integrated recognition of needs, and new collaborative (transformative and hybrid) knowledge.

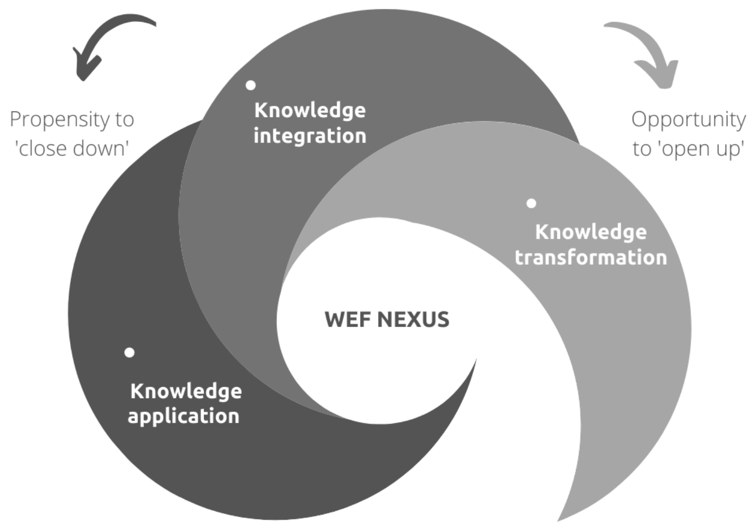

Figure 1. Layers of knowledge and science-policy interfaces on the nexus approach.
Source. (Urbinatti et al., 2020).

Participatory research is still a minority among the emerging research production on the nexus. However, its collaborative properties and hybridization of knowledge among sectors and different social actors strongly supports new social constructs, which can be appropriate to integrate social-ecological complexities (Wahl et al., 2021). Furthermore, it is essential to note the potential of participatory research approaches to stimulate the diversity of knowledge and actions. This property refers to the exercise of humility, making possible dialogical and broadening interactions in a cross-sectoral and multilevel sense, also corroborating more sophistication in governance structures (Giatti et al., 2021).

Analyzing the social participation in the research in Guarulhos, we identified that the research process promoted dialogue where at first there was an absence of interactions associated with exclusion and social vulnerability. Therefore, the application of the participatory process makes it possible to transcend the local level to innovate in the construction of dialogue with social actors at other organizational levels, such as municipal public managers. Indeed, participatory research has played a significant role in bridging different social actors and institutions to result in partnerships and better governance (Giatti, 2019; Wallerstein et al., 2017). These approaches and dialogues are precisely the possibilities of promoting opening up with hybridization and knowledge transformations to sustainability (Scoones et al., 2018; Urbinatti et al., 2020)

In conclusion, the nexus thinking corroborates very relevant aspects as a strategy for understanding and building alternatives aimed at the unsustainability dilemmas through the complexity of SES. In this sense, it is worth noting that qualitative approaches are fundamental contributions to the systemic understanding of the nexus within a perspective not only technocratic or reductionist in the search for efficiency among different sectors. In addition to the studies of systemic narratives, participatory approaches on the nexus should be encouraged to corroborate transformative and creative processes, new collaborations, reduction of asymmetries, and democratization of knowledge. Qualitative and participatory approaches are helpful to explore and to interact with social-ecological dimensions of the nexus; we consider from some Brazilian experiences, but also it can be applied to other contexts since such complexities are inherent to SES.

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CHAPTER 9

Forest security as a fourth dimension of the water-energy-food nexus: empirical evidence from the Brazilian Caatinga

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1. Introduction

The interplay among water, energy and food security (WEF-Nexus) is currently a mainstream framework to assess sustainability of human societies (Biggs et al., 2015). Recognizing, quantifying and understanding the tradeoffs and synergies among these securities poses a huge challenge for the development thinking (Albrecht, Crootof & Scott 2018). Although the WEF-Nexus framework is considered useful due to its parsimony, numerous attempts to add new dimensions to the three-dimensional classical approach have been made in recent years (Dargin, Daher & Mohtar, 2019). Special attention has been given to the natural ecosystems and resources underpinning the goods and services that compose the water, energy and food security (Cairns & Krzywoszynska, 2016). Here we will focus on a specific fourth dimension for the WEF-Nexus, forest security, which is the contribution of forest to support and maintain other securities (Melo et al., 2021).

Brazil holds 12.2% of the world's forests and 2.7% of the world's population (FAO, 2020; UN, 2019). This means that Brazil's per capita forest coverage is among the highest in the world (Crowther et al., 2015). However, Brazil has thus far largely failed to translate this forest coverage into sustainable development pathways (Barbosa, Alves & Grelle, 2021). Deforestation and habitat degradation remains a major problem for countries in the Global South (Hoang & Kanemoto, 2021). Forests are sources of multiple services and goods that human populations depend upon in both direct and indirect ways (Díaz et al., 2015). Most Brazilians now live in cities where economic activities are typically based on industrial and service sectors. Despite the ever-increasing detachment of urban populations from nature, the countryside produces water, food and energy for all. The UN decade on forest restoration is a geopolitical attempt to mainstream the role of forests and their restoration as key strategies for guaranteeing the delivery of ecosystem services.

Forests and their restoration can be directly or indirectly linked to the sustainable development goals - SDGs (Chazdon et al., 2020). Forest service represent key types of so-called nature-based solutions (NbS) due to benefits for humans whilst mitigating climate change. Some of the basic components of human well-being such as access to safe and sufficient amount of water, energy and food (i.e., WEF Nexus) are clearly linked to the ecosystem services provided by forests. For regions such as the Brazilian Caatinga, where its 28 million people inhabitants are mostly dependent on its goods and services (Silva & Barbosa, 2017), understanding and quantifying this forest-dependency is crucial in order to develop strategies for socioeconomic development of forest-dwellers while meeting environmental conservation goals. Assessing forest dependency, however, is not a simple task and demands innovative frameworks and methods that explicitly identify how human and environmental features of the social-ecological systems are interconnected.

Forest dependency of people reflects complex, dynamic social and economic processes including community organization, migration flows and the strength of particular economic sectors, for example (Nerfa, Rhemtulla, & Zerriffi, 2020; Newton et al., 2016). On one hand, strong and direct dependency on forest services is more common among indigenous groups and rural forest-dwellers. Conversely, forest-proximate urban populations are often only indirectly dependent on forest services, and mainly for provisioning services (e.g., water) and cultural services (e.g., recreation). Yet, in between these two categories, there are virtually infinite combinations of types and intensities of forest dependencies that might demand specific management strategies in order to achieve sustainable development objectives (e.g., ecological sustainability, or gender equity). The climate crisis poses a major challenge to heavily affected regions such as the Brazilian Caatinga (particularly by drought) where poor rural populations depend on varying grades of 'benefits from nature' (e.g., woodfuel, game meat, building materials).

Assessing large-scale patterns of forest dependency by humans is nearly impossible in experimental terms. Existing attempts focus on measuring forest-proximate people although proximity is not synonymous with dependency (Newton et al., 2020). Nonetheless, analysis which combines secondary census data and socioeconomic indicators with large-scale environmental monitoring can help elucidate relationships between people and forests. One important but somewhat elusive focus of sustainability research has been scrutinizing the relationship between poverty and environmental conditions (Djoudi et al., 2015; Shepherd, Warner & Hogarth, 2020). The development literature has often associated forest-dwelling with poverty as rural marginalized communities usually lack the necessary capital to rapidly transform landscapes from forest-covered to mainly agricultural (Eriksson et al., 2021). The association between forest-dwelling and poverty, although not causal, can lead to the erroneous notion that development requires deforestation and that proliferation of agricultural land-uses necessarily improve peoples' lives and livelihoods. The pitfalls of this assumption have been shown in many studies that documented the failure of the "business as usual" models of development that generates degradation of natural capital without any, but momentary, improvements in human livelihoods (Rodrigues et al., 2009; Weinhold, Reis, & Vale, 2015). Or, where environmental degradation may perpetuate low incomes (Garrett et al., 2017), or benefit some people yet deepen inequalities (Weinhold, Killick & Reis, 2013).

This chapter examines these questions of deforestation, degradation and development in the Brazilian Caatinga, one of the country's poorest regions which still retains nearly half of its original forest cover. Classical paradigms of frontier development usually (erroneously) associate deforestation with improved human livelihoods and hence reflect the idea that intact forests represent a barrier to progress. Development pathways seeking to replace forest with farmland is based on assumptions that forest-dwellers will either benefit from deforestation-related land-use change and economic growth, or that they are too irrational to take advantage of new (often urban) opportunities and hence are undeserving of further attention. Yet, there is plenty of evidence that any livelihood benefits from deforestation, when they exist, are ephemeral and tend to fade out as long as deforestation advances towards critical levels and resource depletion prompts out-migration to other, emerging deforestation frontiers (López-Carr & Burgdorfer, 2013). This phenomenon, known as "boom and bust", or the rapid rise and fall of socioeconomic indexes related to deforestation dynamics has been successfully described for the municipalities of the Amazonian "arc of deforestation" (Rodrigues et al., 2009; but see Weinhold, Reis, & Vale, 2015). However, the Caatinga tropical dry forest holds important differences with respect to Amazonia and other tropical forests where land use changes have tended to occur rapidly in recent decades. The Caatinga region has a semi-arid climate, is densely populated and deforestation in the last 30 years has been much slower (mean = 4000km^2 per year) than rates registered for the Amazon (mean = 18000km^2 per year), for example (MapBiomas, 2020).

The role of forests in supporting livelihoods and alleviating poverty via WEF nexus was recently conceptualized as forest security (Melo et al., 2021). Forest security could be a fourth dimension of the WEF nexus that provides the necessary ecosystem functions and services that supports water, energy and food securities which, in turn, are fundamental to maintain livelihoods. In this piece we used different datasets from the Caatinga to test if, and how, water, energy and food securities may be dependent on natural vegetation. We present data that demonstrates how water security is dependent on protection of permanent protected areas (APP, in Brazil) such as riverine vegetation and springs. We also show that natural vegetation has an important role for supporting food security in the Caatinga due to its widespread use as rangelands for livestock. Additionally, we show that the Caatinga's rural population (known as Caatingueiros1) and diverse small-scale industries use forest biomass as affordable sources of energy. Here, we provide empirical evidence supporting this concept and conclude this work by discussing the urgency to update the Nexus framework if we are to meet the UN's Sustainable Development Goals.

2. Forest for water

Water scarcity or the degree of variation in precipitation are the main traits for characterizing dry forest around the world and the Caatinga dry forest follows this rule (Pennington, Lavin & Oliveira-Filho, 2009; Silva, Leal & Tabarelli, 2017). But, despite its importance, understanding the role of forests for water-related ecosystem services is a difficult task. The Caatinga is a seasonally tropical dry forest that is not often associated with abundance of water resources. However, water scarcity is a social-ecological phenomenon that has caused massive human out-migrations in the region. The association between human livelihoods, forest cover and water security in the Caatinga is complex and tightly linked to the fate of this social-ecosystem. Level of forest cover is associated with evapotranspiration, runoff, quality and quantity of water in a system (Perkins et al., 2014; Rodriguez et al., 2020). In the Caatinga, up to 88% of the water from precipitation is evaporated and only a small proportion is left for runoff or stock (Andrade et al., 2017).

In order to better understand the role of forests and socioeconomic conditions to the water security in Caatinga, we developed a measure of water insecurity based on the analyses of 39 variables related to water consumption, water availability and both natural and socioeconomic variables (unpublished data). After a principal component analysis (PCA) we ended up with nine dimensions that further composed our composite water insecurity measure (hereafter, WII). We followed the same methodology used to build the well-established Social Vulnerability Index (Cutter, Boruff & Shirley, 2003) which was later applied in Brazilian municipalities by Hummell, Cutter and Emrich (2016). Describing in detail each dimension of this measure is beyond the scope of this book chapter, however, we briefly present how each of the nine dimensions of our index varied among Brazilian states based on the scores obtained from all municipalities in the Caatinga (Figure 1). Noticeably, there is a strong variation across all nine dimensions among states. States such as Alagoas and Pernambuco (AL and PE, respectively) performed badly in seven out of nine dimensions, exhibiting high insecurity values for diverse types of dimensions, natural to socioeconomic variables (Figure 1). On the other hand, one of the poorest states of the region, Piaui (PI), despite performing below the average for human capital, municipal governance and non-industrial water uses, has a good performance for forest protection (i.e., high forest cover), low drought exposure and high spring protection.

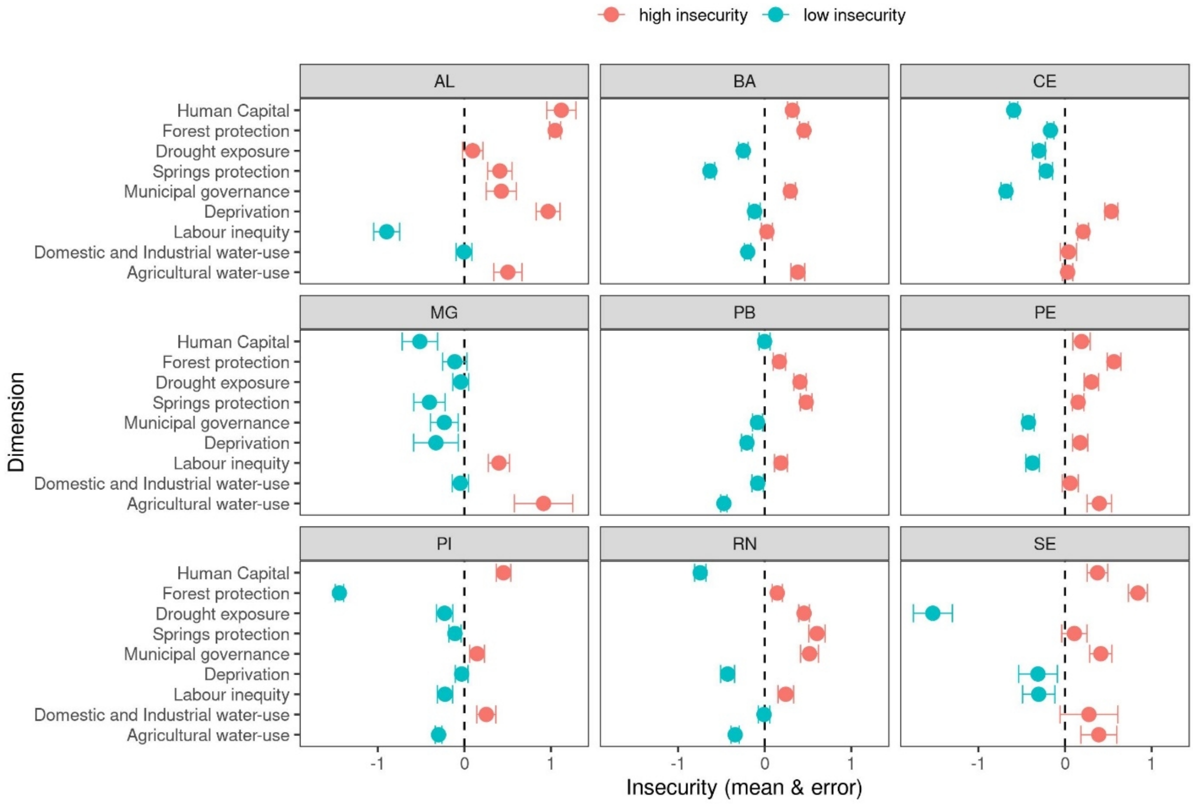

Figure 1. Dimensions of water security index (WII) of Caatinga municipalities grouped by state (average and standard error). Values are z-transformed to zero means and when needed, some dimensions were flipped to express higher values as shortcomings. Two-letter codes refer to Brazilian States with Caatinga biome. AL - Alagoas, BA - Bahia, CE - Ceará, MG - Minas Gerais, PB - Paraíba, PE - Pernambuco, PI - Piauí, RN - Rio Grande do Norte and SE - Sergipe

Source. Elaborated by the authors.

Our analyses suggest that we can approach water insecurity from a broad perspective that goes beyond the supply-demand chain of water. Each of the nine dimensions is composed of several other correlated variables that help us understand water insecurity as more than a natural phenomenon, but instead reflects the interplay between natural and socioeconomic factors. The dimensions are ordered by their importance (i.e., amount of variance explained) top-down in Figure 1. Briefly, the first dimension, named 'human capital', contributes 10% of the total variance and is composed of employment and education variables. Forest protection explained 7% of the variance and denoted the inverse correlation between deforestation and blue water resources. Drought exposure was correlated with the number of water cisterns per municipality and comprised the third dimension (5% of total variance). All other dimensions were retained because they presented eigenvalues > 1 and contributed to variance with values from 4.5 – 4%. Altogether, these nine dimensions summed up to 52% of the variance contained in 39 variables, highlighting that water insecurity is a complex social-ecological phenomenon. Water insecurity reflects not only limitations in the availability (i.e., supply) of this resource but on both social and economic constraints which affect people's access to water.

3. Forest for food

The double burden of malnutrition (i.e., co-existence of undernutrition along with overweight, obesity or diet-related non-communicable diseases, within individuals, households and populations) affects more than 2 billion people worldwide (WHO, 2017) despite the high global food production (Campi, Dueñas & Fagiolo, 2021; Hazell & Wood, 2008). Limitations in access to sufficient, affordable, nutritious food due to poverty and inequality is now regarded as the major determinant of food insecurity (Barrett, 2010; Leach et al., 2020; O'Hara & Toussaint, 2021). Access constraints to food affects the poor more directly, either in urban or rural areas (Castañeda et al., 2018; Klassen & Murphy, 2020). However, in rural areas in particular, equitable access to forest resources for food and income can be crucial in tackling hunger, malnutrition and even poverty (Angelsen et al., 2014; Nascimento et al., 2013; Rasmussen et al., 2020).

In the Caatinga and other dry forests, natural resources such as timber or woodfuel are often used as a source of income (Albuquerque et al., 2017; Angelsen & Dokken, 2018), including during and after shocks (Angelsen & Dokken, 2018; Fisher, Chaudhury & McCusker, 2010). In other words, these natural resources are argued to provide safety nets or 'natural insurance' to rural people in times of greatest hardship. Dry forests can also be used as sources of food, either through edible plants products (Chamberlain, Darr, & Meinhold, 2020; Lins Neto, Peroni, & Albuquerque, 2010; Nascimento et al., 2013; Rasmussen et al., 2020) or bushmeat (Albuquerque et al., 2017; Alves, Gonçalves & Vieira, 2012; Barboza et al., 2016) potentially improving nutrition and well-being. However, a major role that forests provide to food security in drylands is through supporting food production.

3.1 Forests for food production

Forests contribute to food production in many ways, from indirect effects such as climatic regulation, to direct effects, as many forests act as rangelands for grazing livestock. Dry forests control ecosystem's water fluxes and regional water balance (Rodriguez et al., 2020), which are both fundamental to crop success and soil health (Giménez et al., 2020). Forests also support food production via improvement of overall water quality (Portillo-Quintero et al., 2015). For below ground water stocks, Perkins et al. (2014) show how forests improve the amount and the accessibility of water for irrigation in Drylands. Moreover, dry forests also store soil nutrients, which is tremendously important for the Caatinga farmers, since most of them are small-scale poor rural producers with limited access to high quality seed, chemical fertilizer or other inputs (Tabarelli et al., 2017).

Swidden agriculture has been practiced since the beginning of farming itself in different parts of the world (Kennard & Gholz, 2001; Stephens et al., 2019), and is commonplace in the Caatinga. This practice consists in felling a (traditionally) small patch of forest, sometimes a regenerating secondary forest, followed by low intensity burning of the organic material to clear space for planting and provide a rapid nutrient input to the soil. After several years of cultivation, the land is set aside for resting (i.e., a fallow phase of regrowth) until the next farming phase. Sufficiently-long fallow cycles allow the nutrient stock in the soil to recover (Fachin, Costa & Thomaz, 2021; Silva-Forsberg & Fearnside, 1997) and also allows forest regeneration (Barros et al., 2021; Montfort et al., 2021), which over the long run, surpasses more intense fallow systems in terms of field labor, local productivity and forest conservation (Jakovac et al., 2016; Metzger, 2002; Portillo-Quintero & Smith, 2018). Thus, proper forest management, as traditionally done, can put forests to work as a stock of soil nutrients which is often more accessible to poor smallholders than chemical fertilizers (Minten, Koru & Stifel, 2013; Nakano & Magezi, 2020).

3.2 Forests for goat raising

Dry forests also support food production by providing fodder for grazing livestock. In the Caatinga, the European colonization process began with cattle ranchers spreading across the region's larger rivers, where cattle ate mainly natural vegetation (Albuquerque et al., 2017; Silva & Barbosa, 2017). Nowadays, cattle are mostly raised in wetter, more productive areas of Caatinga, such as the Agreste (the Ecotone region across the Eastern border of Caatinga), based on pasture with exotic grasses. Goat production has replaced cattle in drier areas given their superior resistance and adaptability. In so doing, raising goats became the main economic strategy for poor smallholders in drier areas of Caatinga and during extreme drought events (Melo, 2017; Silva & Barbosa, 2017). Because goats are raised extensively using the Caatinga vegetation as natural pasture and play an important role in Caatinga livelihoods, the relationship between forest conservation and goats in the region is receiving increasing attention from researchers (Jamelli, Bernard & Melo, 2021; Melo, 2017; Menezes et al., 2020; Schulz et al., 2018).

To assess the potential role of Caatinga forest in supporting food security (at least for meat, which is also sold by smallholders to buy other household essentials), we combined data of forest cover (we combined all natural areas as "forest" cover since different types of native vegetation cover are used by local people) from Mapbiomas collection 5.0 (MapBiomas, 2020) with municipality-scale goat and cattle production data from official surveys (IBGE, 2020). We also incorporate a drought exposure index (unpublished data - see forest for water topic) into this analysis in order to control the potential influence of local precipitation patterns. We did this analysis at municipality scale, because Brazilian official data is generally aggregated at this level, and it is the lowest administrative unit of Brazil. Given that governance in Brazil is heavily decentralized, municipalities are therefore vital for implementing social and environmental policies. We performed a Spearman's correlation between variables to understand the relationships between forest cover and goat and cattle production.

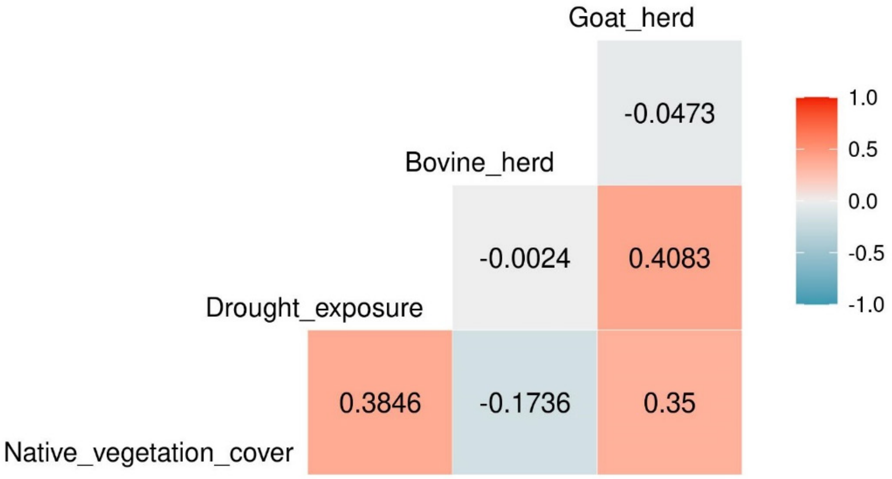

Figure 2. Spearman correlation analysis. More intense colors indicate higher correlation levels. All correlations were statistically significant ($p < 0.05$), except for drought exposure and cattle herd, and between cattle and goat herd.

Source. Elaborated by the authors.

Our results show a clear spatial pattern in forest cover distribution and drought exposure; wetter areas with lower drought exposure are generally more deforested (Figure 2). This is evident in the eastern Caatinga, for example, where there is an arc of deforestation (Figure 3a). Conversely, deforestation appears less advanced in the most drought-prone places, implying that drought risk in these areas constrains agricultural activities. Cattle production is also negatively correlated with forest cover (Figure 2), with some hotspots of cattle production overlapping with focal areas of deforestation (Figure 3a and 3c). However, goat herd size was positively correlated with forest cover and with drought exposure (Figure 2). Examples include the extremely dry central part of the Caatinga and in high-forest cover states such as Piauí (PI in Figure 3a) and the center-north of Rio Grande do Norte (RN in Figure 3a).

