# Assessing Sustainability in the Water-Energy-Food Nexus

by

Glorynel Ojeda Matos

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Graduate Supervisory Committee:

Dave D. White, Chair
Katja Brundiers
Margaret García

ARIZONA STATE UNIVERSITY

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ABSTRACT

With less than seven years left to reach the ambitious targets of the United Nations' 2030 Sustainable Development Goals (SDGs), it is imperative to understand how the SDGs are operationalized in practice to support effective governance. One integrative approach, the water, energy, and food (WEF) nexus, has been proposed to facilitate SDGs planning and implementation by incorporating synergies, co-benefits, and trade-offs. In this dissertation, I conduct three interrelated WEF nexus studies using a sustainability lens to develop new approaches and identify actionable measures to support the SDGs. The first paper is a systematic literature review (2015 – 2022) to investigate the extent to which WEF nexus research has generated actionable knowledge to achieve the SDGs. The findings show that the WEF nexus literature explicitly considering the SDGs mainly focuses on governance and environmental protection, with fewer studies focusing on target populations and affordability. In the second paper, I reframed the water quality concerns using a nexus and systems thinking approach in a FEW nexus hotspot, the Rio Negro Basin (RNB) in Uruguay. While Uruguay is committed to the 2030 Agenda for Sustainable Development, sustainability challenges endure in managing synergies and trade-offs, resulting in strategy setbacks for the sustainable development of food, land, water, and oceans. Reframing the water quality problem facilitated the identification of potential alternative intervention points to support local problem-solving capacity. In the third paper, I conducted semi-structured interviews and examined the meeting transcripts of the RNB Commission to understand local perspectives about how the activities and initiatives taking place in the basin enhance or diminish the overall sustainability.

Sustainability criteria for river basin planning and management were operationalized through qualitative appraisal questions. The case of the RNB illustrates the challenges of coordinating the national development agenda to local livelihood. This dissertation advances the WEF nexus and sustainability science literature by shedding light on the implications of the research trend to support the SDGs, as well as reframing and appraising a persistent water quality problem to support sustainable development.

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# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

Water, energy, and food (WEF) systems are at the core of sustainable development, and the 2030 Sustainable Development Agenda set specific goals for ensuring access to clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), and eradicating hunger (SDG 2). Although set separately, these goals are not mutually exclusive, generating coupled benefits and trade-offs (International Council for Science, 2017; Liu et al., 2018). Hence, the WEF nexus approach has been posited as a bridge connecting the separated SDGs and augmenting collaboration among involved sectors to manage synergies and trade-offs (Lele et al., 2013; Cai et al., 2018; Nerini et al., 2019). What is not yet clear is the extent to which the WEF nexus research has generated knowledge in support of the SDGs implementation. Although these SDGs are set as a global agenda, WEF nexus governance challenges are inherent to each region (Kates, 2001; Lele et al., 2013). Even though governing the WEF nexus toward sustainability requires defining overlapping goals and decision-making (Pahl-Wostl, 2019), few studies have addressed the challenges for cross-sectoral coordination and collaboration in specific regions (Newell et al., 2019; Opejin et al., 2020; Weitz et al., 2017b).

The overarching purpose of the present research studies is to assess sustainability in the WEF nexus for actionable measures to support the SDGs implementation. Accordingly, three research objectives are defined: (1) to assess the knowledge advance generated by the WEF nexus literature in support of the SDGs implementation, (2) to

examine the underlying systemic causes preventing effective WEF cross-sectoral governance responses and identify potential alternative intervention points for potential changes toward sustainability, (3) to conduct a sustainability appraisal on a WEF nexus hotspot providing a new perspective on how to guide WEF systems toward sustainability by embracing sustainability principles. The rest of this introduction is structured as follows. First, I briefly present the theoretical background on the water-food-energy nexus and sustainability sciences underpinning this research. Second, I provide a case description and the significance of the case selected, a WEF nexus hotspot in the South American country of Uruguay. Finally, I conclude with the intellectual merit and broader impacts accomplished through this research.