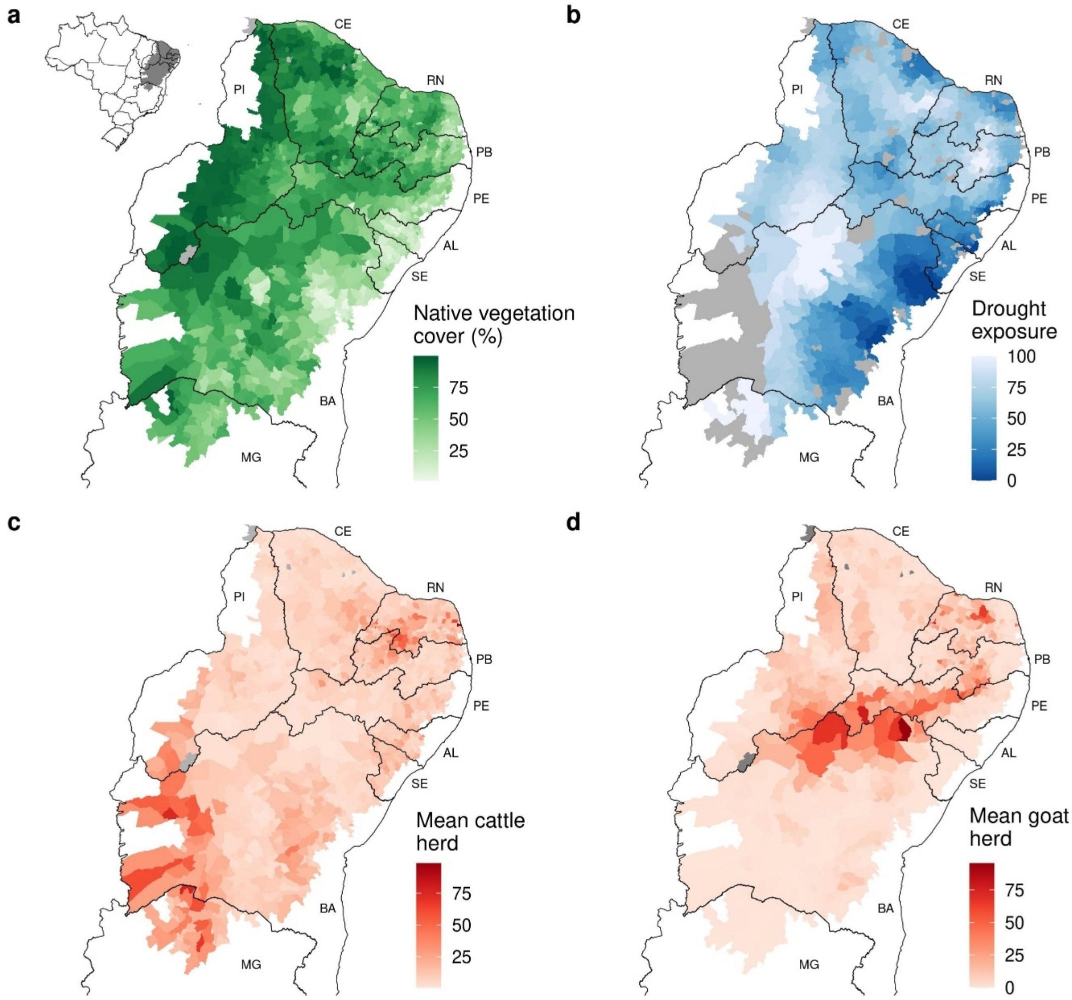

Figure 3. Maps of Caatinga's municipalities of a) Native vegetation cover; b) drought exposure index; c) mean cattle herd per rural property and d) mean goat herd per rural property. Acronyms refer to the Brazilian states that have Caatinga in their territory; PI - Piauí, CE - Ceará, RN - Rio Grande do Norte, PB - Paraíba, PE - Pernambuco, AL - Alagoas, SE - Sergipe, BA - Bahia, MG - Minas Gerais.

Source. Elaborated by the authors.

In drier parts of the Caatinga, goat-raising emerges as an economically and ecologically viable alternative to cattle. As goats are well-adapted to arid climates, Caatingueiros in drier areas prefer this type of livestock. Because goats can forage in native vegetation deforestation is avoided given the other benefits this tree cover provides to rural people (e.g., woodfuel). This explains the correlation we found between drought, goats and native vegetation.

In Caatinga, goat raising using native vegetation as fodder is not only a source of food, but this system enhances food security, since goats are source of income (e.g., by selling to urban consumers), relatively affordable to poorer non-farming households, nutritious, and culturally preferred. Thus, in Caatinga, ensuring long-term, equitable access to forests (i.e., our understanding of forest security, see Melo et al. 2021) has an important role not only for food security, but also for the broader resilience of the rural poor, including (probably) their capacity to cope with and recover from drought.

4. Forest for energy

Partly due to widespread poverty, many Caatingueiros utilize forest resources in order to meet their daily needs, as shown by the aforementioned examples of water and food access. However, the energy resources supplied by forests are explored not only by people, but also by many industries, including brick factories and plaster production (Antongiovanni et al., 2020). Forest biomass that is used for energy can be both in the form of firewood or charcoal and, therefore, has an intrinsic relation with forest degradation but at the same time with energy security.

The wood removal associated with firewood consumption is linked to socioeconomic factors and, as the poverty levels in Caatinga is among Brazil's highest, consumption per capita of biomass can reach around 8 kg per day (Gonçalves et al., 2021). Domestic consumption of firewood is more selective because people search for species that are both abundant and with high calorific content (i.e., denser wood). These characteristics pose higher pressure on abundant hard-wood species, therefore, the impacts of fuelwood gathering tends to be stronger around human settlements (Gonçalves, Medeiros & Albuquerque, 2021). The chronic disturbance associated with wood gathering can alter ecological functioning and biodiversity (Gonçalves, Medeiros & Albuquerque, 2021; Sfair et al., 2018; Silva et al., 2020). At industrial scales, the relationship is different and possibly more aggressive. Industrial annual consumption of firewood in the Northeast region is estimated to be 20 to 30 million cubic meters of firewood (Pareyn, Vieira, & Gariglio, 2015). Moreover, the federal environment ministry considers that the pressure from plaster and brick-making industries are the main causes of deforestation in the Caatinga (MMA, 2010).

There are clear threats from the over-exploitation of forest resources as energy for biodiversity and ecosystem functioning. However, if the energy dependency from forest resources is high as we think, strong interventions to reduce deforestation such as command and control policies (linking satellite monitoring with on-the-ground enforcement) or creation of protected areas would be deemed to fail and likely to increase poverty and social conflict. Alternatively, community forest management and restoration for energy security would be better strategies for aligning the use of forest as an energy source with lower biodiversity loss and ecosystem degradation.

In order to clarify the energy dependency in the Caatinga region from removing and burning natural vegetation, we used data from IBGE survey on plant extraction and silviculture (IBGE, 2019) related to charcoal and firewood production and data of native vegetation cover from Mapbiomas (MapBiomas, 2020) at municipal scales. We found a positive linear correlation between native vegetation cover and charcoal production (t-value = 4.531 and p-value = 6.87e-06) (Figure 4a) and a positive quadratic correlation with

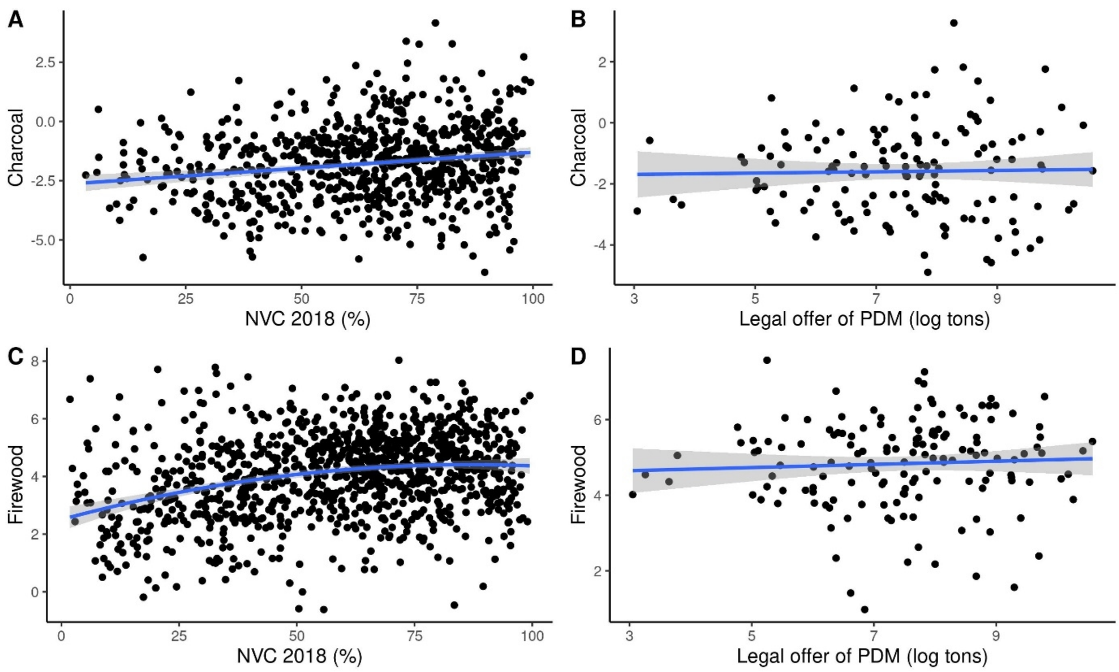

Figure 4. Charcoal and Firewood production in Caatinga and its relation with native vegetation cover and legal offer of plant dry matter. Charcoal, Firewood and Legal offer of PDM are in Log scale. NVC - Native Vegetation Cover; PDM - Plant Dry Matter.

Source. Elaborated by the authors.

firewood production (single term: t-value = 2.528 and p-value = 0.0117; quadratic term: t-value = -1.992 and p-value = 0.0467) (Figure 4c). We also checked whether these positive correlations were related or not to company-controlled forest management areas. Accordingly, we gathered data from the Northeastern Center of Plants Information (CNIP) and compared the production of charcoal and firewood against the legal offer of plant dry matter, but we found no correlation among them (Figures 4b and 4d). Thus, the positive correlations could indicate the dependency on native vegetation for household consumption but also to industrial proposes, revealing the importance of native vegetation for energy security in the Caatinga.

There is a clear trade-off between forest and energy securities. However, if forests are properly managed, this trade-off can be converted into a synergy, where higher forest cover contributes to greater energy security. In the Caatinga, this synergy seems to be true at the present time, since colonization of the region is old and places with low forest cover were deforested to raise cattle, not due to energy production. Furthermore, energy based on native biomass is relatively cheap and changing to other energy sources might be too costly to be implemented in the short-term, especially for poor regions like the Caatinga. Yet, we cannot ignore the amount of wood extracted to fuel the plaster and ceramic industries in Caatinga. Therefore, to improve and maintain this synergy, we should encourage good forest management practices such as exploitation of exotic species Propospis juliflora whose stands currently cover more than 1 million hectares of abandoned pastures in the Caatinga (de Souza Nascimento et al., 2014).

5. Forest security in Caatinga

The Nexus approach is seen by some as a step towards achieving the sustainable development goals (van Noordwijk et al., 2018). However, significant improvements have been made to the original framework proposed during the 2011 Bonn Conference, mostly adding new dimensions (Araujo et al., 2019) or clarifying trade-offs and synergies among the original ones namely water, energy and food (Bizikova et al., 2013). Emphasis on resource management and the recognition that natural systems support the WEF securities has gained increased attention for several reasons. One of the most important is the popularization of the concept of nature's contributions to people - NCP (Dean et al., 2021; Díaz et al., 2018) that recognizes monetary, non-monetary and regulatory contributions as baselines for the good functioning of the coupled human-natural systems.

The Caatinga region is a promising laboratory for assessing human dependencies on goods and services provided by natural ecosystems (Melo, 2017). In this chapter we have shown that the Caatinga dry forest has a prominent role in supporting water, energy and forest security. Caatingueiros rely heavily on forest services to meet their daily needs and to carry out traditional ways of life such as pastoralism (Albuquerque et al., 2017; Antongiovanni et al., 2020). However, this dependence varies greatly regarding accessibility to water, energy and food. Water security depends strongly on socioeconomic features that reflect structures of power and governance of water resources. Demonstrating this complex interplay between natural and social domains, we found that human capital, forest protection and drought exposure are the three most important contributors to multi-dimensional water insecurity. Overall, water insecurity is more severe in municipalities with lower forest cover, high drought exposure and under-development (proxied with measures of health, education and employment).

Food is perhaps an extremely important security dimension which is directly related to the state of Caatinga ecosystems. The natural characteristics of a seasonally dry tropical forest allow people to practice pastoralism as one of the main land uses (Briske et al., 2020). We show, however, that not all types of livestock coexist with Caatinga vegetation. While goat herd size is positively correlated with municipal forest cover, larger cattle herds are associated with deforestation. Although people can raise cattle in extensive ways, these animals require more management and supplementary feeding (during the dry season) than local breeds of goats which are strongly adapted to dry conditions (Silva & Barbosa, 2017). Pastoralism is an ancient practice that helps to feed 0.5-1 billion people around the world and is tightly linked to cultural aspects of diverse regions worldwide. It is estimated that extensive pastoralism in rangelands provides all kinds of nature contributions to people, creates and maintains habitats that are part of people's cultural identities (Dean et al., 2021). Its ecological impacts are linked to the management practices that can either be positive or negative depending on the carrying capacity of the natural environment (Jamelli, Bernard & Melo, 2021; Menezes et al., 2020). Goats are part of the cultural landscape of the Caatinga and of household economies, creating both material and immaterial benefits from nature and environmental regulation NCP (e.g., of water cycles) (Bragagnolo et al., 2017). Of course, other food systems in the Caatinga (e.g., main crops like corn and bean) must be carefully analyzed to provide deeper insight into the food security's linkages with natural processes. However, the role of livestock – especially goats – is of particular interest as this exotic domesticated species apparently can coexist with natural vegetation and contribute to food sovereignty for the inhabitants of the Caatinga.

Energy security is probably the most problematic aspect of the WEF-Nexus for the Caatinga because of the strong dependence of the 28 million people living within its boundaries. Considering that forest biomass is an important source of energy for both domestic and industrial sectors, attending to the demands for firewood and charcoal can affect other securities that depend on nature. Firewood and charcoal production appear quite reliant on illegal logging given the positive correlation between forest cover and production of biomass for energy does not hold when data are analyzed using legally authorized management plans. This is unsurprising considering that the Caatinga ecosystem has been considered of low value for environmental conservation even by researchers who neglected its importance for decades (Leal et al., 2005). The limited aptitude of this region for agribusiness makes its vegetation one of the few sources of monetary income for landowners that explore its biomass for firewood and charcoal when no other economic alternative is available (Sampaio et al., 2017). Land abandonment due to both environmental and socioeconomic constraints can also help to reduce land claims and allow forest regeneration (Sobrinho et al., 2016). Altogether, promoting energy security for the Caatinga's diverse peoples requires recognition that degradation does not result from domestic wood consumption but instead from large-scale firewood and charcoal production. The commodity supply chain of wood for industrial activities is poorly known and demands further scrutiny.

6. Conclusions

We have used multiple forms of evidence to show that the Caatinga's natural vegetation plays a pivotal role in supporting WEF securities. This strongly supports our recent conceptual argument that an updated Nexus framework, which includes forests as a fourth dimension, is not only reasonable but urgent if we are to recognize and value NCP when pursuing the United Nations sustainable development goals - SDG (Melo et al., 2021). Brazilian society experiences contradictory relationships with its natural environment since an important portion of the population lives in the domains of the vanishing Atlantic Forest, whose NCP although limited, can be perceived, principally regarding protection of water resources (Pires et al., 2017). Other biomes such as the Caatinga and Amazonia are inhabited by tens of millions of people whose traditional ways of life depend upon the existence of the forest, both directly and indirectly (Torres et al., 2016). Across these regions, basic food, energy and water securities are linked to natural vegetation services that help to sustain local economies mostly based on agriculture extractivism and services. The case of the Caatinga is even more emblematic as the natural ecosystem provides not only goods and services but a strong cultural identity for local inhabitants (Albuquerque et al., 2017; Bragagnolo et al., 2017). The linkages among WEF securities and forests must therefore be studied in more detail and made clear to the political arena where decisions take place. The Caatinga vegetation is a vital source of well-being and must be treated (as any other natural environment) as a main, foundational dimension of the WEF-Nexus. We therefore refer to the WEFF-Nexus, where the extra “F" letter relates to forest security for people.

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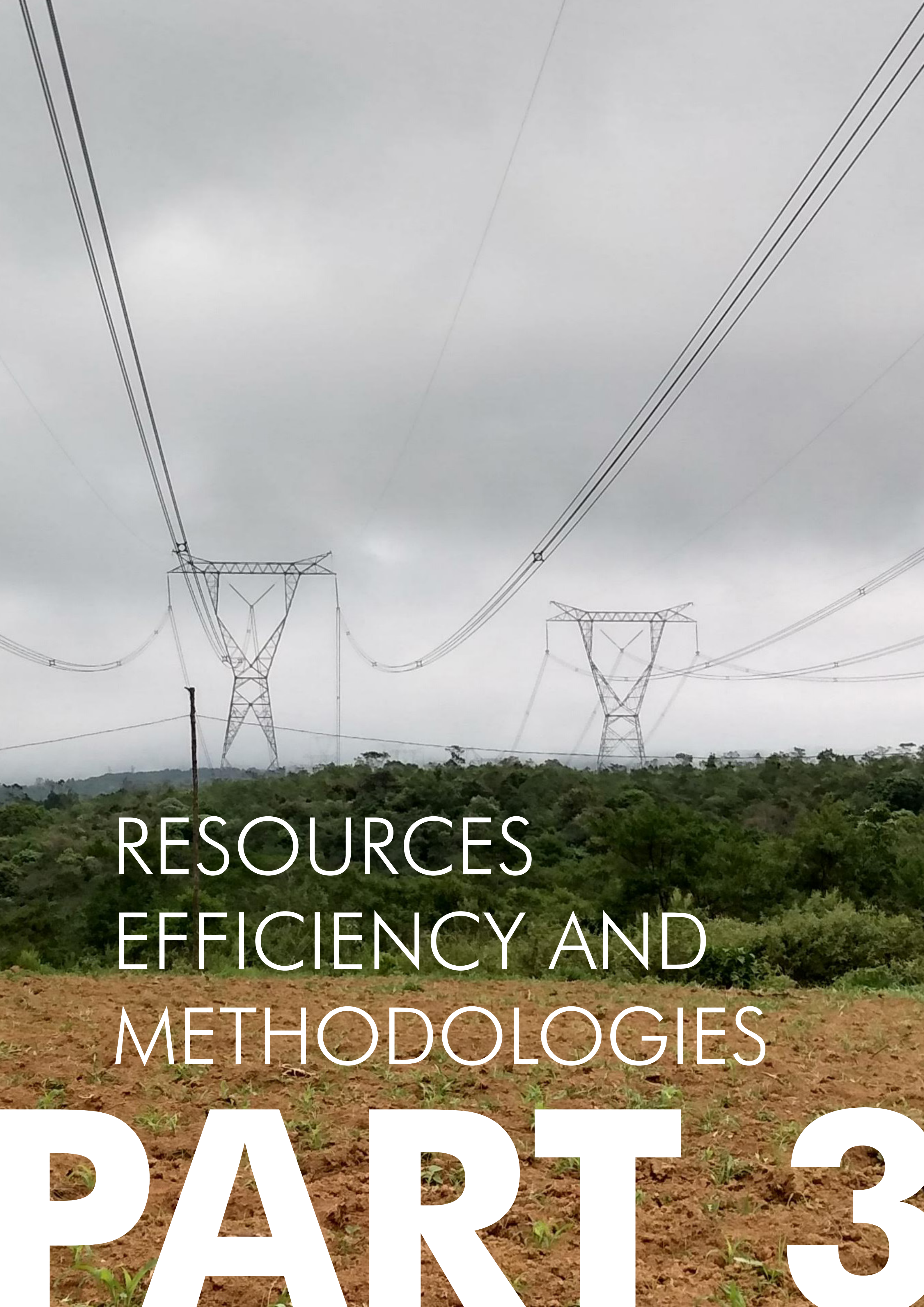

RESOURCES EFFICIENCY AND METHODOLOGIES

PART 3

CHAPTER 10

Nexus Pampa: the NEXUS-MESMIS approach applied at watershed scale

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1. Introduction

The development of techniques allowing the maximization of food production, water preservation, and power generation is nearly always conflictive and divergent. The lack of consensus on this topic stems from the approaches that only focus on a single element, without considering the need for combined values and a medium-to-long-term vision. Owing to this, these efforts (for preservation and development) are organized in an antagonistic way, competing for the exploitation of resources. This lack of balance generates degradation, rural poverty and exacerbates the further encroachment of even more fragile areas. For instance, it is important to understand and seek integrated solutions by recognizing the interdependencies between water, energy, and food resources as their scarcity poses health problems (Giatti et al., 2019). The success of a given society or community depends fundamentally on their ability to manage local natural resources in such a way that they can generate sustainable prosperity. Agricultural development projects seek alternatives to maximize food production. However, it is essential for water management and energy production to be integrated while taking the local conditions into account. It is challenging to be able to integrate these three elements (water, energy, and food) considering the social and environmental impacts. Thus, there is an urgent need for comprehensive research to achieve success in this domain. Although the idea behind the Nexus approach is being widely accepted, there is no holistic understanding of the proposed integration (Zhang et al., 2019).

The Pampa Biome, in Brazil, represents a very old set of ecosystems with their own flora/fauna and great biodiversity. The biome stands out with an immense cultural heritage associated with biodiversity that represents natural, genetic, and cultural heritage of the national and the international importance. The Pampa Biome also houses the largest part of the Guarani aquifer. Moreover, the Ibirapuitã River watershed, which is the focus of this project (Figure 1), is a part of the Ibicuí River watershed in Brazil and the Uruguay River transnational watershed (Brazil, Argentina and Uruguay). The extensive livestock farming (beef cattle and sheep) on native pastures has been the main economic activity in the region since the Portuguese and Spanish colonization of the Americas. These processes not only led to substantial economic benefits, but also opened prospects for the conservation of grasslands and the development of a unique mestizo culture (one of the transnational characteristics, represented by the figure of the so called "gaucho").

Global economic dynamics imply a constant need for the increased production and productivity in order to meet internal and external demands. Due to this, the expansion of agricultural areas and intensification of agricultural activities are widespread. The progressive introduction and expansion of monocultures (mainly soybeans) alongside with exotic pasture species have led to a rapid degradation and adulteration of the Pampa natural landscapes. Natural grasslands provide numerous services such as the regulation of water, provision of clean water, production of forage for livestock, prospects for outdoor recreation, and carbon storage in the soil. For instance, the regulating service provided by livestock systems is endangered and the increase in agricultural production directly threatens the quality and availability of water. This threat has already emerged in several regions of the world, where the process of the agricultural intensification has directly impacted the environment (especially the access to water) as well. At the same time, the availability of electricity in the countryside improves the quality of life (infrastructure and basic services, lighting, household appliances) and increases rural productivity, which

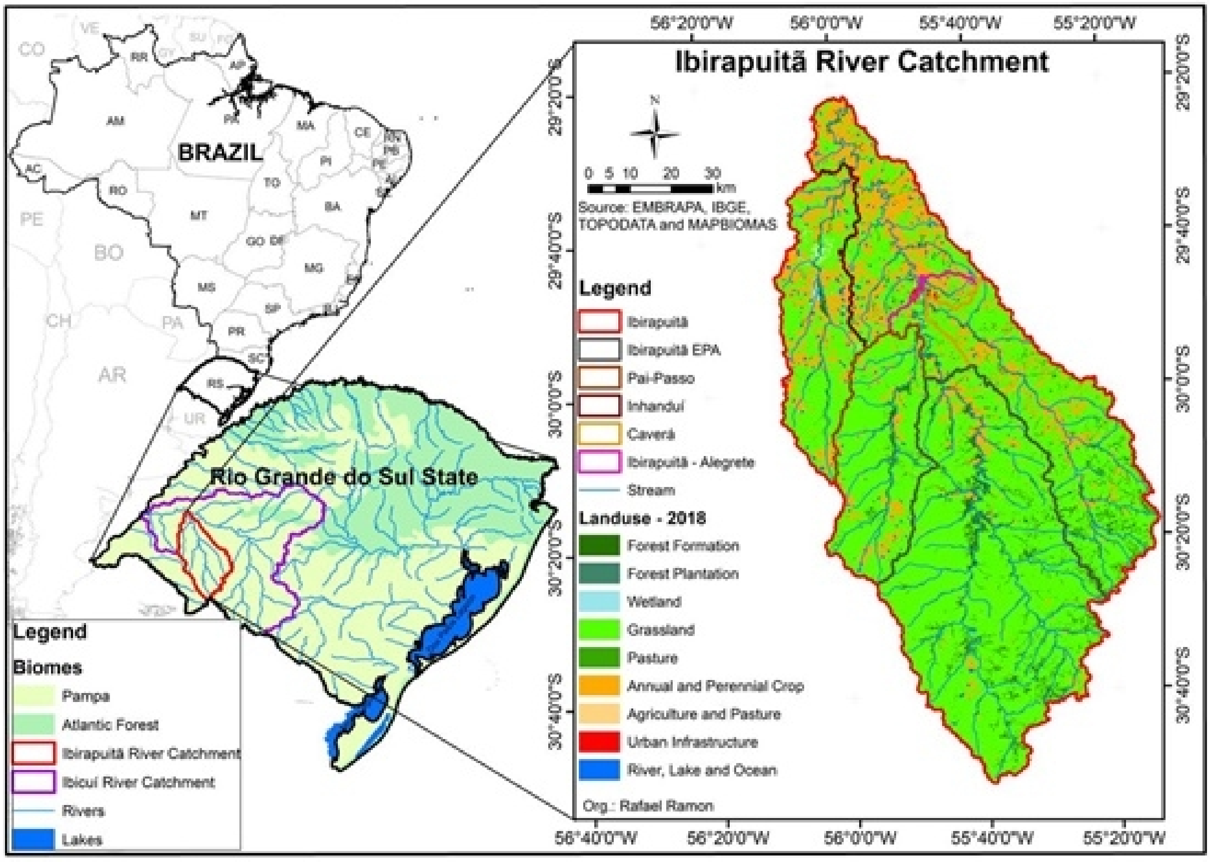

Figure 1. Study area of the Nexus Pampa project, Ibirapuitã River watershed.
Source. Elaborated by the authors.

improves the social and economic quality of local population. Three scenarios have been identified in the Ibirapuitã basin: (i) in the upper part of the basin, the livestock systems have been preserved, (ii) in the central area, there is a large urban agglomeration, while (iii) in the lower part, the land connected to livestock production was intensively used (mainly for crops).

The research efforts on the Nexus in the Brazilian context are inclined toward the trend of international research. In particular, there are mostly studies about such topics as "increased efficiency", "improved performance", "technological innovation", "optimized resource use", "assessed impacts" and "modeling future scenarios". The water-energy-food nexus has not been critically examined by researchers yet, while its benefits in the Brazilian context were not questioned but rather assumed in most existing documents (Dalla Fontana et al., 2020). The authors also emphasize this problem:

> *We conclude by calling for a greater engagement of social scientists in the development of transdisciplinary research on the NEXUS in Brazil. Indeed, the contribution of social scientists must go beyond reviews, critiques, re-conceptualizations and recommendations, including more empirical work from specific case studies in order to contribute to the development of alternative perspectives of the NEXUS. The participation of social scientists and local stakeholders in the development of transdisciplinary research studies may ensure that the human dimension of sustainability and local priorities are considered in the upcoming Brazilian research agenda on the Nexus. (Dalla Fontana et al., 2020, p. 179)*

In order to improve the approach, the Nexus Pampa project adopts the MESMIS methodology, which stems from a socio-environmental approach. The methodology implies the introduction of three main elements (taken as dimensions): water, energy, and food. This categorization allows defining areas and attributes that generate parameters expressing the social and environmental issues in each dimension. This chapter describes how this methodological approach was instrumentalized, given that both NEXUS and MESMIS are based on the systematic approach that facilitated the implementation of the NEXUS-MESMIS approach.

2. The MESMIS methodology and NEXUS

The research method Framework for Assessing Management Systems of Natural Resources Incorporating Sustainability Indicators – MESMIS was developed due to the necessity to create tools that can operationalize the concept of sustainability. MESMIS was initially introduced between 1994 and 1997, following a request from the Rockefeller Foundation to develop a method for assessing the socioeconomic and environmental sustainability of projects of the Natural Resources Management Network in Mexico, (financed by the foundation). Although the methodology had been developed earlier, it was not published until 1999, while being continuously and consistently studied and adapted. The MESMIS operational structure consists of six stages (Speelman et al., 2007), which are carried out using the participatory approaches, whereas the result of each stage is the result of the perceptions and contributions of the actors involved:

Stage 1 - definition and description of the system/systems to be evaluated;

Stage 2 - identification of the system critical points such as advantages and disadvantages that can modify the vulnerability; the latter refers to socioeconomic factors, techniques or processes that can exert significant individual/combined impacts on the attributes of the described systems;

Stage 3 - selection of the diagnostic criteria and indicators: the goal of this stage is to provide the necessary links between attributes/critical points and critical points/indicators.

Stage 4 - measurement and monitoring of indicators. After determining the set of indicators, it is necessary to establish the procedure for conducting measurements and monitoring.

Stage 5 - integration of results. At this stage (the assessment cycle), the results from the monitoring of indicators are consolidated and integrated. This is a crucial synthesis step given the information collected during the previous stages.

Stage 6 - conclusions stemming from the recommendations for management systems. In the sixth stage, the assessment cycle is completed by coming back to the analysis results for a so-called "value judgment" applied to the comparison between the different systems in relation to their sustainability to be performed. Furthermore, a period of reflection on the assessment process takes place during this stage. In the end, the strategies for potentially new assessment cycles are provided for different qualitative scenarios.

Given the basic structure of the method, the adaptation to the NEXUS approach was performed as described by Silveira et al. (2020a). The traditional social, economic, and agroecological dimensions of the MESMIS method were replaced by the NEXUS dimensions (water, energy, and food). For instance, the NEXUS-MESMIS approach transforms the Social-Economic-Agroecological dimensions into the system of Food-Energy-Water. Nevertheless, there is no direct correspondence between them, since social, economic, and environmental factors are embodied in each of the three elements of the analyzed NEXUS (water, food, and energy).

These indicators often complement each other across two or even three dimensions. The MESMIS method was developed implying that sustainable management systems experience constant variability driven by the internal and external environment. Due to this, they should be capable to self-regulate, to transform themselves (while still being functional) and to be productive (Masera, 2008). The latter study showed that these abilities can be analyzed using a set of fundamental systemic properties or generic attributes such as productivity, stability, reliability, resilience, adaptability, equality, and self-management. Therefore, these attributes were modified to the Nexus framework and will be discussed later on.

Figure 2 shows the inclusion of the fundamental systematic properties or attributes that were used to configure the NEXUS-MESMIS approach in this project. Therefore, figure 2 illustrates how the water, energy, and food dimensions are encompassed by the diffuse social, economic, and environmental factors. However, the attributes are permeated (dotted line) by the dimensions, thereby denoting the way in which indicators from different dimensions complement and impact the various attributes.

3. Scale of the approach

The scale of the watershed is considered as the unit of study (as a physical area). This is reasonable because it naturally integrates the physiographic elements (soils, relief, and climate) that define the fragility of the environment with the influence of the productive elements (land use and soil management) through the hydrological cycle (river flow, soil moisture, soil erosion, sediment yield, water quality, etc.).

In such case, we use the Ibirapuitã River watershed encompassing the main productive systems of the Brazilian Pampa (soil, topography, and climate conditions of the biome). The use of the watershed as a unit of the study is advantageous as it allows evaluating the water flow, taking water availability for agricultural production in the soil and irrigation into account. This also enables capturing the positive and negative impacts observed in the flow dynamics of springs, streams, and rivers that affect society. Water availability (estimated using a combination of qualitative and quantitative approaches) is the result of the quality of the productive system, developed in the hillslopes. In particular, the better land use and soil management, the more productive capacity due to greater storage of water. Moreover, this allows regularizing the river flows aiming on the improvement of water quality, as the flow filters through the subsurface layers of soil.

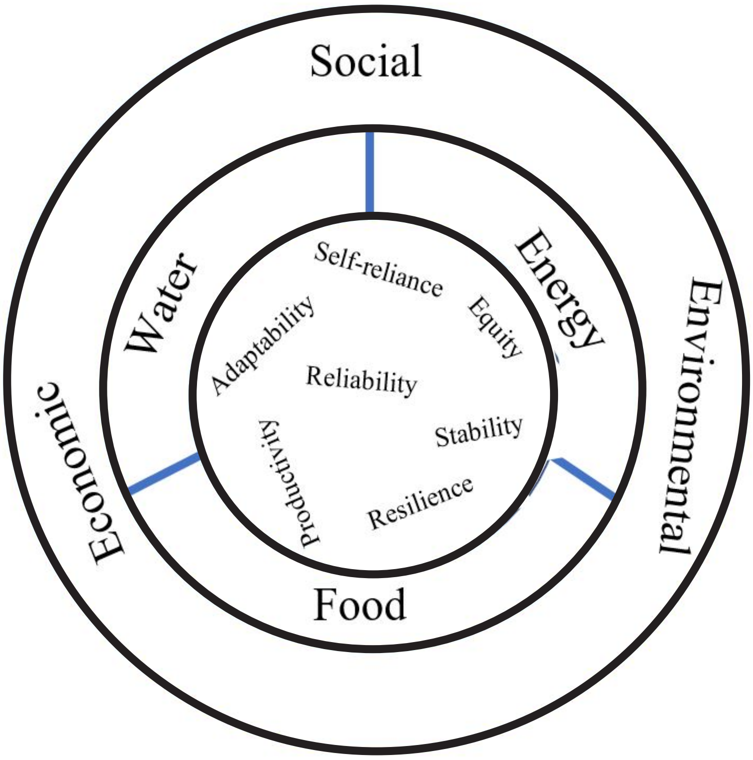

Figure 2. NEXUS-MESMIS approach.
Source. Elaborated by the authors.

One of the objectives of this study is to justify the use of watersheds in the NEXUS-MESMIS approach. The strategy is to assess the applicability of this approach to improve its efficiency, given the limits of the watershed as an assessment unit. In particular, one can quantify/assess the three elements (water-food-energy) using the limits of the watershed, including its internal features (sub-watershed) given the integration of the landscape elements (climate > relief > soil > biodiversity) alongside with the anthropic influence.

The latter influence either stems from the agricultural activity or from any other action that modifies the sustainability indices. It can be assumed that humans socially alter the flow of matter and the energy in the system regardless the type of alteration (either improve the productive capacity or contribute the degradation processes).

It is beneficial to use the methodology for the chosen case because of the sub-watershed. Namely, the main one is composed in order to express each of the three different situations present in other areas of the biome (Figure 1). The dryland farming, combined with the livestock activities, is common for the large areas of the Caverá sub-watershed. Controlled livestock is common in the sub-watershed of the APA-Ibirapuitã permanent preservation area, but with restrictions for the intensification of the production process. Meanwhile, a major part of the Pai Passo sub-watershed houses livestock and features irrigated agricultural activity (for rice). Furthermore, the livestock systems have been preserved in the upper part of the watershed, while the center includes a large urban agglomeration (Alegrete city) and the lower part represents a scenario of the intensive land use, initially implied for the livestock production, but mainly used for crops (Figure 1). The project allows estimating the influence of rural activity on water availability for the urban area and the influence of the city on water availability downstream from the city. This prospect stems from the monitoring carried out upstream from the control section and past the urban agglomerations (Minella et al., 2020). This proposal can be applied not only for the watershed level (as suggested above) but can also be potentially used for finer administrative (such as cities, states, countries), environmental (biomes), and social (communities) scales.

4. NEXUS-MESMIS methodology

The methodology opens a window for two types of analyses: at the level of scopes by dimension, or at the attribute level, where the dimensions are interconnected. In this way, at the scopes is possible to examine the social and the environmental issues indirectly involved in the methodology, while the attributes can address those issues that are directly involved. In particular, the methodology provides a socio-environmental view, which the Nexus approach lacks, as mentioned earlier (Dalla Fontana et al., 2020; Zhang et. al, 2019). Table 1 shows the indicators and variables from the different scopes in the Nexus Pampa project.

4.1 Analysis at the scope level

The analyses of the strengths and weaknesses listed by local agents indicated that the classification can be made for three general scopes, for each dimension (Silveira et al., 2020b):

Food: Organizational and Institutional Environment; Productive and Technological Environment; Commercialization and Consumption

The aspects related to the social and productive organization of the systems were included within the Organizational and Institutional Environment. The goal of this area is to include the indicators that estimate the degree of the system's relationship with other systems and support organizations, the degree of participation, cooperation, and associativity of rural properties, as well as the observation of succession conditions, quality of life, and the infrastructure of the productive activities in the Ibirapuitã River basin. The aspects associated with their productive exploitation were involved in the Productive and Technological Environment. This area includes the indicators related to the types of the management implemented for the production, the degree of dependence on external inputs and capital, the existence of economic management and productive diversification on the property, and the characteristics of the labor force and cattle raiding in the region of the productive system. The aspects linked to the relationship between said systems and the consumer markets were included in the Commercialization and Consumption area. The goal of this area is to embrace the indicators that quantitatively describe the market performance of the productive activities. Indicators that determine the negotiating power and market structure (both are related to the productive system), the extent and types of marketing channels for system outputs, the degree of value added to products, the ability to sell products directly to consumers and their self-consumption.

Energy: Electrical energy; Thermal energy; Mechanical energy.

The areas open prospects for analyzing the term “energy” in order to understand its social and economic impact on the Ibirapuitã watershed in a holistic way. It should be emphasized that the electric energy area will not only

DIMENSION	SCOPE	INDICATOR	VARIABLE
Food	Organizational and Institutional Environment	Tradition and Culture	Importance of culture and tradition in the performance of the activity
		Supporting Organizations	Degree of a relationship with supporting organizations (EMATER, Universities, EMBRAPA, SENAR, etc.)
		Public Policies	Knowledge of and access to public policies
		Social and Associative Participation	Degree of participation in producer associations, unions, and the local community
		Market Cooperation	Existence of joint and/or collaborative marketing
		Energy and Logistics Infrastructure	Conditions of the energy and logistics infrastructure for the development of activities
		Quality of Life	Conditions that provide structural quality of life
		Succession/ Transferability	Existence and predisposition of a successor to continue a given activity
	Productive and Technological Environment	Production Genetics	Racial pattern
		Forage Management	Relationship between load and load capacity of the field
			Forages, invasive plants, and land cover
		Crop Management	System incorporation time
			Percentage in the system
		Herd Food Management	Management type of cattle and/or sheep food
		Dependence on External Inputs	Degree of dependence of the establishment on external inputs
			Impact of scarcity of inputs on production
		Productive Diversification	Proportion of time and income between productive activities
		Economic Management	Use of economic management tools in the property
		Dependence on Capital Flow	Origin of income: retirement, provision of service, another income/Animal Production ratio
		Availability of Labor	Access to available Labor
		Cattle Raiding	Incidence of cattle raiding in the location of the establishment
	Commercialization and Consumption	Market Structure and Price Formation	Characterization of the number of buyers of the main exploration product
			Price negotiation power
		Marketing Channels	Geographical coverage of consumption of the main product of the establishment
			Type of marketing channel for the main product of the establishment
		Value-added	Comparative position of the main product value in relation to other regions
			Comparative price position received by the main product in relation to the region
		Secondary Products	Products marketed in addition to those linked to beef cattle and/or rice farming
		Consumption of Own Production and Direct Selling	Amount of food that the family consumes from the establishment
			Frequency of direct sales of products to the consumer

Energy	Electric Energy	Generation	Independent generation
		Consumption	Continuous use
			High energy-consumption equipment
			Demand
			Excess of reactants
		Network	Access to concessionaire network
			Quality
			Network dependence
	Thermal Energy	Use of Thermal Energy	Cooking
			Personal hygiene
			Environment
			Productive process
		Source of Thermal Energy	Source of Thermal Energy
	Mechanical Energy	Pumping	Domestic
			Productive
		Fossil Fuels	Intensity of use (L/ha)
			Access
			Storage
Water	Human Consumption	Water Quantity	Source meets consumption
		Water Quality	Quality
	Production	Water for Production	Source meets production demand
		Use efficiency	Pastures and dryland farming
			Horticulture
			Rice
		Susceptibility to Indian Summer	Occurrence
			Frequency
	Degradation	Existence of Conservation Practices	Technological soil management
			Soil compaction management
			Plant management
			Water management
		Perception of Erosive Process	Wind erosion
			Concentrated erosion
			Diffuse erosion
			Road-related soil erosion
			River erosion

Table 1. Dimensions, areas, indicators, and variables used in the Nexus Pampa Project.
Source. Elaborated by the authors.

be analyzed with respect to the issue of access to distribution networks, but also with respect to its quality and reliability. These two variables are intrinsically linked to use and directly related to both quality of life, (considering the access to energy as a basic need), and the productive capacity as well. The latter can be increased by some anthropogenic processes as irrigation. Furthermore, the energy axis should not merely analyze the use of electrical energy, but the use of energy for other purposes as well. Therefore, the thermal energy area can be used to analyze the impact of thermal energy sources and use (for instance, the use of wood for cooking and personal hygiene). Complementing the analysis, the goal of the indicators related to mechanical energy is to analyze its source and application by obtaining the information ranging from the transportation to the fossil fuel prospecting and the intensity of their use/storage, as well as their application in the use of generators.

Water: Human Consumption; Production; Degradation.

In the water axis, the areas take into account the impact that water access restrictions have on the well-being of the community and on the proper development of the production system. Both types of impacts (maximizing productive capacity or minimizing degradation caused by water erosion) are implied in the statement above. The analysis is performed by accounting for the rainfall regime in the region of a study, as well as the physiographic characteristics (soil and topography) of the catchment that controls the surface runoff and soil moisture. Despite, the rainfall is not a regional limiting factor for human consumption and production, land use and inadequate soil management can trigger the degradation by water (surface runoff). Moreover, the improvement in soil and water management practices positively affect the water availability for supply by increasing production rates and by reducing degradation rates. This phenomenon is driven by the greater infiltration and, by the increase in water quantity and quality in springs and rivers. Efficient water management strategies in the productive environment prevent degradation by surface runoff, while also favorably increasing its availability for plants, animals, and human beings. The important aspects, such as water quality for urban supply or hydroelectric power production capacity downstream, were also included here. Regarding the region of interest, the Ibirapuitã River watershed stands out with exceptional regional importance, being a part of the Uruguay River watershed, where the Salto Grande Dam is located. Notably, this dam is the main production unit of hydroelectric energy in Uruguay.

Therefore, at this level of analysis, the different indicators are added, in Silveira et al. (2020b), where the indicators that make up each scope can be found.

4.2 Analysis at the attribute level

The importance of the basic attributes of the sustainability concept intrinsic to MESMIS should be emphasized. For this purpose, the description of each of the attributes was used, as reported by Masera et al. (1999), given below.

Adaptability: ability of an agroecosystem to reach the stability after an adverse situation; Self-reliance or self-empowerment: ability of an agroecosystem to regulate and to control its relationships with the external environment.

Reliability: ability of an agroecosystem to maintain the desired benefits at levels close to those generated under normal conditions.

Equity: ability of an agroecosystem to distribute the benefits and costs resulting from the management of natural resources in a fair way.

Stability: a feature of an agroecosystem that promotes a constant productivity in the agroecosystems generated over time.

Productivity: a feature of an agroecosystem able to generate the required level of goods and services, expressed by gains or income over a given period of time.

Resilience: ability of an agroecosystem to recover its potential production after being exposed to damaging disruptions.

Table 2 shows both the attributes and how they are composed of the indicators from the various dimensions.

The adaptability attribute will be used to show how the integration between the different dimensions and the attributes should work. The "Existence of conservationist practices" indicator, (a part of the water dimension), will indicate the adaptability of the system to withstand extreme events as floods or droughts. The system will resist degradation under excessive rain conditions and will use the soil storage to resist the absence of rainfall. From energy perspective, a system should be able to generate its own electric energy, regardless of the source, so it reduces a burden by any adverse phenomenon.

Indicator	**Attributes**						
	Adapt-ability	Self-man-agement	Reliability	Equality	Stability	Produc-tivity	Resil-ience
Tradition and Culture		X					X
Supporting Organizations	X	X	X				
Public Policies			X			X	
Social and Associative Participation		X	X	X			X
Market Cooperation	X	X	X	X			X
Energy and Logistics Infrastructure			X		X		X
Quality of Life			X		X		
Succession/Transferability	X		X		X		X
Forage Management		X				X	X
Crop Management		X				X	
Herd Food Management		X				X	
Dependence on External Inputs			X		X		
Productive Diversification	X	X				X	
Economic Management		X		X			X
Dependence on Capital Flow		X	X				
Availability of Labor					X	X	
Cattle raiding		X		X	X	X	X
Market Structure and Price Formation					X	X	X
Marketing Channels						X	X
Value-added						X	X
Secondary Products						X	X
Consumption of Own Production and Direct Selling					X	X	X
Generation	X		X	X	X	X	X
Consumption						X	
Network	X	X				X	
Use of thermal energy		X		X	X		
Source of Thermal Energy		X					
Pumping						X	
Fossil Fuels			X			X	
Water Quantity		X		X			
Water Quality		X		X			
Water for Production				X		X	
Use efficiency		X			X	X	
Susceptibility to Indian Summer			X				
Existence of Conservation Practices	X	X	X		X		
Perception of Erosive Process							X

Table 2. Attributes and their indicators.

Source. Elaborated by the authors.

Likewise, the more independent the property's electrical network is from the distribution concessionaire, the more adaptable it will be in the situations with a lack of energy from the grid. The "Supporting Organizations" indicator, from the food dimension, assesses the degree of relationship of the productive system and support organizations in the agricultural sector, such as universities, extension and research institutions, etc. This degree of relationship shows the ability of an agroecosystem to reach the stability after an adverse exposure. Another example is the "Productive Diversification" indicator, which checks the proportion of time and income among the productive activities of the property (those with a greater number of activities are considered to be sustainable).

Therefore, the analysis of the attributes is based on the dimension indicators, clearly demonstrating the direct way in which the NEXUS approach captures the NEXUS between water, energy, and food.

5. Conclusions

Brazil has six biomes, which denotes the diversity of natural resources (soil, vegetation, biodiversity) in the country and it is necessary for these resources to be used and managed in a unique way in each region. This study opens a window for evaluation of such issues in a truly unique biome in Brazil, which only exists in Rio Grande do Sul, in the Brazilian territory. Given the common use of natural resources (that are, in most cases, not integrated), the NEXUS-MESMIS approach enable the integration of different sectors (food, energy, and water) while taking into account the social, economic, and environmental issues. Thus, a systematic view paves the way for more efficient assessment of the weaknesses and strengths of the use and the management of the natural resources in the considered environment of the Pampa biome. The scale of the watershed, representative of the biome, is used to this purpose. However, it is evident that the methodology can be utilized at any scale.

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CHAPTER 11

Efficiency analysis of Brazilian cities: the effect of Food, Energy and Water Nexus (FEW Nexus) on Municipal Human Development Index

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1. Introduction

According to FAO (2014), the term "Food-Energy-Water Nexus" (FEW-Nexus, or just "Nexus") refers to a conceptual approach that seeks to analyze the use of water, food, and energy. These three resources are, at the same time, scarce and essential for human development.

FAO (2014) highlights that if policymakers focus their planning of actions only on one of the FEW resources, they can impair the supply of the others. For instance, if a country plans to promote the local agricultural sector, this will possibly add to food supply, and it may cause an increase in the water demand which in turn, might cause a future water deficit. Additionally, a rise in the agriculture supply may lead to a growth in energy (fuel) demand, as more products will need to be transported. Therefore, a more proper approach would be the one that the policymakers focus their actions on the whole FEW-Nexus. In this case, the expansion plan would have to consider both water and energy supply in the analysis.

Therefore, understanding the effects of food, energy, and water consumption and production on socio-economic and environmental indicators has become a strategic issue for all countries, especially the developing ones, that depend on natural resources to promote economic viability. Couto et al. (2021), Dalla Fontana et al. (2020) and Mahlknecht, González-Bravo and Loge (2020) draw attention to the potential for incorporating the Nexus approach into public policy planning in Brazil. For those authors, it is necessary to not only look at the three resources in a systemic way, but also at the regional differences of the Brazilian territory during the planning of public policies, as the country has a heterogeneous distribution in terms of "population, levels of development, availability of resources, geography, quality of public management, size and capacity of states, bargaining power and poverty level" (Mahlknecht, Gonzáles-bravo & Loge, 2020, p. 13).

Dalla Fontana et al. (2020) and Mahlknecht, González-Bravo and Loge (2020) show that there is a lack in the literature with respect to the use of quantitative methodologies applied to the analysis of Nexus in specific cases within the Brazilian reality. For the authors, quantitative methods can provide greater support for public policy decision-makers.

For Endo et al. (2020), the literature still has insufficient quantitative methodologies that contemplate the Nexus in an integrated way. As pointed out by the same authors, the application of quantitative methodologies in case studies can be a way to create more generalist methods that includes Nexus in the analyzes. Moreover, this type of study can be applied to other countries.

Some studies have already used the data envelopment analysis (DEA) as a methodology to evaluate regional Nexus input-output efficiency. The Nexus system has multiple inputs and outputs with specific relationships that are hard to quantify, and DEA models have been successfully applied to evaluate relative efficiency whilst ignoring specific complex relationships in the system (Li, Huang & Li, 2016).

The main goal of this study is to measure the efficiency of converting Nexus-based variables into municipal human development index (MHDI), in Brazil. The DEA model called slack-based measure (SBM) was used to calculate efficiency scores for several municipalities in Brazil. The results can guide policymakers to design regional and city-level policies that can promote a more efficient use of Food-Energy-Water Nexus (FEW Nexus) resources. In addition to the FEW variables, we also considered CO2 emissions in our analysis.

2. HDI efficiency calculation and the use of nexus variables

Few studies have already used the DEA method to analyze the relationship of input variables with sustainability characteristics and the HDI. The use of this method at the municipality-level is even more scarce.

Alves Junior et al. (2016) used three approaches of DEA models (multiplicative, Charles-Cooper-Rodhes - CCR, and the slack based measure - SBM) in the benefit-of-doubt (BoD) form to raw and normalized data. The authors calculated efficiency scores for 187 countries to reconstruct their HDI.

Blancard and Hoarau (2013) applied DEA to analyze HDI efficiency using a set of 32 developing countries, the decision-making units (DMUs). The analysis included sustainability characteristics that were used to compare the results of different models.

Yue et al. (2019) presented a "Sustainable Total Factor Productivity" indicator calculated using a DEA-Malmquist index. The authors applied their model using data from 55 developed and developing countries, with different sustainable development levels. They used variables that consider ecological consumption (energy, land usage, biological resources, among others) as inputs, and the human development index (income, life expectancy, and education levels) as the output.

Campoli et al. (2020) applied a slack-based measure (SBM) DEA model to calculate the efficiency of the Brazilian federative units (FU) in converting government expenditures into millennium development goals. The authors used variables related to a national social program, and the human development index in their analysis, between 2004 and 2014.

Li, Huang and Li (2016) created an index system at the city level using DEA and the Malmquist index methods to compare the input-output efficiency of Nexus for 30 Chinese provinces, from 2005 to 2014. The authors found differences between the results of the model that considered a single resource, and the model that included Nexus variables. The difference in the efficiency scores pointed out that integrated resource management should be implemented to enhance policy results.

Yang and Li (2017) analyzed the Total Factor Efficiency of Water (TFEW) and of Energy (TFEE) in China, from 2003 to 2014. The study used province data, and the efficiency scores were calculated by a DEA-SBM model. Results showed different development levels of TFEW across the provinces, which are inconsistent with their economic level, and that the TFEW is generally lower than the TFEE.

Ibrahim et al. (2019) evaluated the efficiency of Organization for Economic Co-Operation and Development (OECD) countries in terms of Water-Energy-Land-Food (WELF-Nexus) through an input-output index system built at a transnational level, using a robust order-□ DEA model. Results showed that the outcome obtained from the WELF-Nexus efficiency scores is more related to an adequate use of resources than the scores obtained using the minimum WELF resources.

Zhang and Xu (2019) implemented the DEA and the Malmquist index model to assess the Nexus coupling efficiency of 31 regions in China, from 2007 to 2016. The two different methods were used to provide static and dynamic results. According to the authors, even though the Nexus policy failed to improve regional Nexus-coupling efficiency, the same policy was important to maintain the efficiency scores in a certain level.

Miura et al. (2021) applied a network data envelopment analysis (NDEA) to study the production efficiency of the primary, secondary, and tertiary sectors, and the transportation industry in 47 cities of Japan. Each sector was independently evaluated to determine which one contributes the most to CO2 emissions.

Work	Inputs Indexes	Outputs Indexes
Li, Huang & Li (2016)	Total water consumption, total energy consumption, total food consumption, total permanent resident population	Gross domestic product (GDP) per capita, environment index (total gas waste, total water waste, total solid waste)
Yang & Li (2017)	Total number of employed population, capital stock from fixed assets investment, total energy consumption, total water consumption	Regional GDP, wastewater emissions
Ibrahim et al. (2019)	Water withdrawals, renewable energy, fossil fuel, agricultural land, food imports	Food exports, environmental performance index, life expectancy at birth, GDP
Zhang & Xu (2019)	Stage 1: irrigable cultivated area, agricultural water consumption, number of employees in agricultural Stage 2: Industrial water consumption, number of employees in industry, fixed industrial investment	Stage 1: grain yield Stage 2: energy output
Miura et al. (2021)	Number of employees (primary to tertiary, transportation), capital (land, transportation)	GDP (primary to tertiary, transportation), CO2 emissions (primary to tertiary, transportation)

Table 1. List of inputs and outputs used in studies to evaluate Nexus with DEA models.
Source. Elaborated by the authors.

Table 1 summarizes the information about the input and output variables used in the aforementioned studies.

3. Data and methodology

In our study, three inputs were used to represent the annual values of FEW Nexus variables: (i) food consumption ($BRL spent in food) per capita (IBGE, 2021), (ii) energy consumption (Mwh; considering captive, residential, industrial, commercial, and other energies consumption) per capita (EPE, 2021), and (iii) water consumption (thousands of m3) per capita (SNIS, 2021). The lower the value of the inputs, the better, as there is a more efficient use of the resources.

In addition to the FEW variables, we included per capita CO2 equivalent (CO2e) emission (tonnes) in our analysis. Moreover, we developed a model that considered the amount of CO2 emission (tonnes) due to deforestation in the analyzes. These emissions (per capita CO2e; and total or without deforestation as CO2e) were collected in the Greenhouse Gas Emission and Removal Estimating System (SEEG, 2021). We included emissions as undesirable outputs in our models. We did that using this variable as a negative factor in our DEA model (the lower the value of emission, the better). We used the municipal human development index (MHDI) as an output in our models (the higher the value of outputs, the better). This index is calculated and published by Atlas Brasil (Atlas Brasil, 2021), a partnership between the United Nations Development Programme (UNPD) Brazil, the Institute of Applied Economics Research (IPEA), and the João Pinheiro Foundation (FJP). Atlas Brasil adapted the global HDI methodology to the Brazilian context and considered the availability of national indicators in order to calculate the MHDI, which follows the same three dimensions of the global HDI (health, education, and income) (Atlas Brasil, 2020).

The sample consisted of cities (state capitals) from five regions: North (N), North-East (NE), Center-West (CW), South-East (SE), and South (S). When data per capita from the city was not available, we used data per capita from metropolitan regions as proxies. We included the following cities in our study: Aracaju (SE), Belém (PA), Belo Horizonte (MG), Boa Vista (RR), Brasília (DF), Campo Grande (MS), Cuiabá (MT), Curitiba (PR), Florianópolis (SC), Fortaleza (CE), Goiânia (GO), João Pessoa (PB), Macapá (AP), Maceió (AL), Manaus (AM), Natal (RN), Palmas (TO), Porto Alegre (RS), Porto Velho (RO), Recife (PE), Rio Branco (AC), Rio de Janeiro (RJ), Salvador (BA), São Luís (MA), São Paulo (SP), Teresina (PI), and Vitória (ES).

We used the DEA Slack-Based Measure – SBM in our study (Tone, 2001). This model was chosen due to its non-oriented characteristic, which simultaneously maximizes the output (the MHDI) and minimizes the use of inputs (CO2e and FEW-Nexus-based measures) (Tone, 2001).

The specification of the SBM model, (Tone, 2001) assuming variable returns to scale (VRS), is presented in equations (1) through (6):

$$Minimize\ \tau = t - \left(\frac{1}{m}\right)\sum_{i=1}^{m} \frac{S_i^{-}}{x_{i0}} \quad (1)$$

$$t + \left(\frac{1}{n}\right)\sum_{j=1}^{n} \frac{S_j^{+}}{y_{j0}} = 1 \quad (2)$$

$$\sum_{k=1}^{z} \Lambda_k x_{jk} + S_i^{-} - t x_{i0} = 0 \quad i = 1,2,\ldots,m \quad (3)$$

$$\sum_{k=1}^{z} \Lambda_k y_{jk} - S_j^{+} - t y_{j0} = 0 \quad j = 1,2,\ldots,n \quad (4)$$

$$\sum_{k=1}^{z} \Lambda_k - t = 0 \quad (5)$$

$$\Lambda_k \geq 0,\ S_i^{-} \geq 0,\ S_j^{+} \geq 0 \wedge t > 0 \quad (6)$$

Where:

τ: efficiency score, t: model linearization variable, $S_i^{-¿¿}$: slack of the i-th input, $S_j^{+¿¿}$: slack of the j-th output, Λ_k: contribution of the kth DMU to the analyzed DMU, x_{i0}: i-th input of the DMU under analysis, y_{j0}: j-th output of the DMU under analysis, x_{jk}: i-th input of the k-th DMU, y_{jk}: j-th output of the k-th DMU, m: number of inputs, n: number of outputs, z: number of DMUs.

The variable returns to scale (VRS) assumption is preferable when we use ratios in our model, and when the data is represented in percentages. In this type of analysis, if we use the constant return to scale (CRS) assumption, the results will not necessarily be within the 0% - 100% range (Cook et al., 2014).

We additionally used a tiebreaking method called composite index – CI (Leta et al., 2005). This approach consists of a double-frontier method that considers both the standard and inverted efficiencies. The CI (Leta et al., 2005) method is described in equation (7):

$$\tau_k^{composite} = \frac{\left[\tau_k^{standard} + \left(1 - \tau_k^{inverted}\right)\right]/2}{max\{[\tau_k^{standard} + \left(1 - \tau_k^{inverted}\right)]/2 ¿} \} ¿ k = 1,2,3,\ldots,z \quad (7)$$

$\tau_k^{standard}$: standard efficiency of the k-th DMU, $\tau_k^{inverted}$: inverted efficiency of the k-th DMU (i.e., the efficiency handling inputs as outputs and vice-versa).

We used the results of the DEA calculation to rank the DMUs (cities) according to their efficiency levels.

4. Results and discussions

We obtained our results by calculating efficiency scores for all 27 Brazilian state capitals (including the federal district). We developed the following models to calculate scores using the DEA method:

- Model 1: We assigned output values equal to one to all DMUs to calculate the first round of efficiency scores, then used those results with the composite index to untie the results for the DMUs with scores equal to one (benefit of doubt model). We used water, energy and food consumption per capita as inputs.
- Model 2: Included all inputs used in model 1, and the CO2e emission

(CO2e) per capita as an undesirable output. We used the municipal human development index (MHDI) as the output.

• Model 3: An extension of model 2, that includes deforestation in the analysis. This new undesirable output was also measured in CO2e emissions per capita.

We use model 1 as our base model for we consider it our most simple approach. Models 2 and 3 were used to add information to the base model, and to provide more specific results to our analysis. The cities' results for each model can be seen in Table 2. In addition, the outcomes calculated from the three different approaches were compared using regional averages. The results for the regions can be seen in Table 3.

State of the capital city	Region	CI1	Rank CI1	CI2	Rank CI2	CI3	Rank CI3
AM	N	1.0000	1	1.0000	1	0.9690	4
AP	N	0.9535	2	0.8116	4	0.8009	13
RO	N	0.9417	3	0.5643	20	0.5292	21
AC	N	0.9255	4	0.5643	17	0.5292	18
MA	NE	0.8975	5	0.7928	8	0.9193	7
AL	NE	0.8684	6	0.4808	22	0.5292	23
TO	N	0.8584	7	0.7829	9	0.8981	8
CE	NE	0.8486	8	0.9085	2	0.9931	2
RR	N	0.7776	9	0.6718	12	0.8646	10
PI	NE	0.7749	10	0.8066	5	0.9233	6
PB	NE	0.7019	11	0.8027	6	0.9359	5
PA	N	0.6847	12	0.7348	11	1.0000	1
MT	CW	0.6517	13	0.5783	16	0.6302	17
PE	NE	0.6161	14	0.6368	14	0.8446	11
BA	NE	0.5810	15	0.8824	3	0.9759	3
RN	NE	0.5646	16	0.3423	25	0.4049	24
SE	NE	0.5248	17	0.2884	26	0.3369	26
MS	CW	0.4639	18	0.2710	27	0.3139	27
RJ	SE	0.4371	19	0.5626	21	0.7709	15
GO	CW	0.4351	20	0.6537	13	0.8291	12
SP	SE	0.3582	21	0.7758	10	0.7758	14
MG	SE	0.3509	22	0.7973	7	0.8911	9
PR	S	0.3317	23	0.5808	15	0.7482	16
DF	CW	0.3160	24	0.5643	18	0.5292	18
ES	SE	0.2800	25	0.4292	23	0.5292	21
RS	S	0.2565	26	0.3513	24	0.3875	25
SC	S	0.1954	27	0.5643	18	0.5292	18

Table 2. Efficiency Composite Index (CI) of the capital cities.
Source. Elaborated by the authors.

Region	Average CI1	Rank CI1	Average CI2	Rank CI2	Average CI3	Rank CI3
N	0.8773	1	0.7328	1	0.7987	1
NE	0.7086	2	0.6601	2	0.7626	2
CW	0.4667	3	0.5168	4	0.5756	4
SE	0.3565	4	0.6412	3	0.7417	3
S	0.2612	5	0.4988	5	0.5549	5

Table 3. Aggregation (average value) of Efficiency Composite Index (CI) by region.
Source. Elaborated by the authors.

According to the results from model 1, the North was the region with the highest average score, because they showed the lowest consumptions, followed by the Northeast, Central-West, Southeast and the South. The most efficient cities were Manaus, Macapá, and Porto Velho, all in the North. The least efficient cities were: Florianópolis (S), Porto Alegre (S), and Vitória (SE). Also, the results from the model showed that the highest performances were due to the lowest consumptions and, so the score is negatively and highly correlated to the MHDI (significant correlation = -0.8121), because the higher the MHDIs, the lower the efficiency levels related to the consumptions.

In the results from model 2, the cities in the North and Northeast Brazil were, on average, the most efficient DMUs, while the South remained as the least efficient region. However, we found changes between the Southeast and the Central-West regions, meaning that the cities in the prior region became, on average, more efficient. An important conclusion from this result is that it indicates that, when we analyze efficiency considering the MHDI as the output, and include the CO2e in the model, some of the largest cities in Brazil become more efficient. For instance, if we compare the efficiency scores calculated with models 1 and 2 for São Paulo, the largest city in the country, we found that for the first model the city had only the 21st largest score, and for the second, the 10th (see Table 2).

When we expanded our analysis to model 3, which includes deforestation as CO2e, we noticed no significant change in our regional efficiency rank (Table 3). In general, the capital cities have little remnant of forest and deforestation emissions are not very significant. For example, São Paulo’s CI was the same in models 2 and 3. The value of efficiency and CI is related to data and benchmarks, so São Paulo and its benchmarks have relatively low emission from deforestation.

As in the results from model 2, the results from model 3 showed that the North and Northeast regions of Brazil were, on average, the one with the most efficient DMUs (Table 3). However, observing Table 2, Belém (PA) assumed the first position (from 11th to 1st), Manaus (AM) finished in the 4th position of the ranking (from 1st to 4th), and Macapá (AP) was in the 13th position of the ranking (from 4th to 13th). So, the cities' rank changed, but the regional averages trend and regional ranking were the same. The South remained as the least efficient region, and, on average, the cities in the Southeast and Central-West were ranked respectively as the third and fourth in the efficiency rating. So, the deforestation makes the cities change their positions, mainly inside its own region, but, in general, the regions classification is the same as the one from the model 2.

About the slacks (calculated for model 2), the water consumption per capita was the input with the highest average slack, meaning that this is the variable that needs more changes to make the DMUs efficient (reach scores = 1). On average, when compared to their benchmarks, the analyzed Brazilian cities need to reduce their water consumption by 67% to become efficient. Our results show that the least efficient cities are those with highest water consumption per capita. For instance, we ascertained that Florianópolis (S) needs to reduce its water consumption by 92.42% to become efficient (benchmark = Manaus); Curitiba needs a 90.38% reduction (benchmark = Manaus), and Belo Horizonte needs an 89.27% reduction (benchmark = Manaus) in water consumption to become efficient. Even though these results are important to show the difference in efficiency among Brazilian cities and regions, they must be analyzed more carefully. Since the North and Northeast are the regions with the lowest urban service index for water network (Brasil, 2019), the official information regarding the water consumption in those areas may not reflect their real consumption.

Table 4 shows the % of variation to achieve goals and be deemed efficient in model 2 (the efficient DMUs shows 0% variation). An important result is that the calculations obtained from model 2 did not show significant overall changes compared to the base model (model 1), despite including the CO2e.

State of the capital	Region	%MHDI	%Water Consumption	%Energy Consumption	%Food Consumption	%CO2e
AC	N					
AM	N					
AL	NE	4.53%	-5.99%			-35.04%
AP	N					
BA	NE					
CE	NE					
DF	CW					
ES	SE		-68.90%	-22.86%		-4.02%
GO	CW		-74.90%	-18.28%	-10.18%	
MA	NE					
MG	SE					
MS	CW	0.13%	-64.35%	-29.30%	-47.04%	-66.69%
MT	CW		-43.45%	-36.66%	-21.95%	-58.83%
PA	N	2.48%	-60.42%	-34.59%	-13.97%	-0.53%
PB	NE					
PE	NE	0.65%	-83.09%	-1.26%	-22.50%	-26.23%
PI	NE					
PR	S		-81.76%	-31.71%	-3.34%	
RJ	SE		-84.68%	-30.54%	-13.24%	-20.19%
RN	NE	1.96%	-76.19%	-10.65%	-42.17%	-20.53%
RO	N					
RR	N	1.96%	-57.98%	-13.07%	-1.80%	-48.05%
RS	S		-79.81%	-37.35%	-28.35%	-5.49%
SC	S					
SE	NE	1.43%	-76.71%	-9.55%	-44.04%	-59.55%
SP	SE					
TO	N					

Table 4. Percentage of Variation to Achieve the Goals and Be Deemed Efficient in Model 2.
Source. Elaborated by the authors.

Similarly to the interpretation of the analysis from Alves Junior et al. (2021), and considering the inefficiency levels and slacks used to calculate the variations, when we assay the variation needed per region to achieve the highest efficiency levels, we found that the cities from the N would have to increase their MHDI between 1.9% and 2.48% or decrease 60.42% inputs. The cities from the NE would become efficient if they increased their MHDI between 0.13% and 4.53% and decreased the use of their inputs by 83.09%. In the CW, the increase in MHDI necessary for the cities to become efficient would be 0.13% of the MHDI, followed by a decrease of 74.9% in the use of inputs. The cities from the SE do not need to increase the MHDI to reach the highest efficiency level but would need to significantly decrease the use of inputs (84.68%). The results obtained for the southern cities are similar to the ones found for the southeastern ones. However, their decrease in the use of inputs would be lower (81.76%).

It is important to mention that water per capita availability in the N is different from the other regions, which generates a high percentage of change needed for cities from other regions to reach the efficient frontier levels according to this model, but it can be considered a limitation of the model. For future research, it is recommended to study the water availability per capita in the N, because it may be due to lack of infrastructure and development rather than an improved efficiency.

5. Conclusions

This study aimed to propose the use of a DEA model to create a composite index to evaluate the efficiency of cities in terms of converting Nexus-based variables into human development. We used the municipal human development index (MHDI) and CO2e emissions in Brazil as outputs to calculate efficiency scores. The DEA is a valuable tool for multicriteria decision-making as it provides significant and essential outcomes that can be used to guide public policies. In addition, DEA has been used as a methodology to evaluate regional FEW Nexus input-output efficiency, since FEW Nexus system's multiple inputs and outputs have specific and hard to quantify relationships, and DEA models successfully evaluate relative efficiency whilst ignoring specific complex relationships in the system (black box).

In summary, the results pointed out that the cities with higher MHDI are the ones with the lowest scores, but the highest consumptions. While the cities from the N and NE are the most efficient decision-making units in the country, the cities from the SE are ranked as mid-efficiency scores, and the cities from the CW and S are the most inefficient ones. We found that deforestation mainly affects the inter region ranking. In all regions we found cities with high deforestation levels, which led to similar regional ranks with or without deforestation. Moreover, even though the cities from the South do not need to improve their MHDI to become more efficient, their high consumption and CO2e emission negatively affect their efficient scores and place them within the last positions in the ranks. With that said, our results could be used to guide policy makers to design strategies to reduce CO2e emissions and consumption that could result in waste.

We recommend that future research focus on the analysis of the cities' performance with the highest and lowest consumption and emissions levels. They could also study the benchmarking of sustainable consumption in Brazil and evaluate additional variables, such as resource allocation, infrastructures' quality, local resources availability. For future research, in terms of modelling, we recommend focusing on the Dynamic and Network aspects of the FEW Nexus problems to overcome that limitation, because it is an important aspect of the nexus, mainly when discussing the goals to be deemed efficient.

Acknowledgments

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CHAPTER 12

Collaborative methodological approaches towards Water-Energy-Food nexus

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1. Introduction

The global environmental changes have led to many social and environmental impacts, affecting societies unequally (Pihl et al., 2021; Pahl-Wostl, 2019). The transition to sustainability demands inter-multi-transdisciplinary strategies to understand and synthesize the inherent complexity of socio-environmental systems (Pihl et al., 2021; Steffen, Richardson, Rockström et al., 2020), considering all the sectors involved (Funtowicz & Ravetz, 1993). Water-Energy-Food (WEF) nexus approach addresses these social and environmental challenges.

WEF nexus approach focuses on current environmental and social issues and promotes an innovative perspective about synergies and trade-offs of natural resources management (Araujo et al., 2019). Integrative strategies between sectors and disciplines and the inclusion of a diversity of stakeholders in a decision-making process have been highlighted in nexus publication (Benites-Lazaro et al., 2021; Araujo et al., 2019; Hoff, 2011). However, these same publications point to methodological challenges when dealing with different institutional structures and representative scales of water, energy, and food sectors, as well as its relation to social, environmental, and economic sustainability.

This chapter presents the collaborative strategies experienced within the context of the project: "Nexus - Transition to sustainability and water-energy-food nexus: exploring an integrated approach with case studies in the Cerrado and Caatinga", on facing the challenges of a multiscale, intersectoral and multi, inter and transdisciplinary agenda. The concept of transdisciplinarity advocated by this project departs from the recognition of the broad and intertwined debate on its definition, its multiple interpretations, and applications (Scholz; Steiner, 2015). However, we make some basic assumptions related to the idea of epistemic architecture, toward a process of collective construction of knowledge for developing the concepts in this chapter.

2. Methodological challenges of water-energy-food nexus research

Nexus exposes intrinsic challenges of theoretical and methodological nature (Araujo et al., 2019). "The nexus approach arises from an understanding that water, food and energy security are crucial to human well-being and that these three sectors are interconnected" (Benites-Lazaro et al., 2021, p.

128). This perspective is widely presented as an important key to integrated management of natural resources and environmental governance, and to improve environmental, climate, human and political security (Hoff, 2011; Hoff et al., 2019; Benites-Lazaro et al., 2021).

The basic premise for nexus implementation and inclusion on scientific and political agenda is that water, energy, and food systems are connected and integrated components (Hoff, 2011; Pahl-Wostl, 2019; Araujo et al., 2019; Lebel et al., 2020; Benites-Lazaro et al., 2021; Pahl-Wostl et al., 2021). Therefore, this interconnection of distinct social, political, and governmental systems demands a combined methodological framework (Araujo et al., 2019).

Studies on the nexus concern two dimensions: (i) interdisciplinarity, which addresses the trade-offs and synergies between water, energy and food systems and sectors, and the inherent complexity of these linkages (Endo et al., 2020; Benites-Lazaro et al., 2021); and (ii) transdisciplinary, which focuses on cooperation between stakeholders to improve intersectoral governance (Hoff, 2011; Kurian, 2017; Endo et al., 2020) by "translating systems thinking into government policy-making processes and balancing different user goals and interests" (Endo et al., 2020, p. 46). The second dimension is especially relevant in this chapter.

Research challenges of nexus agenda go beyond the trade-offs and synergies between water, food, and energy systems. The spatial and temporal scale synchronization are factors that demand more investigation to develop frameworks (Endo et al., 2020) and have repercussions on the dialogue between science and politics:

> *This alignment of boundaries and management units poses additional difficulties to access and synthesize information concerning the intersection between nexus dimensions. In fact, the boundary of each dimension: water, energy and food, has different spheres, which makes it quite challenging to characterize and manage interactions beyond the spheres of control and influence of any given nexus dimension. (Liu et al., 2017, p. 5).*

This exchange of knowledge between science and politics is also an important aspect to the transdisciplinary nexus dimension because this is related to "translating systems thinking into government policy-making processes and balancing different user goals and interests" (Endo et al., 2020, p. 46) to improve nexus governance.

The spatial and temporal issue and the exchange of knowledge between science and politics compose the main issues treated in this chapter. To face these challenges, we resort to two collaborative processes in a multi-centric perspective. This process aims to bring together multiple interests between institutes and researchers to analyze and define local scale areas of studies. This collaborative process is part of the methodological framework of the whole Nexus project1 and will be described in the section Collaborative processes: local scale definition and diagnostic indicators.

3. Collaborative approach in inter and transdisciplinary research

The complex nature of sustainability demands a multi, inter, or even transdisciplinary approaches (Funtowicz & Ravetz, 1993; Ducrot et al., 2008; Mitchell, Cordell & Fam, 2015; Blythe et al., 2017; Klenk, 2018). They must involve an expanded community of peers in decision-making to deal with the underlying uncertainties of socio-environmental systems (Funtowicz & Ravetz, 1993).

Water-energy-food nexus thinking conceptually brings a favorable scenario to interaction between stakeholders and sectors, from the agenda-setting stage to the implementation of strategies and policies. Therefore, to understand its mechanisms, its study demands a qualitative framework to incorporate elements such as policy and governance, that helps to understand their influences in interlinkages between sectors (Lazaro et al., 2021). However, nexus promotes sustainable integration with a different perspective:

> *The nexus approach sheds light on the challenges of implementation by introducing concepts of trade-offs and thresholds and consequently emphasizes the importance of transdisciplinary approaches to sustainable development (Kurian, 2017, p. 105).*

Interdisciplinary research occurs when “multiple disciplines work together to tackle common problems” (Steffen et al., 2020, p. 56). Transdisciplinarity, on the other hand, goes beyond the limits of academic disciplines. There is a consensus that it represents more than the composition of multiple disciplines to tackle a scientific or social problem. Collaboration is usually a central aspect (Mitchell, Cordell & Fam, 2015; Blytheet al., 2017; Klenk, 2018), with the participation of stakeholders outside scientific and academic institutions being considered an important element of transdisciplinary processes (Funtowicz & Ravetz, 1993; Ducrot et al., 2008; Scholz & Steiner, 2015; Blythe et al., 2017; Klenk, 2018; Rigolot, 2020).

According to Scholz and Steiner (2015), transdisciplinary can be summarized as the processes that relates interdisciplinary research (scientific knowledge and rigor) with knowledge of multi-stakeholder discourses (experiential knowledge) and are based on knowledge integration from science and practice (Figure 1). There are different team structures to academic knowledge construction (Academic knowledge - Scientific subteams), in which three collaboration team configurations are associated (Figure 1). Mono-disciplinary collaborations represent teams that work with one field perspective. In the Nexus Project context, for example, teams that work with the climate, hydrology, and biodiversity, fall into that category. Cross-disciplinary collaborations are teams composed of several areas of expertise connected by an area or research subject, an interdisciplinary perspective. Participatory research has a transdisciplinary perspective, which goes beyond the limits of academic and scientific audiences, including a variety of stakeholders.

We understand that the process of collective construction of transdisciplinary knowledge brings together disciplinary and interdisciplinary collaborative structures and participatory structures. Collaborative structures are those that exclusively involve the production of academic knowledge, that is, carried out by scientists and experts from the scientific community. On the other hand, the participatory structure consists of the collective construction of knowledge that integrates knowledge beyond the academic community. It should contemplate knowledge of the entire social stakeholders (e.g., traditional knowledge, policymakers, decision-makers, media, etc.) in a horizontal perspective, over the same research object. Therefore, the participatory process involves multiple collective exchanges, a mutual learning process, language and terms alignments and ontological comprehension.

Therefore, transdisciplinary can be characterized by “collaboration with diverse partners who possess varied knowledge systems and epistemologies” (Steelman et al., 2021, p. 641). Thus, it highlights that “transdisciplinary differs fundamentally from applied research or unidirectional knowledge transfer” (Scholz & Steiner, 2015, p. 531).

Concerning the feasibility of transdisciplinary research, it is necessary to deal with the range of collaborative complexity that occurs within a large project addressing human-natural systems (Morton et al., 2015). This kind of initiative often requires multiple components of collaboration, organized in sub-teams with specific objectives and different levels of integration, working as mono-disciplinary collaboration components, as well as cross-disciplinary collaboration groups and others focused on participatory processes systems (Morton et al., 2015).

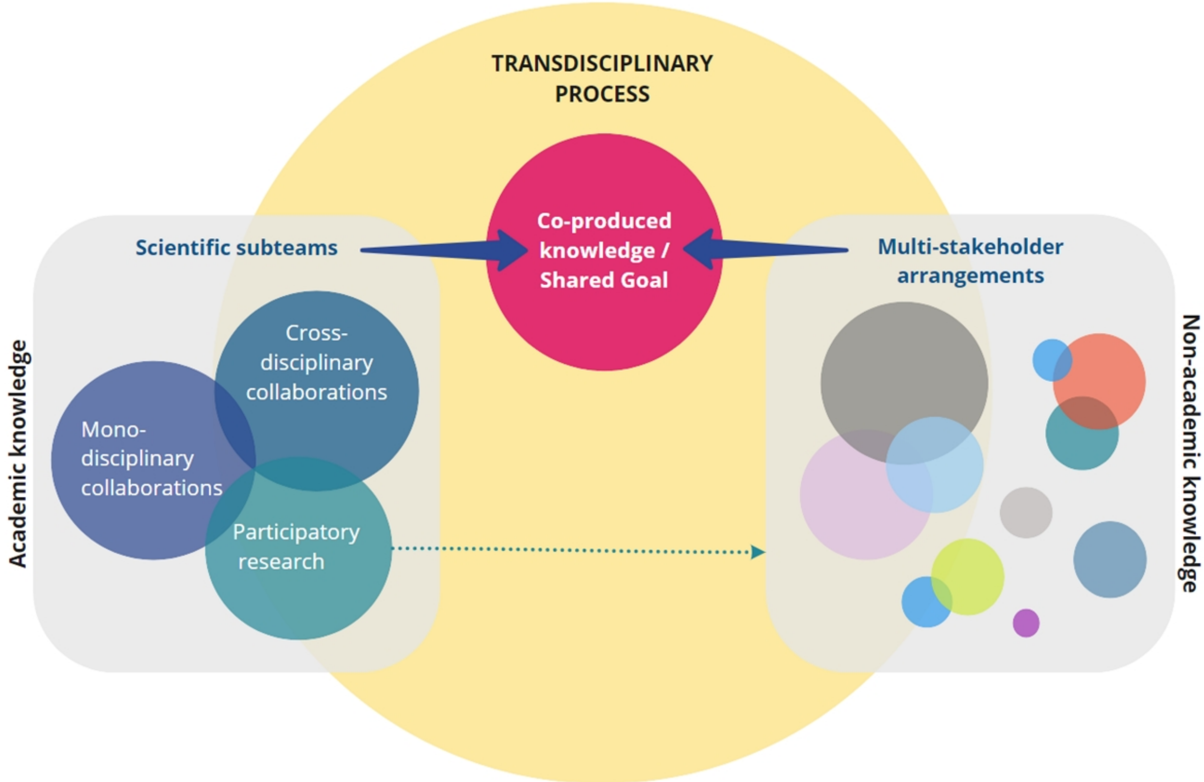


Figure 1. Graphical representation of the transdisciplinary process involving scientific teams and multi-stakeholders' arrangements.

Source. Elaborated by the authors.

4. Nexus Project

The Nexus project is funded by the São Paulo State Research Foundation (FAPESP) and has a strong adherence to the objectives of the FAPESP Research Program on Global Climate Change (PFPMCG). The project has a research focus at the local and regional levels, combining three scales: biomes (Cerrado and Caatinga), hydrographic basins (São Francisco and Parnaíba), and local (municipalities in the region) (Figures 2 and 3).

Cerrado and Caatinga biomes have the greatest potential for agricultural expansion in Brazil, in terms of land availability (Brock et al, 2021), but also a high potential for solar and wind for energy production. Their natural resources are also vital for climate regulation, human survival, and wellbeing. Nexus Project aims to explore how a participatory approach could support the transition to a sustainable future in these two biomes. It integrates qualitative and quantitative methods of the natural and social sciences at multiple scales to define scenarios and indicators that reconcile the three pillars of sustainability (economic, social, and environmental) in food production and use of natural resources (Figure 2).

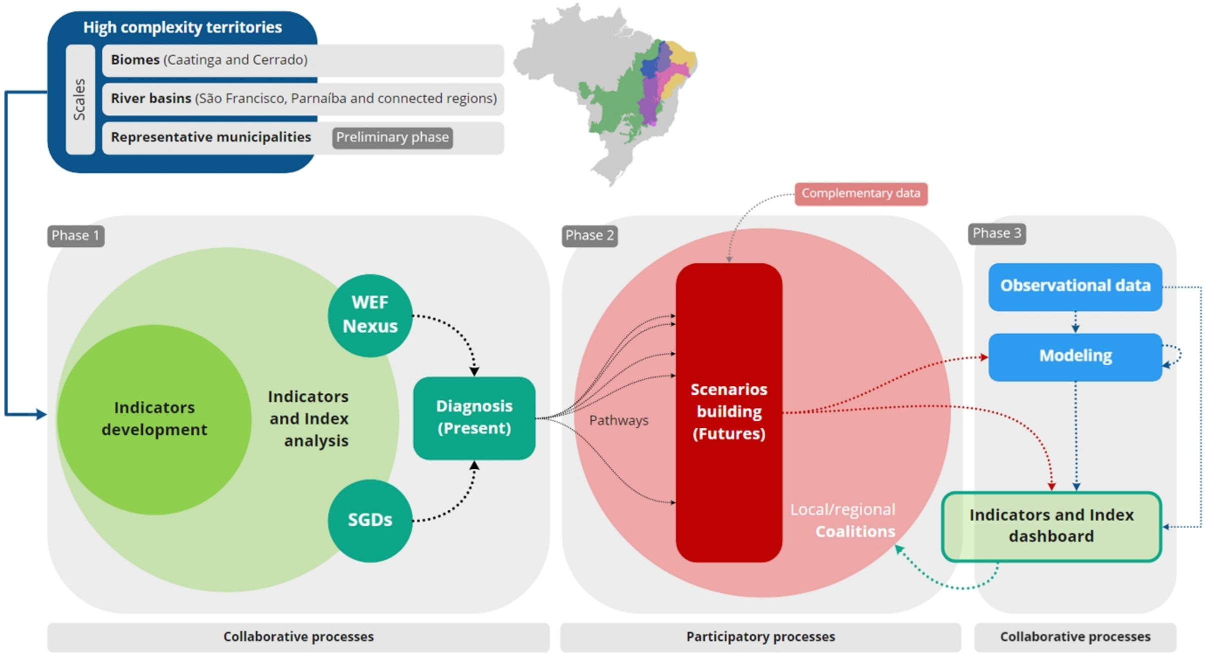
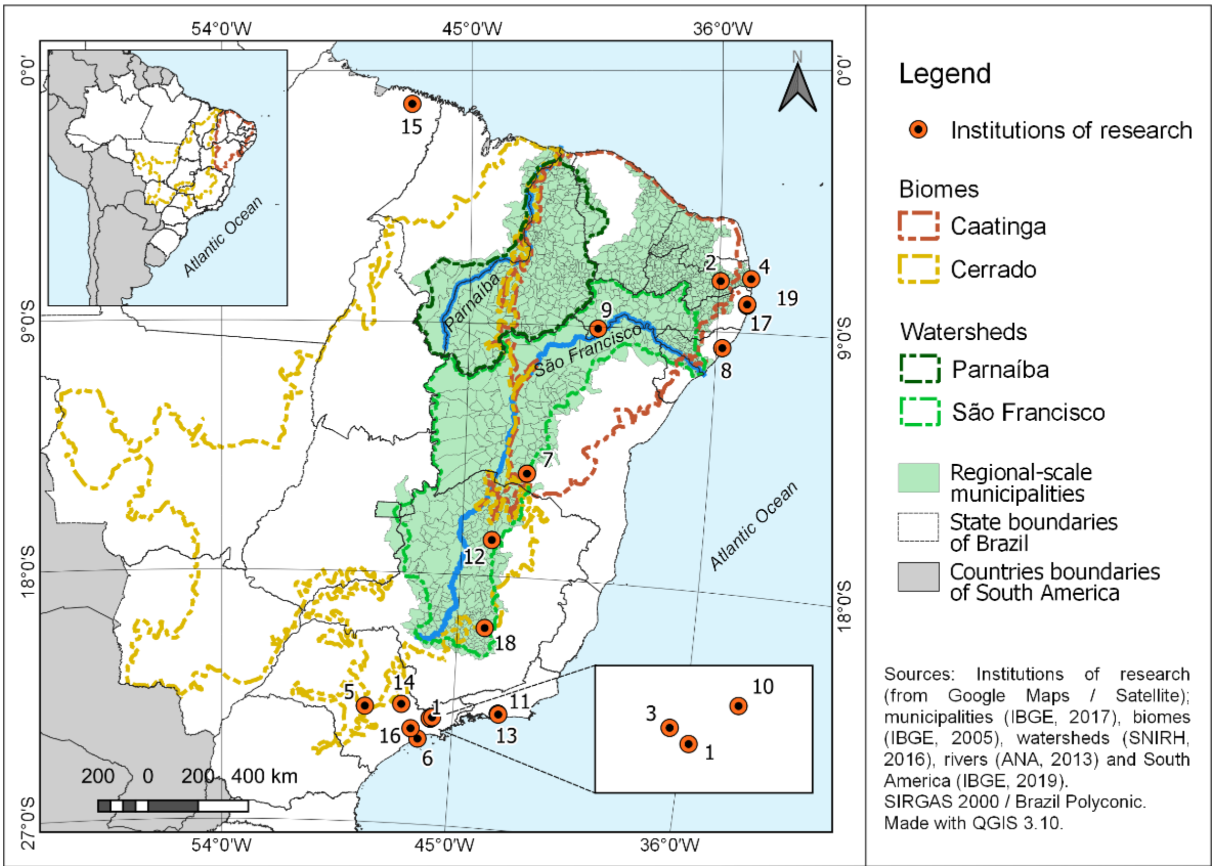


Figure 2. Overall methodology of Nexus project.

Source. Elaborated by the authors.

The project – which will last five years (2018-2023) – has three phases with specific goals (Figure 2). Phase 1 focuses on past and present aspects. It includes the organization and analysis of data on the social, economic, institutional, and environmental dimensions of the study area toward sustainability indexes that reflect the current context. The theoretical-methodological approach of phase 1 is a collaborative and multidisciplinary process involving mono-disciplinary collaborations and cross-disciplinary collaborations (interdisciplinary research) (Figure 1) from different institutions of the Project (Figure 3). Phase 2, "Participatory research" (Figure 1), focuses on the future of the study area by building qualitative and quantitative participatory scenarios, characterizing a transdisciplinary process, as it involves, in addition to different teams of researchers, non-academic stakeholders. Phase 3 involves the synthesis of activities among the scales, analyzing social transformation trajectories to achieve sustainability.

The transdisciplinary nature of the Nexus project requires the collaboration of different disciplines and institutions (Ducrot et al., 2008; Endo et al., 2020) with arrangements that consider academic and non-academic knowledge, especially in phase 2 with participatory scenario-building. Although collaborative approaches – the object of this chapter – have different configurations and academic stakeholders, the collaborative process of this project took place between researchers from several institutions and regions in Brazil (Figure 3).



1 Instituto Nacional de Pesquisas Espaciais/INPE/MCTI; 2 Instituto Nacional do Semiárido/INSA/MCTI;
3 Fundação de Ciência, Aplicações e Tecnologia Espaciais/FUNCATE/FUNCATE; 4 Centro de Ciências Exatas e da Natureza/CCEN/UFPB;
5 Faculdade de Ciências Agronômicas de Botucatu/FCA/UNESP; 6 Instituto do Mar/IMAR/UNIFESP;
7 Campus Guanambi/IFBAIANOGNB/IFBAIANO; 8 Centro de Ciências Exatas e Naturais/CCEN/UFAL;
9 Embrapa Semiárido/CPATSA/EMBRAPA; 10 Centro Nacional de Monitoramento e Alertas de Desastres Naturais/CEMADEN/MCTI;
11 Fundação Oswaldo Cruz/FIOCRUZ; 12 Centro de Ciências Humanas/CCH/UNIMONTES; 13 Museu Nacional/MN/UFRJ;
14 Embrapa Meio Ambiente/CNPMA/EMBRAPA; 15 Campus Capanema/UFRACAP/UFRA; 16 Museu de Zoologia/MZ/USP;
17 Centro de Tecnologia e Geociências/CTG/UFPE; 18 Fundação de Desenvolvimento da Pesquisa/FUNDEP/FUNDEP;
19 Universidade Federal Rural de Pernambuco/UFRPE.

Figure 3. Study area with biomes and watershed scales and spatial distribution of research institutions in Brazil.

Source. Elaborated by the authors.

5. Collaborative processes: local scale definition and diagnostic indicators

This section describes two experiences of a collaborative process: (1) define the local scale of the project (preliminary phase, Figure 2) and (2) select the indicators for diagnosis of the present on the Biome Scale (phase 1, Figure 2).

5.1 Local scale definition

The collaborative process was essential for engaging researchers into contributing for the next studies in such municipalities to select municipalities for the project's 'Local Scale'. The Local Scale must be representative of the subsequent scale – Regional Scale, as well as being relevant and feasible for the Project studies. To this end, the purpose of applying a cross-disciplinary collaborations approach was to identify representative variables for the region, identify locations with effective or potential collaborations with local institutions, statements about possible relevant elements to the definition of these municipalities, and discuss and vote on the most suitable municipalities for the Local Scale.

The selection of variables took place through a “world-cafe" process, toward themes prospection. The world-cafe[2] aims to disseminate information and assemble the knowledge of researchers and experts on different topics, promoting interaction of researchers through targeted discussions on a subject. The main idea of the world-cafe was to gather what is known about indicators and available data related to Nexus themes. A one-day workshop was framed based on this methodology using as resources maps and common vulnerability situations of the project's regional scale, and thematic roundtables with researchers.

Through the rotation of research themes and ideas, it was possible to balance the knowledge between experts from different areas, as well as to reveal new perspectives and uncertainties that are normally hidden or neglected in large plenary sessions, with this cross-disciplinary collaboration (Morton et al., 2015).

To capture the locations where there were effective or potential institutional partnerships, a map in panel format was available during two weeks in the institution (CCST/INPE) building hall so that the entire community

2 http://www.theworldcafe.com/

could take notice of such information. This first collaborative stage enabled selecting an initial set of variables; mapping of uncertainties and future adjustments to the variable's development; locations with effective or potential institutional collaboration; and the integration of the project community. This integration project-community is a fundamental meta-methodological process for sustaining collaborative activities.

After the compilation of data and checking its availability from the collaborative stages, the second step comprises computational data processing, which generates a regionalized index of priority municipalities, concerning relevance and representativeness within the regional scale (Figure 3). This index was based on the Self Organizing Maps (SOM) method (Kohonen, 1998), which allows identification of patterns of selected variables and clustering of the universe of municipalities.

With the index of priority municipalities created by a computational model, there was another collaboration process to bring together researchers into discussing the consolidated results and choosing the local areas with high potential for the study. This process involves greater complexity than the previous one, as it is no longer a prospective approach, but a decision-making process. After the presentation of the index of priority municipalities, researchers were distributed to focal roundtables, oriented by maps, and prepared by the workshop facilitators team. The group discussion focused on defining the municipality that met the greatest number of aspects of interest for the project science.

The challenge of reaching a consensus is a non-trivial task that necessarily involves the formation of coalitions, the construction of arguments and their negotiation with other participants in the process. The idea goes beyond choosing local areas but strengthening ties among different groups of researchers. As a result of this phase, four priority municipalities were selected. Another positive and constructive outcome was the emergence of action groups that showed interest in similar locations and themes, identifying, and capitalizing synergies among subprojects and, finally, the exposure of theoretical and methodological barriers.

All these elements and the entire process have revealed a great engagement of the community toward interdisciplinary pathways. As well, a positive breakthrough from the conflicts and discussions that naturally emerged and that an interdisciplinary effort might face. We consider this meta-methodological concern as important as the indicator's definition of local areas. They are the fundamental pillars of any interdisciplinary development.

5.2 Indicators collaborative construction and analysis

The objective of indicators development (Figure 2) is to build and analyze a set of thematic indicators in the Cerrado and Caatinga biomes, which will serve as a baseline for participatory scenario construction.

Indicators are usually used as a tool for visualizing the reality of the analyzed object. Indicators comprise a way to inform and measure behavior or state of a system or phenomenon in terms of expressive and perceptible attributes (OECD, 1993). Due to these characteristics, indicators have been used to translate and communicate social and environmental complex phenomena (Maggino, 2017) to the broad public, but mainly to decision-makers and environmental managers, to monitoring targets of sustainable development (Jannuzzi, 2006; Van Bellen, 2006).

The indicator development derived an analytical structure of construction of indicators, and analysis of indicators. The construction of indicators strategy aimed at organizing a set of initial indicators that will be used to build the baseline. This organization started from collaborative prospecting activities and production of indicators from eight thematic groups - Water Resources, Agriculture, Forest Conservation and Biodiversity, Land Degradation, Energy, Socioeconomics, GEE and BGQ Cycles and Climatic Risks - on project researchers' thematic affinity. This capillary organization culminated in a proposition of 127 indicators, by the aforementioned thematic groups, which were collected for a local scale and stored in the dedicated database.

After indicators' construction, they were submitted to an indicator analysis strategy. The basis for this analysis is the Sustainable Development Goals (SDGs) of Agenda 2030. The SDGs are the most prominent entry points for nexus mainstreaming (Hoff, 2018), because both – nexus approach and the SDGs – share the same principles of cross-sectoral integration and universality, while the achievement of a target must be considered without the cost of another one (Nilsson, Griggs & Visbeck, 2016). This analysis consists of framing the initial set of indicators in relation to the SDG and WEF Nexus conceptual frameworks (Figure 4), to aggregate the indicators into themes, goals and layers that have adherence to issues applied to territories, topics of interest and decision-makers.

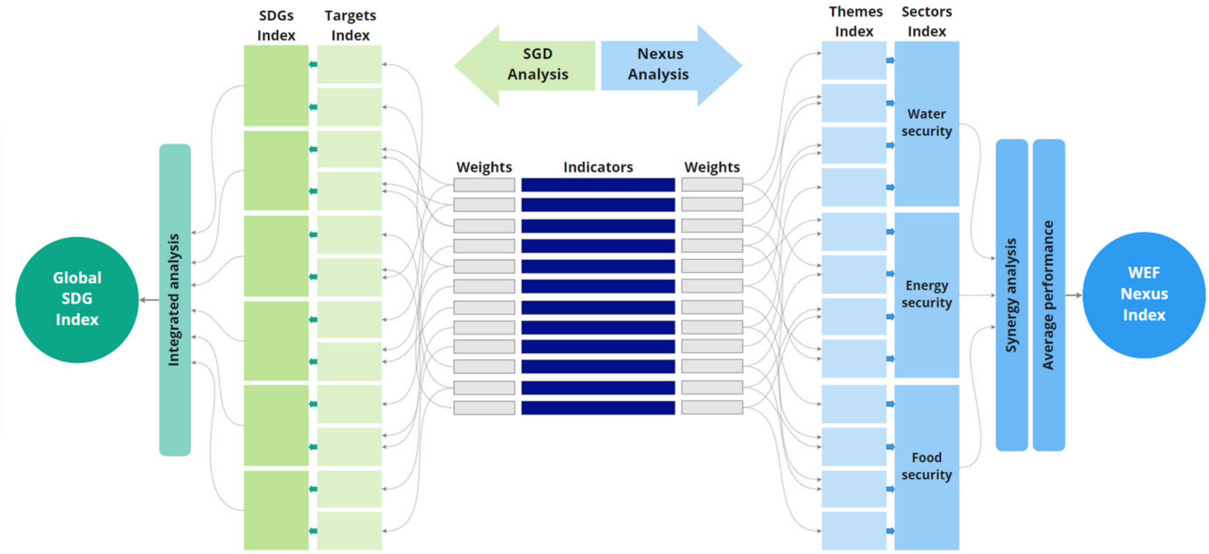


Figure 4. Nexus project indicators and the SDG Agenda Index.
Source. Elaborated by the authors.

The project's internal indicator analysis team2 organized statistical analysis, aggregation, and treatment activities, according to Nardo et al. (2008) and Becker et al. (2019). At each preliminary output, experts were consulted and asked to evaluate the data, weights, and treatment process, in a constant flow of collaborative interaction. This step shall culminate in an adherence matrix, which has the potential not only to aggregate indicators according to multiple filters of conceptual frameworks, but also to provide multiple layered views on maps.

This conceptual model innovates by relating a pool of indicators of common relevance to the SDG and WEF Nexus conceptual frameworks (Figure 4), as well as keeping a cross-disciplinary collaboration interface between experts within the classical framework of constructing indicators. This engagement of experts throughout a fundamentally quantitative process ensured the permanent flow of ideas and interactions between participants.

We highlight the fact that underlines that this model goes beyond a pure verification engagement, as far as the process promotes spaces for reflexive interaction. Participants, from the discussion on indicators, has perceived themselves in a complex chain of interactions that goes beyond the data itself. They started to recognize the form of scientific construction, the consolidation and consensus-building processes, the understanding of multiple points of view and, finally, an interdisciplinary construction process as the objects of analysis.

6. Challenges and potential solutions of the collaborative approach

Challenges of water, energy and food nexus research are commonly related to the integration of three dimensions. For this project, this integration challenge is potentialized by the great number of researchers from multiple centers in the Northeast and Southeast regions of Brazil, in an interdisciplinary perspective.

This operational context might be translated into a challenge of embracing a great diversity of ontological and epistemological perspectives. Therefore, the challenge faced is to reconcile the research agenda of each field of knowledge, respecting its scientific and methodological peculiarities, in parallel to the agenda of the Nexus Project.

To deal with this diversity inherent to the nexus thinking, and to follow a common path within the project, collaborative strategies were adopted to promote integration of the researchers to make joint decisions, on common issues to all individual research agendas: local scale definition and diagnosis indicators.

In local scale definition, the set of technical resources - indicators and SOM - made it possible to harmonize epistemological/ontological perspectives and to integrate different demands and scientific approaches, towards collaboration and dialogue.

In our view, the integration aspect is more than reading data together. It is more about developing continuous dialog spaces which can enhance a reflexive process of construction and analysis of data, process, and perspectives from the diversity of technical areas. We observe from this experience that the learning process is time consuming and must generate materiality from the very beginning. For this reason, this collaborative strategy ought to be well structured, continuous over time, hierarchy horizontal and must provide enjoyable exchanges.

Both the local scale and the indicators of diagnosis processes will support the next stage of the project: the scenario construction - participatory research (phase 2, Figure 2). At this moment - between phase 1 and phase 2 - the challenge will transcend the researcher locus. The next step will have a transdisciplinary character (Figure 1), with the inclusion of actors from outside academia and research institutions.

Challenges still exist in the implementation of the several ongoing research of the Nexus project, as well as in the dialogue between all the researchers. Therefore, it is important to revisit and be aware of the key moments that demand integration and collaborative decisions, to promote and facilitate them in nexus approach research.

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CHAPTER 13

A methodology framework to access the impact of rural practices in the food-water-energy security nexus

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1. Introduction

According to Bosshard (2000), the concept of sustainability is one of the most challenging of recent times. This concept began to be disseminated in some specific disciplines in the 1970s. Almost two decades later, with the Brundtland Report (Western Cape Education Department, 1987), this term gained notoriety and expanded to different areas of research, in addition to being projected among decision makers worldwide. In this report, sustainable development is considered a process of change in which the exploitation of resources, the orientation of investments, the directions of ecological processes and institutional change are harmonized and in accordance with the needs of current and future generations. This concept of sustainability derives from the view that humans are impacting the environment at such an intense pace (using nature unsustainably) that it will soon result in the depletion of natural resources.

At the Rio 92 World Conference, the term sustainability was finally fully incorporated into the global agenda. Since then, the challenge of reconciling economic growth, environmental preservation and improving the population's living conditions is increasingly greater. Faced with this challenge, the restrictions imposed by environmental legislation and society's demand for environmentally friendly production, multiple approaches and tools are important strategies to support best land use decision. These functionalities have been developed to assess the impacts of (planned) activities on either individual dimensions of sustainability (e.g., environmental impact assessment; social impact assessment), as well as impacts on the interrelations of all three dimensions (sustainability impact assessment) (Schindler, Graef & König, 2015). However, existing frameworks still miss indicators to assess impacts on the food-water-energy nexus.

By 2030, it is estimated that the world population will be 8.3 billion people, putting further pressure on energy, water, food, land use and mineral extraction, especially in the developing world (Rockefeller Foundation & GBN, 2010). Between the years 2000 and 2050, maintaining the current pace, it is estimated that the global water demand will increase by up to 400% for the industry; 140% for energy generation; and 130% for supply, with irrigation decreasing by approximately 15%. These concerns are exposed in the 2030 Agenda, mainly highlighted in the sustainable development goals (SDG 2) Zero Hunger, (SDG 6) Clean Water and Sanitation and (SDG 7) Affordable and Clean Energy.

When translating the projections into quali-quantitative terms and their impacts on estimated economic costs, the World Economic Forum on global risks identified water security as one of the major global challenges, which could exceed $ 400 billion of business risks. Marcial (2015) highlights that, for the next nine years, the biggest concerns will be the industrial sector and the water supply for society. The author also points out that, by 2030, approximately one billion more people will live in areas with water scarcity and almost half of the world population will live in areas with severe water stress. On the other hand, integration between water user sectors is expected, especially in developed countries, generating greater benefit in the allocation of water resources (NISTEP, 2010).

In this context, changes in the flow of rivers will also affect the water levels in the reservoirs used to generate electricity, which is an intensive use of water resources (Trivedi et al., 2012). Meeting the growing energy demand will generate increased pressure on continental water resources, with repercussions on other users, such as those in agriculture and industry (WWAP, 2015).

Agricultural activity follows the same trend. By 2050, agriculture will need to produce 60% more food globally, and 100% more in developing countries. Since the current global growth rates of water demand for agriculture are unsustainable, the sector will have to increase its efficiency in the use of water, reducing losses and, even more importantly, increasing the productivity of crops in relation to the water resources used (WWAP, 2015).

Thus, it is imperative to create synergies to maximize the efficiency of natural resources according to the needs of society. One way is to consider sustainable rural practices as potential facilitators of this process, in view of the multifunctionality of agriculture (Vos & Hoogendoorn, 2000).

As questions on food, water and energy are complex, they need to be addressed in combination and cannot be treated as stand-alone problem. Applying a nexus approach allows a systematic integration to address issues related to food, water and energy security at various levels, generating different scenarios (Rasul, 2014; WEF, 2011; Hoff, 2011; Hellegers et al., 2008). This approach looks for ways to conceptualize and, if possible, quantify the links between FWE in a single structure capable of generating integrated assessments focused on food, water and energy security (Flammini et al., 2014).

Some of the elements considered by FWE nexus include: (i) the three sectors have billions of people without access (quantity, quality or both); (ii) there is a growing global demand and resource constraints for all of them;

(iii) the different availability on a regional scale and variations in supply and demand; (iv) the strong interdependencies with climate change and with the availability of natural resources (Bazilian et al., 2011).

While the nexus approach is growing in popularity to address the interconnected issues of global challenges, there is a lack of problematization of the concept of nexus governance (Urbinatti et al., 2020). To manage the highly interlinked dimensions of food, water and energy, it is required in fact strong coordination and negotiation across sectors and temporal and geographical scales, making the nexus governance a multi-level challenge involving a variety of actors and institutions (Pahl-Wostl, 2019; Stein, Barron & Moss, 2014; Weitz et al., 2017). Conflicting interests of stakeholders, as well as consolidated institutions and policies that address sectoral pressures in silos, need to be understood to build up mechanisms that allow continuous dialogue throughout the project's implementation.

In this sense, citizens as stakeholders are increasingly demanding to be engaged in planning decisions that affect them and their communities, at scales from local to global and this requires changes in how models are built (Voinov et al., 2016), as an alternative to promote a more effective governance process.

2. Multi-functional agriculture and the FWE nexus

Multifunctional agriculture (MFA) refers to the ability of agricultural activity going beyond its primary role of producing food and fibre; and also providing several other functions such as renewable natural resources management, landscape and biodiversity conservation, and contribution to the socio-economic viability of rural areas (Renting et al., 2009). This concept can be extended to the notion that the contributions of agriculture to environmental externalities also covers development challenges like food security, poverty alleviation, social welfare and cultural heritage.

In general, it is possible to affirm that agricultural lands represent an opportunity to improve the ability of soils to provide ecosystem services through the adoption of good agricultural management practices, since these practices can maintain or even increase the input of organic matter in the soil (Novotny et al., 2020). Therefore, the main drive of the MFA is agricultural practices. On one hand, conventional practices can affect the water sector through land degradation, changes in runoff, and disruption of groundwater discharge;

however, conservation agriculture can improve the soil quality and contribute to MFA.

The agricultural sector is relevant for the national economy – after achieving record growth in 2020, the Brazilian agribusiness Gross Domestic Product (GDP) rose by 5.35% in the first quarter of 2021 (CEPEA, 2021). Thus, it is important to integrate the food production vision in generating other benefits for society. The main objective of this chapter is to present a methodology framework for evaluating the impact of rural landscape management practices on the FWE nexus.

To this end, the Rio Claro municipality, in Rio de Janeiro State, is used as a case study, located in the Atlantic Forest biome. The Atlantic Forest is the Brazilian biome with the highest population density within the country, hosting 72% of the population, and contributing for 70% of the Brazilian GDP (SOS Mata Atlantica, 2020). In this way, the demand for water, energy and food in this biome is high. The intensive use of their land for agriculture, urbanization and industrialization has led to high rates of deforestation, which resulted in the loss of many ecological functions, especially those related to the supply of FWE (Joly, Metzger & Tabarelli, 2014; Rezende et al., 2015).

Rio Claro municipality has about 20,000 inhabitants (IBGE, 2020) and its entire area contributes directly to the Ribeirão das Lajes reservoir, an important source of water and energy for the metropolitan region and the city of Rio de Janeiro/Brazil, the second most populated city in the country. The predominant land use is pastures, and it presents a low use of agriculture conservationist practices; thus, environmental problems resulting from the degradation of its lands. This is a very common scenario that we can find in the cities in the Atlantic Forest biome. Hence, developing integrated studies considering the FWE security nexus is fundamental in this context, especially the possibility of transforming the landscape through conservationist practices that can restore the quality of the lands, increasing agricultural production, reducing erosion and optimizing water use and energy generation.

3. The FWE methodology framework

We considered the FoPIA (Framework for Participatory Impact Assessment) methodology (Morris et al., 2011) a starting point to build our FWE nexus evaluation. The FoPIA is meant to enable assessments of policy impacts that are sensitive to national, regional and native sustainability priorities by harnessing the knowledge and expertise of national, regional and native stakeholders who play a central role within the analytical process. The analysis of specific sustainability problems gives rise to realistic national and regional policy and land use change scenarios (Morris et al., 2011; Coutinho et al., 2017). Still, the FoPIA has been useful to arrange for the participatory assessment of serious changes in land use and within the possibility of sustainability, key elements in our investigation.

Additionally, due the complexity of food security, water security and energy security concepts, this methodology is framed to evaluate the "availability and stability" dimensions of each security component.

Therefore, the methodology framework was developed as followed:

i. Project support database

A database was built using secondary data available in official dataset (free data) to subsidize the landscape characterization; the rural practices to be evaluated; the definition of attributes and indicators and the indicators' analysis performance. This database was also used to establish the areas of direct (municipality of Rio Claro) and indirect influence (other municipalities of the study area) on the Ribeirão das Lajes Reservoir (Figure 1).

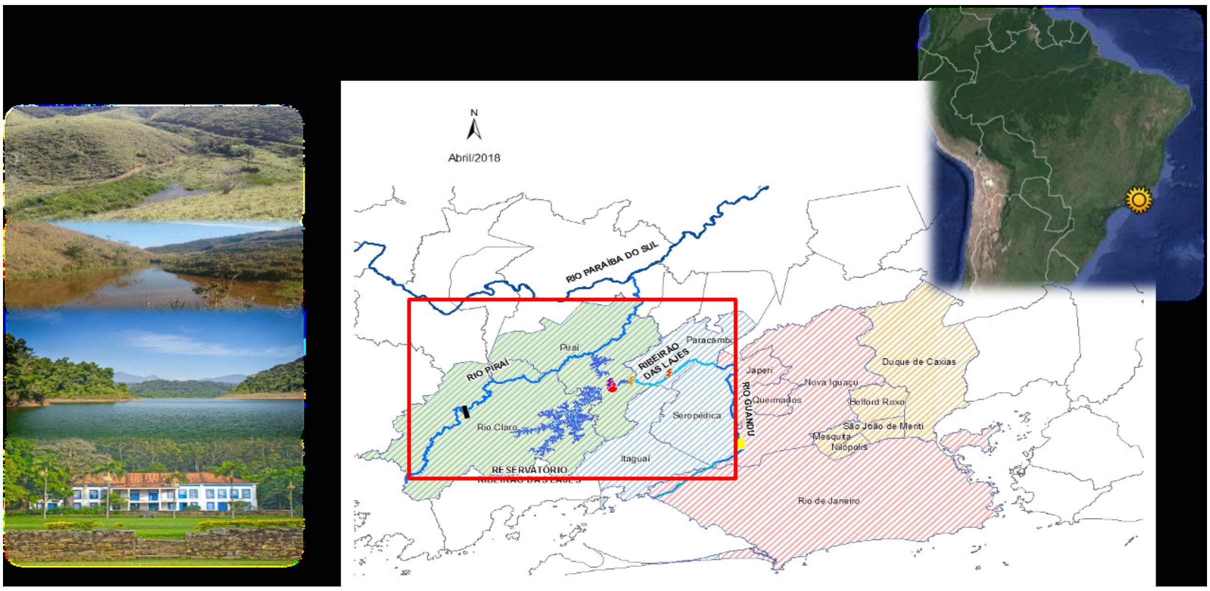

Figure 1. Study area and its surroundings.
Source. Elaine Cristina Cardoso Fidalgo.

In order to validate the information, two field trips were carried out: one in the first year of the project and the second one in the third year. The main goal of the first field trip was to support the final list definition of the agriculture practices to be evaluated in our study. Thus, based on the IBGE agricultural census, from the years 1995, 2006, and 2017 and in a field trip, we defined agroforestry, spring protection, pasture rotation and sanitation as the most relevant rural practices considering the past and present land use in Rio Claro municipality.

The second field trip's main goal was to present the information that has been collected to the local rural extension agents, and make adjustments, if necessary.

ii. Literature review

We performed a literature review to assess research papers that link rural practices and their impact on food, water and energy production. Brazil is a country with an important agricultural sector, and there are many studies investigating the impact of agricultural practices on soil erosion and water runoff within Brazilian landscapes (Xiong, Sun & Chen, 2018). We focused on the Brazilian Atlantic Forest biome as a study case. We searched the Web of Science database, using a combination of keywords with at least one rural conservation practice (Spring protection / Headwater protection; Riparian restoration; No tillage; Conventional crop / Conventional agriculture; Minimum crop; Organic crop / Organic Fertilization / Organic agriculture; Green adubation / Green fertilization; Crop rotation; Terrace; Level crop; Containment basin; Basic sanitation; Rural tourism / Agritourism; Agroforestry / Agroforestry; Fallow; Soil manage / Soil management; Pasture rotation / rotational grazing; Manure treatment), and one security aspect (Water; Energy / power / hydropower; Food; Agricultural production; Crop production) and one location-related word (Brazil; Atlantic Forest). We restricted our search to terrestrial landscapes in rural, agricultural, mixed rural-urban or natural habitat regions, in the Atlantic Forest Biome, thus excluding strictly urban or marine landscapes (Duarte et.al., 2021).

iii. Public Policies survey

A survey and systematization of public policy instruments on federal (national level), state (State of Rio de Janeiro) and municipal (with a focus on Rio Claro municipality) was carried out. The correlated public policies were analyzed one by one regarding their relevance for the study region and in relation to FWE security.

The policies were classified and selected using the following criteria: being in force, taking into account the aggregation of income, containing terms related to sustainability, including participatory processes, contributing to the provision of ecosystem services, providing for awareness and training actions, and having terms related to FWE security.

iv. Participatory workshop and definition of landscape attributes and indicators

At the end of the first year of the project, a group of 32 professionals joined an expert workshop held at Embrapa Soils, Rio de Janeiro - Brazil. The goal was to adapt part of the FoPIA methodology, basically comprised in three stages: (1) to define the project baseline, based on all the secondary data collected and systematized (items i and ii); (2) The definition of the landscape attributes; (3) The definition of indicators for each landscape attributes defined for each FWE nexus security.

The landscape attributes were proposed based on the concept of "Land Use Functions" (Pérez-Soba, Petit, & Jone, 2008; Turetta & Coutinho, 2015), that are related to the way each land use class can contribute to a certain objective. For the purpose of our study, the concept is understood as how each land use / land cover can contribute to FWE nexus security.

Organized in thematic groups – food, water, energy – the experts had the chance to discuss and define the most appropriate landscape attributes and indicators to evaluate the impact of rural practices in the FWE security nexus, that was presented in the closing plenary. We can cite "diversification of agricultural production" as an example of the landscape attribute set by the thematic group dedicated to the "food" pillar. And the indicator selected to evaluate the performance of this attribute was the "nutritional value of agricultural production per inhabitant" (Fidalgo, Turetta & Pedreira, 2021).

The criterion to determine the landscape attributes were their ability to trigger changes in the availability and stability dimensions; and the criteria to set the indicators were their capacity to demonstrate the impact of a rural practice in FWE security nexus as well as their availability on the project database (item i).

v. Data integration

The data integration will follow a quantitative analysis, based on data collection to identify and assess the interlinkages between water, energy and food systems. This work clarifies which environmental and social resources are under pressure, identifies critical interlinkages, competing interests and therefore which 'nexus' issues may arise in the future. It includes collecting data on both the status of the ecosystem resource as well as socio-economic aspects, making use when possible of existing datasets (Flammini et al., 2014).

For each indicator, a benchmark value was established, based on existing legislation/literature or comparing Rio Claro performance with the municipalities that are part of its micro-region, which is an administrative level based on similarities set by the IBGE (2017). Then, based on the literature review (item ii) we could determine the impact of the selected rural practices - agroforestry, spring protection, pasture rotation and sanitation - on each indicator, evaluating the FEW security nexus in a business-as-usual scenario and considering a scenario of each rural practice implementation.

The results were presented for the most relevant stakeholders for our study case (Melloni et al., 2020) in order to check the adequacy of the proposed interventions and generate validated results that are able to be applied and contribute to an improvement in the FWE nexus security. It can raise awareness of the interlinked nature of global resources systems to be considered in decision-making processes (Flammini et al., 2014).

vi. E-learning platform

To facilitate and encourage the implementation of rural practices aligned with the framework proposed in the project in question, we adapted the benchmarking concept. In the project, it refers to the process of comparing the individual performance of each rural property with the performance of others that are engaged in similar activities, resulting in learning from the lessons of these comparisons, involves measurements and evaluations based on the proposed indicators production (food), environmental impact (water and energy) and the conservation practices adopted. Thus, an electronic platform was developed so that rural producers in the Rio Claro region, and similar contexts, with the support of technicians from rural extension institutions, can access performance indicators related to nexus, in addition to exchange integrated practices carried out in the basin (Ribeiro et al., 2020).

The platform is organized into 6 parts: (i) Home page, that contains general information about the project, the team, the platform itself and the registered properties; (ii) Indicators tab, with interactive graphics for direct comparison of properties after choosing attributes and indicators; (iii) Practices tab, that allows spatial visualization of applications; (iv) Benchmarking tab, that performs graphical comparisons between performance and practices, based on the nexus dimensions; (v) the Success Cases tab that contains different rural conservation practices from outside the basin; and (vi) Practice Registration to upload new practices.

vii. Nexus FWE governance assessment

The start point was a preliminary stakeholder analysis that identified actors and institutions that should be involved in the decision-making process, and also a panorama of entities, categorized in private, public, academia, and nonprofit entities with different interests that required communicative efforts to ensure participation and public representation regarding the FWE nexus evaluation (Melloni et al., 2020).

Based on the sustainability impact assessment tool, ScalA, we suggest a set of criteria to address such issues in an ex-ante assessment: (i) accountability gaps, (ii) administrative gaps, (iii) policy gaps, (iv) capacity gaps, and (v) data and information gaps; and 43 indicators from the nexus literature and the OECD categorization of multi-level governance gaps were defined to address a multilevel governance (Löhr et al.; OECD, 2018).

We summarize the methodology steps in figure 2.

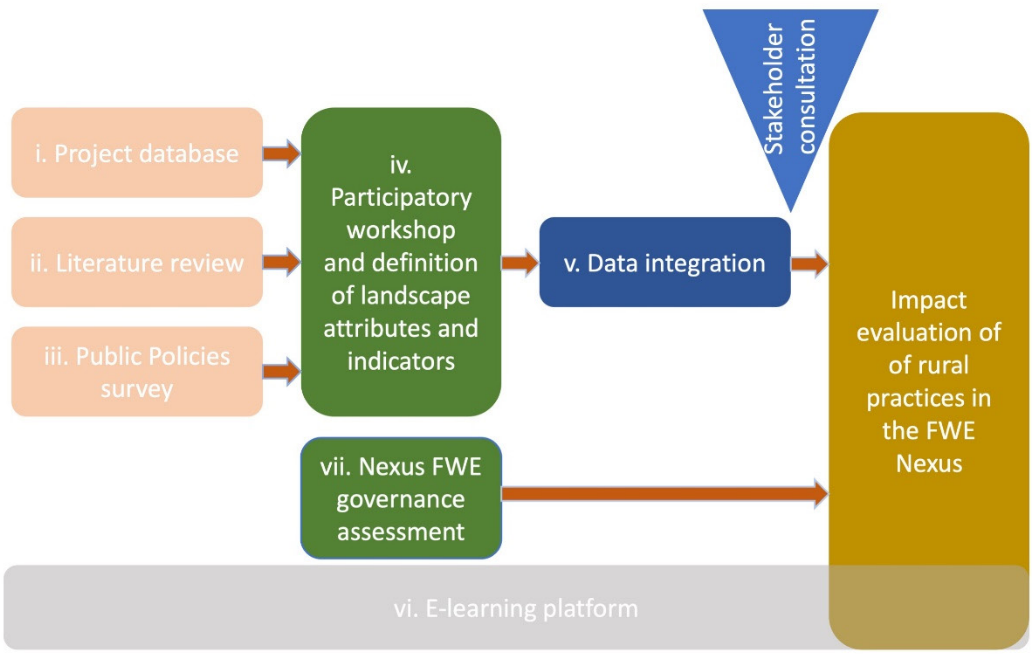

Figure 2. Methodology steps to evaluate the impact of rural practices in the FEW nexus.
Source. Ana Paula Dias Turetta.

4. Conclusions

Considering all the scenarios about population growth and the increasing demand for food, water and energy, we highlight the potential of MFA to provide a range of benefits – beyond its primary function that is to produce food – through the promotion of conservationist practices in rural landscapes.

We presented a feasible methodology framework to evaluate the impact of rural practices on the FWE security nexus in the Atlantic Forest biome. The basis of this methodology is the use of secondary data and a participatory approach. Thus, we ensure a bottom-up approach, promoting the stakeholder engagement and a low cost, promoting its applicability.

One of the main advantages of the framework is to use secondary data, available on official database. It reduces the cost, since the data is free, and stimulates its application by decision makers, especially those responsible by the cities' administration. Thus, we expect to promote a horizontal flow of information and decisions that can be helpful and easy to reproduce in other situations, improving the operationalization and FWE nexus governance.

However, the application and use of this FWE nexus assessment is subject to the supply of knowledge and the right technical expertise, as well as the data availability in adequate spatial and temporal scale. It's therefore important that the relevant actors identify experts, define training needs and consider the specified data sources.

In order for this approach to be implemented as an instrument of territorial management and development, we also highlight the importance to take in account the existing political instruments at different levels (national, regional and local), capable of encouraging and ensuring changes in an integrated manner with positive impacts on FWE security.

With the results of this nexus assessment, it is possible to compare the impacts of rural landscape interventions on FWE nexus. The advantages include the best decision on the employment and capital costs; and to determine how an intervention can perform in different contexts. All this enables the decision makers to prioritize and provide interventions considering the 'nexus' interlinkages.

The nexus FWE approach provides an innovative and versatile framework to systematically assess cross-sectoral interactions and is a noteworthy tool for analysis and for triggering more inter- disciplinary work. To reach this goal, it requires strong coordination and negotiation across sectors and across temporal and geographical scales, making the nexus governance a multi-level challenge involving a variety of actors and institutions.

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CHAPTER 14

Biomethane as a fuel for the transport sector in Brazil and the United States: an analysis based on the water-energy-food nexus

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1. Introduction

Global population growth forecasts that the need to adequately provide and manage food, water, and energy supplies will increase. In this context, the concept of the food-water-energy nexus becomes progressively important as the complex and interrelated nature of these global resources is understood and the need for more coordinated management of these assets across sectors and scales is desired.

In this chapter, we intend to show the potential and limitations of using biomethane as an alternative energy source for Brazil and the United States, two countries with significantly diverse transportation sectors. The estimated demand and the local availability of biomethane in these countries will be explored. Finally, the potential effects of the adoption of biomethane as a primary fuel in the transport sector will be discussed using the water–energy–food nexus.

Biogas represents a renewable source of sustainable energy for current and future generations. It is obtained from the treatment of vegetable, animal, human and industrial waste that is widely available in one or more of these forms in most countries. Although it is mainly composed of methane (CH4), which is 21 times more polluting than carbon dioxide (CO2) when released into the atmosphere, when biogas is purified, it is converted into biomethane. Biomethane can serve as an alternative to non-renewable energy sources and to diversify the energy matrix by serving as a substitute for fossil fuels. Moreover, it has the potential to transform environmental liabilities into economic assets (electric, thermal, and vehicular energy use), and provide greater energy security.

The transition to low carbon fuels for urban transport systems appears to be inevitable. In fact, the historical dependence on fossil fuels as a primary source of energy for post-industrial urbanization is being strongly questioned given the ever-decreasing availability of petroleum, and the social, economic, and mainly environmental consequences of its widespread use.

In 2019, known oil reserves in the world reached 1.7 trillion barrels, remaining at the same level as in 2018, with a small drop of 0.1% (ANP, 2020, p. 28). Oil, although finite, will never be exhausted entirely since there will always be some that for purely economic reasons will not be extracted. The concept of "depletion" of the oil reserve would apply to the availability of it at a viable price compared to alternative energy sources. The use of oil for specific applications where it might be irreplaceable will likely continue to exist in the foreseeable future. Even so, considering a global consumption of around 95 million barrels/day (ANP, 2020, p. 32), the known world reserves would be depleted in about 50 years.

The direct and indirect environmental consequences of the exploitation and massive use of fossil fuels has been an increasingly important argument in society, and the search for alternative sources of energy with less impact has led several countries to invest significant resources, especially in the last three decades. However, the sustainable development discourse has become diffused and lost in fragmented analyses of relatively small-scaled projects, that while successful, fail to address the overall deteriorating environmental conditions in the world (Atkinson, 2007).

Even international protocols, signed by a considerable number of countries, including several heavy polluters, have not produced significant results. The Kyoto Protocol, enacted in 1997 and signed by 174 countries, and the Paris Accord, enacted in 2015 and signed by 195 countries, are examples of international treaties that formulated a collective response to the consequences of the current development model based on the intensive use of fossil fuels for energy generation. Achieving the objective of restricting the increase in global temperature within the limit of 1.5°C requires, in addition to decreasing deforestation at the global level, stopping the burning of fossil fuels. A radical transformation in energy production and consumption is necessary, and replacement processes have been slower than initially expected.

Several alternatives to replace oil as fuel for the transport sector have been developed and applied in various countries: electromobility, the use of biofuels such as biodiesel and biomethane, Vehicular Natural Gas (VNG) and even hybrid alternatives combining different fuels. Rather than a simple economic assessment of technologies, the choice of the energy model for transportation in cities depends in part on technology development, availability of energy sources, and local demand. This transition is also driven by political, social, and mainly environmental considerations. These are especially important for decision-making and can be decisive in the choice of the model to be implemented.

Biomethane is one alternative to fossil fuels. Biomethane, also known as "renewable natural gas", comes from the purification of biogas. It can be used as a substitute for fossil fuels for sustainable urban transportation, emitting 86% less CO2 compared to gasoline (European Commission, 2011, p. 60).

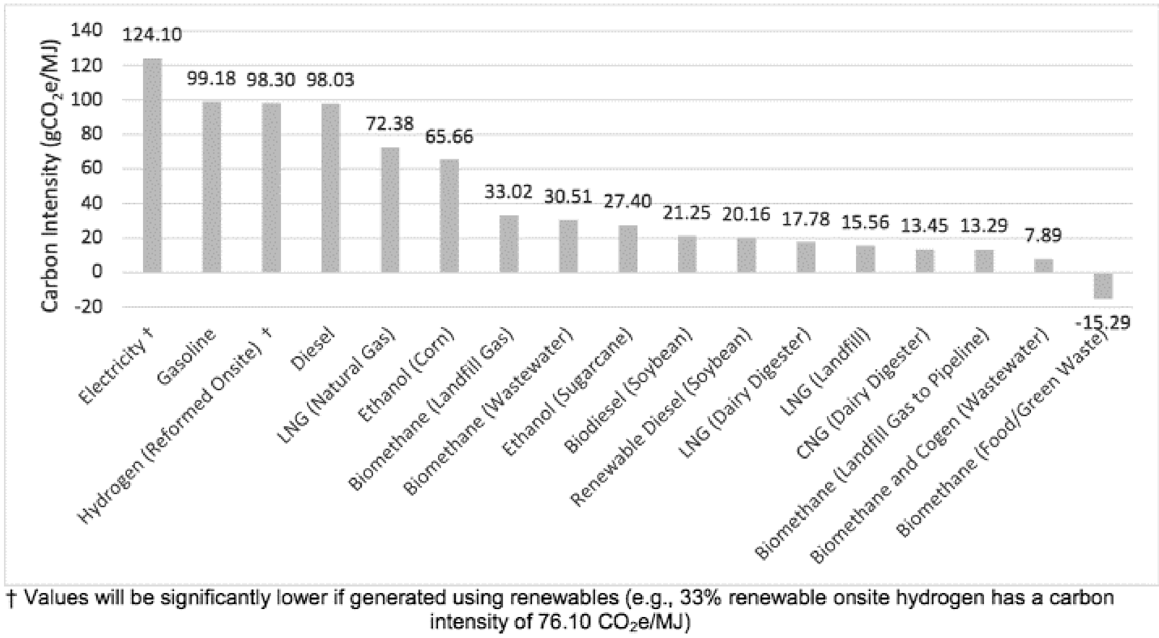

Figure 1. Pathways and fuel carbon intensities.
Source. California Energy Commission, 2015.

Figure 1 compares the main fuel alternatives for the transport sector based on carbon intensity, expressed in mass of equivalent CO2 emitted for each 1 MJ of energy produced. The use of electricity or Hydrogen are alternatives with a high production of CO2, but that depends on the technology and sources for its generation. For example, even though electricity can generate zero carbon in its use, its production and transmission can incorporate processes with a high carbon footprint.

Biomethane is a relatively low carbon intensive fuel (-15,29 g CO2e/MJ). The CO2 emissions, which are released into the atmosphere during biomethane combustion, is equal to the amount of carbon dioxide that is emitted during natural decomposition of the original organic matter (manure, for example). The negative profile of carbon intensity appears as the purification of biogas into biomethane as it reduces the CO2 content and it will not be released into the atmosphere.

However, such results can vary "if the residue after digestion (the digestate) is stored in the open air as it continues to produce methane". The most appropriate method to mitigate this is to have a closed digestate storage and methane recovery system. Compared to other renewable sources of energy, Biogas from liquid manure has the lowest emissions, being negative as it avoids water, air, and soil pollution, transforming these liabilities into assets (Figure 2).

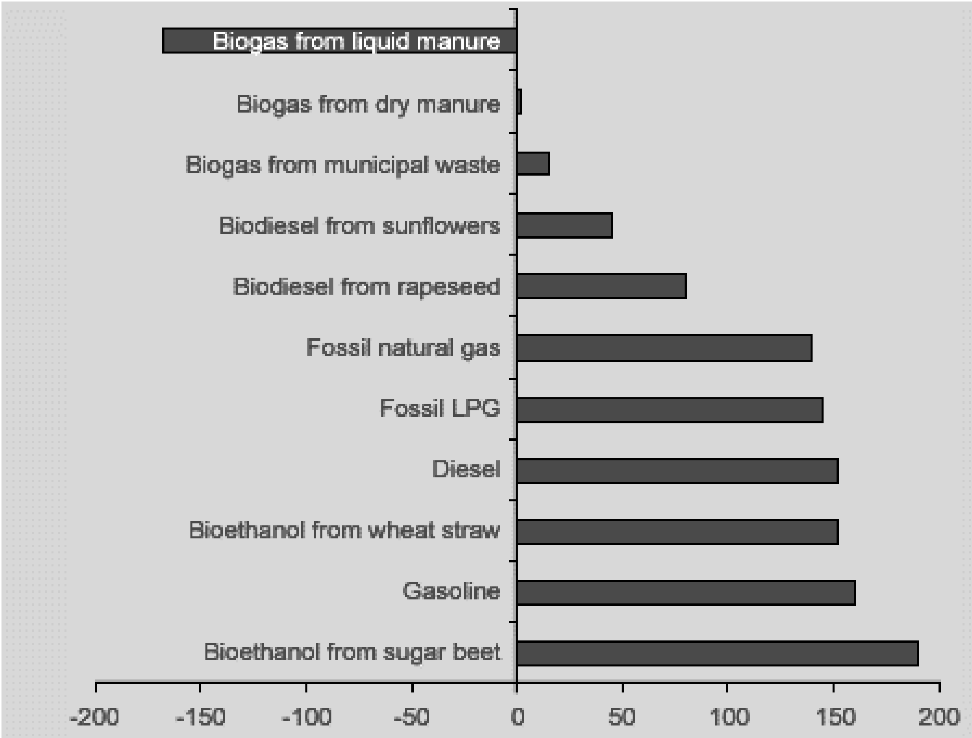

Figure 2. Comparison of biofuels emissions (grams of CO2 equivalent per km).
Source. European Commission, 2011.

2. Biomethane's potential as a primary source of transport sector fuel in Brazil and the USA

Brazil and the United States show a similar indicator profile regarding the opportunities for producing and using biogas and biomethane as a renewable source of energy (Table 1); they are among the five countries with the largest population in the world and largest territorial extension (5th and 3rd position, respectively) (World Bank, 2020); are leaders in food production, 4th and 3rd place, respectively, representing 9% and 10% of all world production (FAO, 2014); they stand out for high energy consumption, with the 9th and 2nd positions (IEA, 2020), and occupy the 1st and 3rd places in terms of highest availability of water in the world (CIA, 2011).

These countries also have a large agricultural sector. In Brazil, agriculture represents 24,31% of the country's GDP in 2020, which greatly favors the development of technologies for biogas use, using the waste generated by these activities and supporting the diversification of its energy matrix (CEPEA, 2021).

Description	**Rank**	
	Brazil	U.S.
Population1	5th	3rd
Territorial extension1	5th	3rd
Water availability2	1st	3rd
Energy consumption3	9th	2nd
Food production4	4th	3rd

Table 1. Relevant Indicators for Biomethane Production: Brazil and the US.

Sources. 1 World Bank, 2020; 2 CIA, 2011; 3 International Energy Agency, 2020; 4 Food and Agriculture Organization, 2014.

In addition to these factors, Brazil has intensive biodiversity and availability of water, along with a favorable weather that may strengthen its position as a global leader of biogas use in transportation and other sectors. According to Sachs (2008), Brazil's vast territory shelters varied ecosystems, most of them endowed with abundant water and forest resources and climates favorable to the production of biomass. In addition, the country has significant amounts of residues derived from livestock, mainly pig and cattle production, which can contribute to the production of biogas. Compared to Brazil, there are very few countries in the world that have such favorable conditions for the creation and application of trinomial biodiversity-biomass biotechnology (Sachs, 2008). Atkinson (2007) corroborates this view, stating that there are only a handful of countries with the potential for renewable sources of energy at such large scale and that significant progress on sustainable energy still needs to be made by the majority countries around the globe.

The transportation sector is a high-energy consumer in Brazil and in the Unites States, responsible for 33% and 28% of the total energy use share, respectively. In both countries, fossil fuels are dominant in this sector: in the U.S., they account for 89% of total transportation energy sources, and 76% in Brazil (IEA, 2020). The main sources of consumption in Brazil include diesel (45%), gasoline (29%), and ethanol (24%) (EPE, 2019). In the U.S., the main sources of fuel consumption are gasoline (59%) and diesel (25%). Biodiesel, including ethanol, represents 7% and natural gas 5%.

Ethanol is responsible for the reduction in fossil fuel dependence in Brazil, as it is produced mainly via sugar fermentation. Its production in Brazil is predominantly based on a no-tillage system of sugar cane which contributes to carbon sequestration, improves soil properties and biological nitrogen fixation. However, it increases the use of finite natural resources, notably phosphorus and potassium from the soil, which impacts fauna biodiversity and contaminates the water table. In the United States, ethanol is produced mainly with corn.

In recent years, it was confirmed that the use of ethanol in Brazil has contributed to lower greenhouse gases and consequently lower pollution of cities. A study conducted by the Brazilian Company of Agricultural Research (EMBRAPA, 2009) concluded that ethanol contributed to approximately 77% less CO2 emissions when compared with diesel oil, and 76% less when compared with Brazilian gasoline containing 27% ethanol.

Despite the reported reductions in CO2 emissions, Runge & Senauer (2007) criticize the production of food-based ethanol, such as sugarcane in the case of Brazil or corn in the case of the US, for its negative effects on world food security. By putting pressure on the world supply of edible crops, the rise in ethanol production will translate into higher prices for both industrialized and basic foods worldwide. As such, these biofuels can influence food and oil prices in a way that could profoundly disrupt the relationship between food producers and consumers, and between nations.

Other authors affirm that the quantity of food produced in both countries far exceeds the local population's needs, and is able to accommodate additional growth in ethanol production, spurring economic growth through the generation of new jobs and additional income (Hoffmann, 2006).

Analysis of the biogas and biomethane potential in both countries (taking into account the livestock sector), concluded that the U.S. has a potential to produce the equivalent of 4.8 billion gallons of gasoline for vehicles and provide residential power to around 3.2 million inhabitants per year, besides reducing methane emissions in an estimated range of 4 - 54 million tons of GHG/year by 2030 (Pasqual Lofhagen, 2018). Brazilian's biogas potential is enough to provide power to an estimated 6.21 million inhabitants per year and the biomethane potential is estimated at 1,961,171 million gallons per year, which is equivalent to 1,667.42 million gallons of diesel or 1,848.34 million gallons of gasoline, according to table 2.

Both countries have made important advances in developing biogas and biomethane regulatory frameworks, but a holistic and integrated view is still lacking. The use of biomethane for urban mobility would avoid the emission of 28,423,983 kg CO2e per year in Brazil and 74,327,145 kg CO2e in the U.S., replacing or complementing 44% of the diesel demand in Brazil and 16% of demand in the U.S.

Description	Brazil	United States
Biogas production (million m3/year)	11,421.3	29,866.0
Energy supply (million residents)	6.2	3.2
Biomethane potential (million gallons/year)	1,961,171.9	5,128,344.6
Diesel potential (million gallons/year)	1,667.42	4,360.21
Gasoline potential (million gallons/year)	1,848.34	4,883.29

Table 2. Comparison of the livestock biogas potential: Brazil and the US.

Source. Pasqual Lofhagen, Bollmann &Scott, 2017.

Encouraging the use of biogas requires a deeper understanding of the water, energy, and food nexus balance, not only because of the energy produced, but also the environmental externalities that it triggers.

> *The nexus concept explores interactions of multiple sectors across multiple scales, specifically management of food, water and energy security in local, regional, and transboundary settings, and the trade-offs and synergies created by competing resource use and policy agendas, requiring cross-sector and cross-scalar coordination and integration of resource management and environmental governance (Grenade et al., 2016, p. 3).*

3. Reflections of the water-energy-food nexus as a tool for the potentiality biomethane projects: opportunities and limitations

The water-energy-food nexus gained notoriety at the Bonn Conference in 2011. The event was organized to articulate policies to be presented at the United Nations Conference on Sustainable Development (Rio+20). In the document prepared by Hoff (2011), the concept of the water-energy-food nexus emerged as an approach to potentially increase security in the production and supply of these three elements, considered fundamental for the individual and collective survival of a population.

The nexus focused conceptual and empirical analysis of the connections between its elements and provided a framework to coordinate more integrative policy development and management practices.

> *A nexus approach can also support the transition to a Green Economy, which aims, among other things, at resource use efficiency and greater policy coherence. […] Conventional policy- and decision-making in 'silos' therefore needs to give way to an approach that reduces trade-offs and builds synergies across sectors – a nexus approach (Hoff, 2011, p. 4).*

While the water-energy-food nexus provides an analytical framework, the scalability of its application remains contested. As the human population grows, economies develop, and globalization accelerates, the nexus provides one approach to collaboration across sectors and industry and advance co-management of natural resources, yet it remains to be seen whether it will be embraced, internationally, as a guide in decision making.

At the Rio+20 Conference held in 2012 in Rio de Janeiro/Brazil, representatives from 80 countries presented their social and environmental priorities for sustainable development (Table 3). The shaded social issues are those mentioned in at least half of the submissions, thereby forming the set of 11 social priorities for Rio+20. Among them, the issues water, energy, and food received great support by the government representatives as fundamentals for human life once they are considered as indispensable for human survival, and only after ensuring survival, it is possible to consider their sustainable development.

Even with this recognition, it is observed that the priorities must be identified and negotiated because they are the reflection of an environmental, social, economic, cultural, and psychological context of a population occupying a certain territory. Due to the heterogeneity of environmental conditions and population demands, as well as the variability of these demands over time, priorities vary from place to place, which reflects the lack of unanimity indicated in Table 3. In any case, the use of the Nexus was generally supported and, henceforth, researchers and practitioners have embarked on developing strategic priorities around the concept to advance sustainability (Kibler et al., 2018).

For Moraes & Ferraço (2018), the main premise of the nexus approach is that the hyperlinked worlds of water, energy and food are increasingly interdependent and the impacts on one sector affect others. However, from the point of view of its management, water, energy, and food resources have historically been treated in a disconnected manner by government structures that are still heavily sectorized, causing serious management problems. At this specific point, the application of the nexus as an integrative and systemic framework has the potential to reduce these problems and improve the overall efficiency in the management of environmental resources. In this way, the water-energy-food nexus can be understood as a systemic and integrative process of knowledge management in the identification and analysis of problems, in the selection of alternatives for their resolution, as well as in the creation of rules and goals for decision making processes (Secchi, 2012).

Another important aspect to be mentioned is that the nexus is not limited to the integrated management of natural resources. It has the potential to expand the discourse around sustainability by incorporating social side effects into conceptual analysis, for example, public health. Current environmental problems are complex; their scale is global; their impact is long-lasting and interrelated. As a result, policies designed to solve environmental problems cannot be determined based on scientific rationality alone. Rather, they must be based on politically negotiated consensus. Thus, in the formulation of policies, the forum for scientific debates is broadened to include, in addition to technical aspects, a range of interest groups that contribute to the formulation of decisions (Funktowicz & Ravetz, 1997).

SOCIAL PRIORITY	NUMBER OF SUBMISSION MENTIONS
Access to energy	68
Food security	65
Income poverty	64
Water and sanitation	60
Jobs / decent work	56
Health care	53
Education	50
Resilience	48
Gender equality	43
Voice and participation	43
Social inequity	41
Access to transport	30
Culture and indigenous rights	23
Adequate housing	19
Social protection	14

Table 3. Social and environmental concerns raised in governments' submissions to Rio+20 (out of a total of 80 submissions)

Source. Raworth, 2018.

The real understanding of the nexus approach has not yet been assimilated in international practice, mainly due to the transdisciplinary character of the perspective. The need to aggregate various analytical perspectives related to the fields of economics, environment, law, engineering, administration, and political science, among others, is a fundamental problem because it requires integrating the contributions of these academic fields. Nonetheless, there are institutional structures that promote a transdisciplinary approach. In Brazil, the Federal Constitution of 1988 provides for a harmonious participation between the public authorities and society in general for the management of natural resources. Law No. 9433/1997, which institutes the national water resources policy, demonstrates this concern when it institutes the participation of civil society and government in management collegiate bodies. For Souza Jr. (2004), in several cases the participation of the academic-scientific stakeholders, which represents an important advance in the discussion of the environmental problems, can destabilize through scientific argumentation the balance in the decision-making process. So, this proximity between science and political power can have undesirable consequences in a fully democratic and interdisciplinary decision-making process.

The same can occur in decision-making processes involving the management of the energy and food system, as both scientific and economic rationality can be used to establish policies that are not consensual among the interdisciplinary views involved.

The current practice of public management in the key sectors of development, which includes natural resources, is still based on a sectored public administration, with each sector being managed by its own logic. Government and private interests, which are not always in agreement, are difficult to resolve in order to stimulate public-private partnerships in the management of the relations between the elements that comprise the nexus, notwithstanding the challenges of managing each individual sector. In Brazil, water regulation and inspection are sectoral and represented by the National Water Agency (ANA), which is part of the Ministry of Environment (MMA); the electric energy sector is represented by the National Electric Energy Agency (ANEEL); the food sector, even without having its own regulatory agency, is managed in its productive aspects by the Ministry of Agriculture, Livestock and Supply (MAPA). The specific difficulty of each sector to implement its own objectives and targets is compounded by the lack of connection between these sectors, which in practice are interconnected, mainly to face common problems such as the effects of the global climate crisis, with the forecast of intensify conflicts over access to natural resources within its competence.

4. Applicability of the nexus for the assessment of biomethane

Water is an essential natural resource for human life and is also an input to produce agricultural goods in the fields and along the supply chain. Energy is needed to produce and distribute water and food: to pump water from underground sources or surface, to propel tractors and irrigation machines, to process and transport goods, and to transport people. Food production is constantly under pressure to meet the increasing demand caused by population growth, needing to be concerned not only with the production, but also with the waste generated. These three axes are under constant pressure, as food, water, and energy supply for all are priorities and human needs of the same greatness and complexity.

The water-energy-food nexus explores interfaces of multiple sectors across multiple scales, taking into account local, regional, and transboundary settings, "and the trade-offs and synergies created by competing resource use and policy agendas, requiring cross-sector and cross-scalar coordination and integration of resource management and environmental governance" (Grenade et al., 2016, p. 15).

The UN University (2014) points out that increasing food production in 50% by 2050 will require 45% more energy and 30% more water, which demonstrates that greater efficiency in energy production and use of other renewable sources other than water will be required. In this scenario, biogas stands out as a systemic source of energy, being generated by the appropriate treatment of vegetable, animal, human and industrial waste, transforming environmental liabilities into economic assets through two main results: a direct one, by the generation of electric, thermal, or vehicular energies (biomethane) and biofertilizers; and an indirect one, with the reduction of greenhouse gas emissions and, consequently, the mitigation of climate change.

It is worth mentioning that the energy generated by biogas and biomethane must be considered complementary and not exclusory to the other sources of energy, contributing to the diversification of the energy matrix. In addition to promoting these environmental and economic benefits, biogas promotes local social development, since the process for its production constitutes and sustains a relatively complex supply chain, requiring specialized local labor, technical and scientific support, and awareness and empowerment of the local population related to the biogas and biomethane process of production and management.

In this perspective, the WEF nexus has emerged as a useful concept to explain and address the complex and interrelated nature of these global resources, on which we depend to attain different social, economic, and environmental goals. In practical terms, it presents a conceptual approach to better understand and systematically analyze the interactions between the natural environment and human activities, and work towards a more coordinated management of the use of natural resources in all sectors and scales. Effective management of the nexus can help identify solutions and create synergies, allowing more integrated planning and costs, decision-making, implementation, monitoring and evaluation (FAO, 2014).

The discussion about WEF nexus forces us to think about the impact that a decision in one sector can have not only in that sector, but also on others. By anticipating potential trade-offs and synergies, it is possible to design, evaluate and prioritize response options that are feasible in different sectors. Recognizing these synergies and balance, the trade-offs is essential to jointly ensure water, energy, and food security.

According to International Renewable Energy Agency (IRENA, 2015), renewable energy technologies, for example, can address some of the trade-offs between WEF, bring considerable benefits in all three sectors and can allay competition by providing energy services using less resource-intensive processes and technologies, compared to conventional energy technologies. Figure 3 presents the compiled data about WEF scenarios for Brazil and the US, demonstrating their potential and opportunities for the WEF scenario.

5. Conclusion

In the Brazilian case, economic development policies were in the past, and, in a certain way, they are still based on the acceptance that we have sufficient water resources to supply the growing urban population, to supply even the highly water intensive activities in the productive sectors, and for the generation of the electricity needed to meet current and future demands. As a consequence, it is not necessary to imagine reciprocal interferences between these sectors of the economy, and, therefore, their development can occur through sectorial plans that are not articulated or are weakly articulated with each other.

However, the climate changes caused by the La Niña phenomenon and the deforestation are directly impacting water availability throughout the country, but more deeply in the south and southeast regions. Today it is already proven that the reduction of humidity caused by the deforestation of the Amazonian Forest harms the rain regime responsible for recharging the rivers and reservoirs that are important to generate electricity, supply cities, and support industrial activities and food production. The fact that we can nowadays observe increasingly prolonged cyclical periods of drought where the interval of these cycles is not sufficient to replenish these reservoirs shows that in many cases the use of water is already greater than its recharge capacity. And this phenomenon tends to place water as a scarce commodity, where energy production, food production and water supply become competitors, generating conflicts.

WEF	Brazil	USA
Water availability	43,000 m^3/capita/year	10,000 m^3/capita/year
Water distribution	Uneven: 80% of water is in Amazon region with less than 5% of the Brazilian population	Uneven
Water consumption	Average 166 L/capita/day	Average 378 L/capita/day
Main water use	Irrigation 75% Livestock 9% Urban supply 8% Industry supply 6% Rural use 2%	Thermoelectric plants 45% Irrigation 32% Public uses 12% Industry supply 4% Mining 1.5% Urban supply 1% Livestock 0.6% Others 2.7%
Energy from renewable sources	Total 76%: Hydro 64% Biomass 8% Wind 4%	Total 13%: Hydro 6% Biomass 2% Wind 5%
Vulnerability	Highly dependent of hydroelectricity and highly vulnerable to climate change and to the increase of water consumption, because legislation prioritizes human consumption	Better distribution among energy sources and less dependent of one. The problem is the massive use of oil and coal with impacts on greenhouse effects
CO2 per capita	2.3 ton CO_2/capita/year	16.2 ton CO_2/capita/year
Food	Great potential for food production (land available, water available and good climate). Production will increase in 40% up to 2050: need investments in technology and innovation for production	Great potential to food production (land and water available and good technology)

Figure 3. Compiled data about WEF scenarios for Brazil and the US.
Source. Pasqual Lofhagen, 2018.

In this sense, national strategic planning needs to realign its attitudes towards a new scenario that we have been witnessing for the past 10 years, where it is necessary to adapt sectoral growth strategies to a model of intersectoral analysis aimed at resolving existing conflicts, and that will be progressively more significant in the future. In these terms, the rational basis of the water-energy-food nexus allows us to foresee the limitations and the possibilities for improvement in our national development model.

The economic development that considers environmental and active restrictions for future generations represents an adequate initial structure as we look for sustainable energy models. The water-energy-food nexus model allows us to refine the picture of sustainability economic development-environmental protection-social equity, considering the main natural resources, explaining relevant externalities and allowing the exploitation of conflicts and synergies at multiple scales.

One of our goals is to inform the energy policy that will lead to sustainable solutions. A multi-scale exploration of water, food and energy will provide the information needed for a more comprehensive analysis of energy policy. Although the water-food-energy nexus is an essential first step, we must also consider the elements that are implicitly considered in the nexus, especially the expected changes in production and consumption patterns. For example, sustainable consumption involves changes in lifestyle and culture that will impact energy use, partly as a result of strategies to change the behavior of individual consumers. We must also remember that solutions to environmental problems must be based on politically negotiated consensus.

From the energy point of view and considering the need to diversify the national energy matrix and incorporate elements of long-term sustainability, biomethane represents an opportunity that must be carefully considered as alternative sources of renewable energy are sought. Its adoption has generated environmental benefits, such as general reductions in greenhouse gases, allowing the transition to fuels with a low carbon footprint. An initial analysis seems to indicate that biomethane has potential as a renewable energy source essential for economic development in line with the search for a green economy.

Finally, consumers in Brazil and the United States currently depend on biodiesel and ethanol for their daily activities. Both countries have to learn from each other, given the diverse challenges and successes experienced in changing production and consumption patterns for renewable sources of bioenergy.

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CHAPTER 15

Relationship between resource-oriented sanitation and the Nexus approach: water, energy and food perspectives on management and technologies

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1. Introduction

The global population will reach 8 billion by 2025 and 9.3 billion by 2050 (Rodell et al., 2018; Jama-Rodzénska et al., 2021), and will consequently hit an increase in waste, wastewater and sludge production. In this context, it is estimated that the countries with the highest amount of municipal wastewater production are United States, China, India, Brazil, and Indonesia (Mateo-Sagasta et al., 2017). However, about 20% of the total Global production can be recovered (Rhyner et al., 2018; Nhamo et al., 2018).

Resource-oriented sanitation (ROS) proposes changes in the paradigm of the classic design of engineering and sanitation, rethinking urban infrastructure and the built environment. It introduces a range of (eco)technologies that enable the integration of water reuse with nutrient recovery, including energy production. Consequently, opting for solutions based on the ROS concept allows for a lower impact on the environment, mitigating possible effects on climate change caused by the sanitation sector.

The concept of sustainability in sanitation requires that wastewater treatment technologies, in different scenarios – with centralized Wastewater Treatment Plants or decentralized technologies at household level – be considered as resources and not only to mitigate environmental impacts. A valuation view of the by-products in the context of the Nexus concept, with separation of domestic sewage at source or not (Paulo et al., 2019a).

The water, energy and food sectors are intrinsically linked. Decisions in one sector will affect others. Producing energy uses water; treating water consumes energy; producing food consumes water and energy; among other relationships. Therefore, isolated and/or disconnected approaches from other sectors do not result in the intelligent solution of complex problems.

The chapter addresses the potential of resource-oriented sanitation to contribute to the Nexus approach. Different scenarios are presented, with better strategies and intelligent solutions for decision makers, legislators and the general public, in water management and energy and food production.

2. Resource-oriented sanitation (ROS) and Nexus approach: water, energy and food

The resource-oriented sanitation (formerly Ecological Sanitation or Ecosan and more recently as Sustainable Sanitation) concept has the main focus on source separation, applied mainly for decentralized or semi-decentralized sanitation systems. For instance, the collection and treatment of urine and feces can be a source of nutrients and be reused as fertilizer in the agricultural sector (Wielemaker, Weijma & Zeeman, 2018).

To be considered sustainable1, a sanitation system should be economically viable, socially acceptable, and technically and institutionally appropriate. For this reason, the combination among environmental and economic aspects proposes a Circular Economy perspective through recirculation of nutrients (Alvarenga et al., 2017). For instance, Roy (2017) presents in his review that toilets with urine and feces separation are installed as a prerequisite for the efficient recovery of nutrients, especially nitrogen and phosphorus. Being a key element in a closed loop towards safe sanitation (Jama-Rodzeríska et al., 2021). Also, in arid regions, such as Israel, South Africa and some parts of the United States, the reuse of water for different sectors is a new reality (Almuktar, Abed & Scholz, 2018). Despite that, in countries like Brazil, this is a particularity in rural areas and eventually in (peri)urban areas. The cultural acceptance, low government investment (especially in the sanitation sector), and an excessive bureaucracy, including the universalization mindset based on sewers collection system and large centralized Sewage Treatment Plants, are some of the reasons.

The biofertilizer supply on agricultural crops by itself is not the only requirement to achieve the sustainable goals, the water supply also plays a huge role (Cosgrove & Loucks, 2015), approximately 69%, especially in developing economies. Water resource availability requires technologies to improve management and access, once the world availability of water is estimated at ~1.4 billion km3 (Rodell et al., 2018). The fact is that extreme hydrological events, such as lack of water in the hydrographic basins where the water sources are located and excessive rainfall in urban areas, lead to water scarcity and problems with floods and landslides. In this sense, the classical engineering concept seeks water sources farther away, which increases the cost of water supply. In developing countries, losses in distribution networks make the systems costly, requiring more energy and consuming more chemicals.

Furthermore, the energy sector associated with water and food is part of the sustainable development as well, it is estimated an enhancement by 3.2% per year in this sector (Zhao & Magoulés, 2012), for example countries as China, United States and India use nearly 70% of the global energy, ergo, this usage growth will affect biodiversity loss and ecosystem degradation.

In this sense, the relationship between water-energy-food (Nexus approach) drew the attention of scientists, researchers and stakeholders interested in sanitation value chains and waste management (solid and liquid) began to identify viable and sustainable business models (Gwara et al., 2020), which recognizes the complex interdependencies between these sectors and seeks to analyze them as a single system to promote resource sustainability and effective governance (Galaitsi, Veysey & Huber-Lee, 2018). Hoff (2011) identifies productive sanitation among the opportunities to improve water, energy and food security, defining it as a system that safe recycle excreta, other organic waste products, water to crop and other biomass production, in order to increase overall resource use efficiency. In this view, resource-oriented sanitation has the potential to generate multiple benefits in the provision of public services, including both economic and resources efficiency, creating positive impacts on the environment by reducing water consumption, significantly reducing or avoiding contaminated discharges, generating renewable energy, improving fertility and water retention capacity of soils, besides reducing the dependency of resources-demanding chemical fertilizers.

Water and sanitation are under the United Nations Sustainable Development Goal 6. Achieving this goal is recognized as a precursor to achieving several other goals (SuSanA, 2017). Resource-recovery sanitation systems, within the context of this chapter, can help achieve SDG 2 (end hunger) and SDG 12 (sustainable consumption and production).

2.1 Resource-oriented sanitation cases in a Nexus approach

In the literature review carried out by Hu et al. (2016), the authors classified research in this area into different types, such as: (i) the type of effluent or the source of wastewater, (ii) in relation to performance treatment technologies, (iii) assessments of technical and economic feasibility (Lehtoranta, Vilpas & Mattila, 2014), (iv) analysis of social and environmental impacts (Malekpour et al., 2013) and the acceptability of society and managers. Some examples of studies are: application and treatment of human urine (Simha et al. 2021), composting of human feces (Magri, Philippi & Vinneras, 2013), use of different styles and types of toilets (Anand & Apul, 2014), treatment of different wastewater separated at the source (black water, yellow water, brown water and gray water) (Mo & Zhang, 2013). These studies were carried out at different scales, such as: house or building, schools, villages or colonies. However, it was noted that there are still few studies on a more systematic and holistic assessment of all ROS components (Thibodeau et al., 2014) or even linking ROS with the Nexus approach.

This sort of (eco)technologies and sustainable tools involve the householders in the decision-making process, ensuring the long-term sustainability of the systems. Also, it is important to highlight how the cultural context (social and policies aspects) can influence the choice based on different purposes. For this reason, some technologies that could be applicable to the Brazilian scenario are pointed out in this study (Table 1). Some cases were selected based on the links of ROS studies with the Nexus approach.

In addition, in Figure 1, two scenarios are presented, (i) conventional sanitation: without reuse or recovery of nutrients; and (ii) sustainable sanitation, where the (resources) are separated and by-products are used with safe and appropriate technologies (process/treatment). It is possible to apply the ROS concept to Nexus approach in (semi-)centralized Sewage Treatment Plants or at the household/condominium level.

The scenarios and technologies illustrated are: nutrient recovery from blackwater with zero-discharge by evapotranspiration tank; constructed wetlands for water reuse and food production; solar disinfection to improve final effluent quality for safer food production; use of urine and feces as fertilizer; and transformation of sludge into biosolids agronomic potential and/or soil quality improvement.

Table 1 has quotes from cases in Brazil and Figure 1 makes it possible to understand how these could be applied. Either in a centralized or decentralized context, in a condition of adaptation from an unsustainable environment, or in an environment from the beginning, at the design stage, already based on the link between ROS (resources) and Nexus (products for water, energy and food). After the table, a text was prepared with the intention of bringing other studies, in addition to the table (quotes) and not only in Brazil, dealing with the application of technologies in relation to resources (human urine and yellow water; feces and blackwater; greywater; domestic wastewater (and microalgae potential; bioenergy) and products (water, food and energy) from the perspective of ROS and Nexus.

In Brazil, the rural and peri-urban areas have greater adaptability to use these technologies (Magalhães Filho et al., 2019; Magalhães Filho & Paulo, 2017), as normally the separation of effluents (urine, blackwater, greywater) already occurs and in some cases the system is already without water (dry

Resources, inlet	User interface / Technologies	Process / Treatment	Nutrient recovery and pathogens inactivation/ reduction	Products, outlet Main nexus approach	Authors, Location
Blackwater	Flush toilet / Evapotranspiration Tank (TEvap)	Physical separation / Digestion	Nutrient recovery and zero-discharge	Bananas, Biomass Food	Paulo et al. (2019a), Paulo et al. (2013), Brazil; Mo & Zhang (2013), Worldwide.
Domestic wastewater, Greywater and Sludge	Flush toilet and GW production / Constructed Wetlands (CW)	Physical separation / Digestion / Phytoremediation	Nutrient recovery and water reclamation	Fertilizer (Fertirrigation), Biosolids Water / Food	Amorim Júnior et al. (2021), Magalhães Filho & Paulo (2021), Gonçalves et al., (2020a), Atalla et al. (2020), de Oliveira et al. (2019), Sezerino et al. (2015), Paulo et al. (2013), Paulo et al. (2009), Paulo et al. (2007), Brazil.
Domestic wastewater and Greywater	Flush toilet and GW production / Solar Disinfection (SODIS)	UV / Time	Nutrient recovery and water reclamation	Fertilizer (Fertirrigation) Water / Food	Santos et al. (2021), Santos et al. (2020), Pansonato et al. (2011), Botto et al. (2009), Brazil.
Domestic wastewater, Greywater and Sludge	Flush toilet and GW production / Anaerobic Digestion - UASB reactor	Physical separation / Digestion	Biogas production Effluent and Sludge required pos-treatment	Biogas (Bioenergy) / Microalgae biomass Energy	Azeredo et al., (2020), Gonçalves et al., (2020b), Soares, Martins & Gonçalves, (2020), Scherer et al. (2018), Jorquera et al. (2010), Brazil.
Human urine, Yellow water, Brown water, and Feces	Urine-Diverting Dry Toilet (UDDT) Urine-Diverting Flush Toilet Waterless urinal / Storage tank	Time / Heat	Nutrient recovery and water reclamation	Fertilizer (Fertirrigation) Water / Food	Medeiros et al. (2021), Medeiros et al. (2020), Chrispim et al. (2017), Botto & Santos (2013), Magri, Philippi & Vinneras (2013), Rebouças et al., (2011), Brazil

Table 1. Technologies, resources and products (water, energy and food).

Source. Elaborated by the authors.

sanitation systems, urine or feces without flushwater). Withal these are exactly the areas where there is no access to conventional sewage services.

In the urban environment, it is unfeasible to adapt buildings when they are already built. However, with the Brazilian housing deficit, new units and housing complexes can be planned with some technological options, such as the reuse of greywater, as it is accepted, especially in times of drought and scarcity. Fiscal and economic incentives are recommended, requiring the construction of an agenda in favor of the Nexus and ROS, with public policies including the social dimension in this decision-making process. In this case, several areas, such as civil construction, water resources, sanitation, the electricity sector, among others, must be involved.

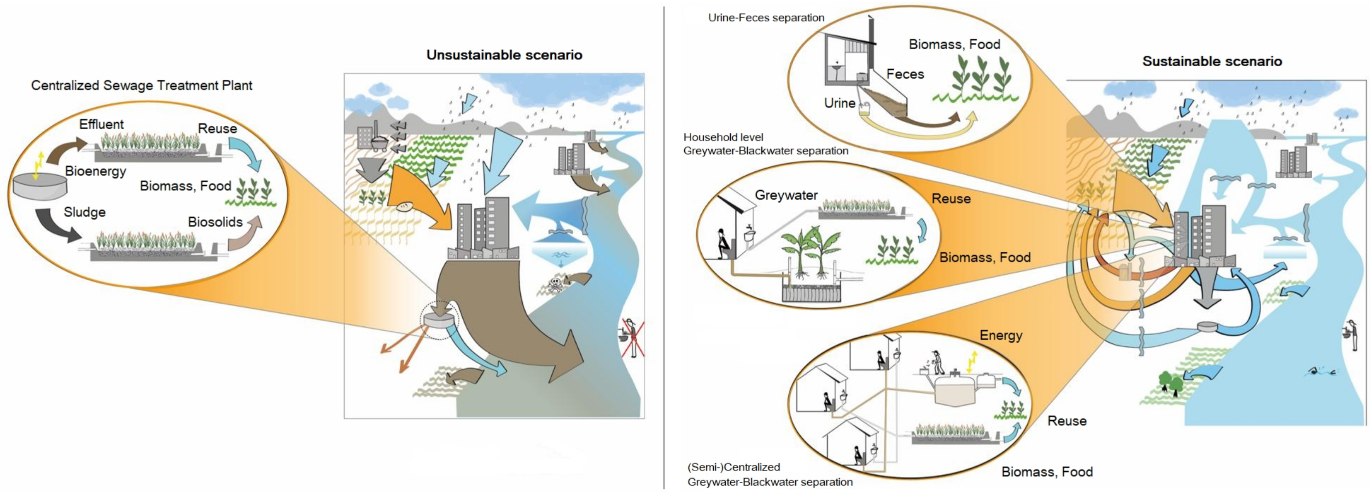

Figure 1. Sanitation systems scenarios and water-energy-food potential at household and (semi-) centralized level.

Source. Adapted from GTZ (2003). Ecosan – Closing the loop in wastewater management and sanitation – Shortcomings of conventional wastewater systems.

2.1.1 Human urine and yellow water

Materials considered as sanitation wastes have valuable nutrients such as N, P, organic carbon and energy. Hence, human urine is recommended to be used as fertilizer, once it can offer approximately 90% of N, 60 to 76% of P, and 50 to 80% of K (Childers et al., 2011).

There is potential to recover the nutrients present in human urine on an urban scale, through adequate infrastructure that must be implemented or adapted, from collection and storage to final use (Medeiros et al., 2020). It can be retrieved by using water(less) urinal or diverting-urine toilets (dry or flush), for instance.

To identify energy demand, Medeiros et al. (2020) analyzed water consumption and environmental impacts of crop fertilization with human urine compared to mineral fertilizers. The Material Flow Analysis and Life Cycle Assessment methods were adopted covering the alternatives from cradle to grave. The agricultural fertilization with full volume of human urine closer to the source presented smaller energy demand and environmental impact indicator values when compared to solid mineral fertilizer, despite the uncertainties. The energy demand of human urine fertilization was 10% larger than the one with mineral fertilizer in the baseline scenario, despite its variability. The largest energy demand contribution of human urine was transportation (94%) due to the mass of water that follows the urine nutrients, followed by Production and

Application. The energy break-even point for human urine to start being more advantageous compared to mineral fertilizer was a transportation distance smaller than 134 km.

Urine treatment is commonly made only by storage before its use as fertilizer. Botto (2015), in a study carried out in Ceará state, proved that storage can be a low cost and very effective treatment method considering local climate. Other authors, as Medeiros et al. (2020) used Alkaline stabilization of urea in urine using a passive dosing system in the urinals (Flanagan & Randall, 2018). Randall et al. (2016) recommend the addition of hydrated lime to human urine to stabilize nitrogen (in the form of urea) and recover precipitated phosphorus (calcium phosphate). Richert et al. (2010) suggest microbiological treatment techniques to reduce odors and gain nutritional value. In fact, the recovery of human urine enables the reduction of water demand and wastewater treatment, providing a positive impact on the sanitation system (Medeiros et al., 2020). It is estimated that each 1 m^3 of human urine collected in urinals, without water, saves 25 m^3 of water. The various benefits of recovering human urine, such as reduced water demand and generation of avoided effluents, are more relevant in economic terms when compared to recovered nutrients (NPK) (Atlee et al., 2019).

2.1.2 Feces and blackwater

Feces and blackwater can be used as resources, through the application of different resource-oriented sanitation techniques/technologies. In flush-toilet systems, treating blackwater is required to use its nutrients and/or reuse water. In dry-toilets systems, feces are treated and used as fertilizer.

2.1.2.1 Feces

Dry-toilets are a low cost and low-maintenance technology suitable for rural or (peri)urban areas that demand fertilizers and have no sewage treatment, which saves a lot of water and energy that is used to clean water from toilets. It is a simple system that uses dry material as an additive to cover feces, followed by storage (around 6 months) to sanitization. Magri, Philippi & Vinneras (2013) evaluated additive options based on inactivation of pathogens. The most promising treatment alternative was oyster shells and Ash with Urea, as it showed large reductions of all the bacteria and phages, and it was also efficient for inactivation of Ascaris suum.

After treatment, feces have great potential for improving the fertility of impoverished soils because of its high contents of phosphorus and potassium in ionic form. An evaluation of the effectiveness of human manure as a source of nutrients was made by Mnkeni and Austin (2009) in South Africa. Human and goat manure were compared using cabbage as a test crop. Human feces resulted in higher cabbage yields than goat manure but was overcome by inorganic fertilizer. For greater agronomic effectiveness, the human excreta can be co-applied with some inorganic N fertilizer as it proved to be a poor source of nitrogen. Nevertheless, dry toilets save huge amounts of water and energy, and this fact alone is a strong reason for its implementation.

2.1.2.2 Blackwater

The 'dry box toilets' are not yet widely used in Brazil, despite the obvious benefits of the approach. Cultural aspects are the principal factor since it is easier to use the 'flush and forget' system. Hence, a suitable option for blackwater produced in flush toilets could be a soil and plant-based system such as evapotranspiration tanks (TEvap) and constructed wetlands.

This kind of system uses plants and soil to treat blackwater, recovering its nutrients and reusing water. TEvap is a simplified treatment system, aiming at zero liquid discharge, or it can be combined with infiltration trench and constructed wetland to water reuse or groundwater recharge. Paulo et al. (2019b) contributed to TEvap development, proposing a design equation based on climate conditions. The study analyzed a system that operated for almost 4 years and the results showed that it is possible to introduce an ecological and low-cost alternative to conventional septic tank solutions, to manage blackwater at household level, allowing for the reuse of the nutrients.

2.1.3 Greywater

Greywater comprises wastewater from showers, bath, lavatories, kitchen sinks, dishwashers and laundry, what make its composition very diverse. Chemical, physical and biological treatment processes, such as sand filtration, constructed wetlands and membrane bioreactor, have been evaluated for treating greywater (Paulo et al., 2007; Chrispim & Nolasco, 2016).

Constructed wetlands are the most common decentralized sanitation system for greywater treatment (Magalhães Filho & Paulo, 2021). The main reasons for its popularity are the simplicity of the technique and its great treatment capacity. The system supports high flows without the need for operational knowledge or power and has high pollutants removal rate. The load acceptance makes this system perfect to treat greywater, since it represents the greatest amount of household wastewater.

This system creates an environment similar to natural wetlands, that use functions from soil, vegetation and organisms to treat greywater/wastewater. Constructed wetlands, which can be combined with evapotranspiration systems (Magalhães Filho et al., 2018), provide the necessary conditions for microorganisms to assist in the degradation process (Bernardes et al., 2016). As water passes through the wetland, it slows down, and many suspended solids become trapped in the vegetation and sediment. Through biological processes (Bernardes et al., 2021), pollutants are transformed into more soluble forms and absorbed by plants, including ornamental plants to improve landscape (Caputo et al., 2019). Good pollutant removal rates are achieved, and greywater can be reused (Silva et al., 2017). It is estimated that when implementing greywater reuse, the economic potential savings are between 25-30% of drinking water consumption in a household (Ghisi & Ferreira, 2007).

Given the importance of reuse greywater, many studies are developed to improve decentralized methods and promote on-site reuse. While Couto et al. (2015) studied a simplified system consisting of an anaerobic filter and UV disinfection for the treatment of gray water in a Brazilian airport, Chrispim and Nolasco (2016) evaluated a bioreactor (MBBR) on a university campus. The results indicated the need to reduce turbidity, which could be done with the addition of sand filtration and chemical oxidation to meet reuse regulations (Chrispim et al., 2017).

Hybrid systems combining more than one technology are showing promising results to greywater treatment. Paulo et al. (2013) used a hybrid system combining a horizontal flow constructed wetland and vertical flow constructed wetland to treat greywater onsite. Pansonato et al. (2011) proposed a solar disinfection (SODIS) for the post-treatment to CW-treated greywater. This combined system was very efficient because CW removes turbidity which makes SODIS more efficient and compact.

Depending on the final greywater uses and quality requirements, the application of one simple system could be sufficient. For example, the final effluent obtained by Chrispim and Nolasco (2016) met Brazilian water quality requirements for several types of irrigation, including agricultural. Reusing greywater to agricultural irrigation has a positive impact in nexus approach, as it grows food without high water demands and treats sewage with low energy requirement.

2.1.4 Wastewater (domestic): (micro)algae potential

Resource recovery from centralized wastewater treatment plants is also possible, depending on the technology applied. There is a trend in the studies related to (micro)algae. Therefore, this example is going to be used to illustrate a possibility to produce biomass and water for reuse, recover nutrients, and reduce the impact on energy consumption.

Microalgae treatment represents a sustainable and cost-effective biotechnology. Combining microalgae production with wastewater treatment has many benefits, since farms use mineral fertilizers, which require significant energy inputs for their production and transportation, while wastewater contains the same nutrients "for free". Using wastewater as a nutrient source, we achieve cheaper microalgae production and sustainable sewage treatment.

At the same time, water bodies cannot receive high amounts of microalgae, due to their high content of organic matter, nitrogen and phosphorus, which can be used as substrates for bacterial growth (Rawat et al., 2011). Hence, harvesting is the best solution for ponds. Furthermore, algal biomass contains a high amount of lipids, which can be used for the production of biofuels, increasing its commercial value. (Rawat et al., 2011). The main techniques applied to harvest microalgae include: centrifugation, flocculation, filtration and sorting, sedimentation, flotation, electrophoresis techniques, and ultrafiltration (Scherer et al., 2018).

Closed systems have been developed to overcome challenges like energy demands, and the most common ones found in Brazilian research are Photobioreactors (PBR), Anaerobic Sludge Blanket reactors (AGS), Moving Bed Reactors (MBR) and Upflow Anaerobic Sludge Blanket reactors (UASB). Open systems like ponds are more common but have higher evaporation losses, higher water requirements and higher contamination risks compared to photobioreactors. In contrast, photobioreactors require less energy use and are associated with low levels of greenhouse gas emissions (Jorquera et al., 2010). These are closed systems with higher biomass production, although they are more expensive to construct, operate and maintain than open (raceway) ponds.

Biomass production from biological treatment involves a lot of steps from microorganism cultivation until harvesting and biogas production. These processes also demand specific conditions like pH, nutrients, temperature, retention time and other variables that need to be closely observed. To improve this mechanism, technologies need to be developed in order to decrease energy requirements and to increase energy production from biomass.

2.1.5 Bioenergy

Bioenergy can also be applied to sanitation processes to destroy or inactivate pathogens from human excreta, for this reason, the thermal EcoSan concept has being highlighted through drying (Richert et al., 2010), composting, and lactic-acid fermentation (Factura et al., 2010), which aims to prevent environmental pollution and recycle resources, including the nutrients in human excreta and wastewater.

New opportunities in energy or sanitation examining the integrated potential for utilizing excreta in agriculture was the main aim of Krause and Rotter (2018) study, they defined three scenarios: (i) describes the current state of using a three-stone fire for cooking, and a pit latrine for sanitation; (ii) represents a technology change towards using a biogas system for energy provision, and a UDDT for sanitation; and (iii) represents a technology change towards using a sawdust gasifier for cooking, and a UDDT with subsequent thermal sanitation of feces.

These technological options allow it to avoid local environmental threats including soil depletion and deforestation, once the adoption of such technologies could inevitably lead to a greater availability of residues such as biochar, biogas slurry, and sanitized human excreta or agro-industrial effluents. This means availability of resources for soil fertility management through nutrient recycling, contributing towards sustaining local agricultural productivity (Boncz et al., 2008; Magalhães Filho et al., 2017; Lima et al., 2020).

2.2 Social dimension

The nutrients recovery from human excreta fertilizer on agronomic trials show that it can improve physicochemical properties of the soil and crop yields (Leal Filho et al., 2019). In this sense, developing strategies to link excreta-agriculture-development, co-optimizes sanitation and nutrient recovery from human excreta, which would pollute the environment. From the point of view of agriculture, the water-energy-food nexus approach and the relationship between water-soil-waste (by-products), by linking environmental resources to sustainable management, aim to reduce trade-offs, create synergies, increase availability water and energy, improve food security, sustain ecosystem services, reduce resource scarcity, reduce poverty and hunger. Through a more coherent approach with the need to integrate public policies, to provide a synergistic framework for dealing with natural and human systems that face increasingly complex problems (Krausse & Rotter, 2017; Gwara et al., 2020).

To provide safety, technologies to treat urine and feces from non-mix toilets are required to promote the acceptance and implementation. Understanding the environment, surroundings and the habits of householders is crucial to implement resource recovery systems. Low-middle income countries, for instance Brazil, must face some barriers in the sanitation sector to ensure the effective population participation during the planning process. For this reason, Magalhães and Paulo (2017) carried out socio-environmental research in Quilombola communities to understand their engagement on sustainable wastewater treatment technologies implementation. The lack of information, as presented in this study, limits participation in the decision-making process and makes it difficult to expand the ROS and Nexus concepts.

Although the National Rural Sanitation Program[3] includes participation in the process, at the urban level, the Municipal Sanitation Plans had the objective of carrying out social mobilization, but in fact this does not occur in the decision-making process.

2.3 New policies

The management of urban water and energy plays an important role in the development of cities, as they are dependent on these resources, as well as need to protect the environment to ensure people's well-being (Lofman et al., 2002). In this context, the water-energy nexus has been increasingly studied (Galaitsi, Veysey & Huber-Lee, 2018). The initiatives focus on mitigation of the impacts of water and energy, enhance water and energy security (Kennedy & Corfee-Morlot, 2013) reduction of investments in new water and energy public assets (Parikh & Parikh, 2011), and on the environment (Schueftan & González, 2013).

The public water and sanitation service depends on the adequate choice of sustainable technologies to save water, enable the recycling of water and nutrients and promote energy efficiency. To ensure sustainability, policies for integrated water management must be proposed. The demand-side principles incorporated into such policies encompass financial measures (incentives, tariff adjustment), non-financial measures (awareness campaigns, promotion of technologies for water efficiency), mandatory measures (water regulations) or optional measures (water certifications) (Lee, Tansel & Balbin, 2011).

3 Brasil. Ministérios das Cidades. Fundação Nacional de Saúde. Programa Nacional de Saneamento Rural. Brasília: Funasa, 2019. http://www.funasa.gov.br/documents/20182/38564/MNL_PNSR_2019.pdf/08d94216-fb09-468e-ac98-afb4ed0483eb

Nevertheless, the sustainable management of the water and energy sectors depends on the availability of accurate data (Stillwell & Webber, 2010), but there is a lack of information about the energy intensity of water services, alternative water sources and many others, once such alternatives are necessary for designers and planners to ensure the incorporation of water and energy efficiency's objectives into the development of sustainable water strategies.

Existing information in national databases focus only on the centralized sanitation, without the use of by-products. In addition, the municipal / state plans and national guidelines and public policies do not include goals and indicators focused on the Nexus.

Regarding policies, the National Rural Sanitation Program indicates several technologies appropriate to the Nexus concept, but in urban areas this does not usually appear in Municipal Sanitation Plans. However, with the new regulatory framework for the sector (Federal Law 14.026/20202)[4], there are incentives for reuse, but it would be important for this to be included in the contractual goals between service providers and municipalities. It should be noted that advances cannot be made only in the regulatory environment, but also in access to the service (universalization), including technological options that provide reuse and use of by-products.

3. Perspectives and challenges for ROS and Nexus in an urban resilience and circular economy context

In the Circular economy, resources are used within the context of increasing urban resilience and value creation from the recovery and reuse of resources that would otherwise be lost (Villarroel Walker et al., 2014). Transforming urban society from a linear to a circular metabolism is a trend in many developed countries. In low-income countries, green values and opportunities are less developed and have a generally lower priority among many key stakeholders, and public budgets are too constrained to make the right investments.

A core principle of the Water–Food–Energy Nexus in the economic urbanization context, can lower energy costs of wastewater treatment compared to sourcing freshwater from long distances or the ocean (Gebrezgabher et al., 2015). In terms of energy, the costs are high and more susceptible to breakdowns, which can be some of the challenges to many treatment facilities (Murray & Drechsel, 2011). In areas where the bulk of the wastewater reuse is

4 This Law updates the legal framework for basic sanitation, among other issues pertaining to the sector. http://www.planalto.gov.br/ccivil_03/_ato2019-2022/2020/lei/l14026.htm

for restricted crop irrigation, advanced treatment may not be required, and the use of appropriate technology can produce water with much lower investment and maintenance costs.

In Brazil, many small agricultural cities produce huge amounts of agro-industrial waste(water). Entre Rios, in Paraná was one of these cities, with a massive swine farming economy. Since 2019, a partnership between Parque Tecnológico de Itaipu (PTI) and Centro Internacional de Energias Renováveis (CIBiogás) created a biogas plant from swine waste. This technology allows producers to sell the energy and whatever it may be a waste that has already economic value. Nowadays, 72 city hall buildings already use energy from these bioreactors. However, implementing these technologies needs studies seeking techno-economic feasibility, as developed by Lima et al. (2020), including information systems with adequate data to implement public policies based on incentives and not only on control and inspection with the aim of fines.

With the development of resource-oriented sanitation, many innovative components would be developed to meet the requirement of sewage treatment and result in the appearance of the new ROS systems. The costs of some components (e.g., vacuum toilets, vacuum pipes and solid–liquid separators) may decrease as the manufacturing development and mass production, which could improve the dilemma of high costs for introducing sustainable systems.

Thus, investments in sustainable resource recovery require careful analysis about what technologies are better suitable to the local context. In sub-Saharan Africa for example, some of the challenges are the institutional limitations on funds for infrastructure operation and maintenance resulting in failure gaps in the systems (Murray & Drechsel, 2011). In Morocco it demonstrates options for how to bypass this bottleneck, once the municipality collects sewage fees to recover its operation and maintenance costs, (i) treated wastewater to crop farmers; (ii) reed grass from the constructed wetland; (iii) sludge compost; and (iv) methane gas from energy recovery (Rao et al., 2015).

Brazil follows a common path for developing countries, where there is a lack of data to support the development of policies on resource recovery from wastewater. Only a few studies (Chrispim et al., 2017; Paulo et al., 2019b) were based on decentralized and source-separation sanitation systems. Therefore, new studies in this area for different types of buildings/housing and in different regions of the country and the world will play a fundamental role in the development of energy efficiency and water conservation (Vieira et al., 2014). In-depth research on water-energy-food relationships will improve its understanding of the implications of the nexus concept with ROS. Including the full range of alternative water supply and sewage systems to improve urban water planning and decision making with a focus on sustainability.

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Understanding and managing the complex interaction between water, energy and food is considered to be one of the major challenges of the 21st century. As global projections indicate that the demand for these resources will increase significantly in the next decades under the pressure of population growth, urbanization, economic development, climate change, diversifying diets and lifestyles, cultural changes and technological transformation, developing sustainable solutions that guarantee resource security became paramount (Hoff, 2011).

In this book, we aim to gather academic researchers that bring empirical and theoretical elements to critically reflect on how the concept of the nexus is being incorporated into research in Brazil, and whether and how the nexus is making any contribution to enhance knowledge in different scientific fields. Their contributions also shed light on what are the main societal problems in the Brazilian context that the nexus is helping to better understand and find possible sustainable solutions.

THE WATER-ENERGY-FOOD NEXUS

What the Brazilian research has to say

BRAZIL

2022