## 1.2 THEORETICAL BACKGROUND

### 1.2.1 Water-Energy-Food Nexus Approach

Awareness of interdependencies among the water, energy, and food (WEF) sectors arose after the global food crisis in 2008, the Nexus Conference in Bonn in 2011, and when the 2011 World Economic Forum's Global Risks Report was released, which identified the WEF nexus approach as a solution to manage cross-sectoral interconnection leading to severe unintended consequences (Hoff, 2011). The WEF sectors are interconnected by natural processes, input-output interdependence, overlapping infrastructures, and competing objectives at local and regional scales (Cai et al., 2018; Pahl-Wostl, 2019). For instance, multipurpose dams could provide water, hydropower, and irrigation, and energy and agriculture may compete for water supplies. Recognizing these interconnections between sectors is intended to facilitate managing

synergies and trade-offs, and the origins of the WEF nexus are strongly focused on resource security (Pahl-Wostl, 2019). This is unsurprising, given that WEF sectors provide critical services enabling country and human development. For instance, from a human development perspective, WEF systems deliver the resources to fulfill the most basic physiological needs (viz. Maslow's hierarchy of needs (S. S. Clark et al., 2018).

Several bibliometric studies have reviewed the trajectory and current state of knowledge on the WEF nexus dating back four decades (Albrecht et al., 2018; Chen et al., 2019; Kliskey et al., 2021; Newell et al., 2019; Opejin et al., 2020). These studies revealed the research hotspots and trends across research communities and the remaining research gaps. For instance, Albrecht et al. (2018) systematically reviewed WEF nexus methods used to evaluate the cross-sectoral interdependencies. This study pointed out that much research has focused on quantitative methods coinciding with further studies' findings (Newell et al., 2019; Opejin et al., 2020). Newell et al. (2019) noted that studies from the environmental science field dominate the understanding of the WEF nexus over the social science field, even when scholars have posited that WEF nexus affairs are not limited to environmental issues (Bazilian et al., 2011). Opejin et al. (2020) also found that studies on WEF synergies and tradeoffs mainly focus on disciplinary perspectives.

Despite decades of research, studies on social aspects such as governance, institutions, and decision-making are limited (Newell et al., 2019; Opejin et al., 2020). Relatively little is understood about "qualitative institutional capacities and intersectoral governance challenges" (Opejin et al., 2020, p.1), even with an urgent call to reform existing institutional arrangements focused on sectors in siloed (Cai et al., 2018).

Cooperation has been beneficial in reducing investment across the WEF sectors (Payet-Burin et al., 2021). Still, cross-sectoral coordination and collaboration conditions have been essentially overlooked (Weitz et al., 2017a). Furthermore, Kliskey et al. (2021) assessed the practice of stakeholder involvement in WEF nexus studies. They reported that only 20% of the examined publications mentioned that other individuals outside the research team were involved.

A limited number of studies have addressed the governance challenges of the WEF nexus approach. For instance, Pahl-Wostl et al. (2021) proposed a diagnostic framework to assess scale-related governance challenges. Pahl-Wostl (2019) produced an analytical framework identifying WEF sector interactions by linking actors via ecosystem services to identify governance deficits. Greer et al. (2020) highlighted effective communication's importance in identifying and negotiating tradeoffs. Ricart et al. (2020) examined end users' perceptions (viz., plant managers and irrigators) on the desalination model of seawater provision and management and found that managers and irrigators disagree. Jones & White (2022) reported advances to overcome barriers to collaborative governance, including finding common ground, increasing resources for collaboration, and establishing win-win solutions between parties.

The evidence points out that those studies using empirical approaches (Liu et al., 2018), qualitative methods, focus on governance (Opejin et al., 2020), and gathering stakeholders' perspectives (Kliskey et al., 2021) deserve more research attention. More research is essential to understand the role of human decisions in trade-offs and adaptation preferences across WEF sectors to prevent the cascading effects (Faeth &

Hanson, 2016). The limited research incorporating stakeholders' perspectives posits a risk for policy implementation and the level of engagement with proposed solutions (Díaz et al., 2017; Kliskey et al., 2021). Shared criteria are needed to support decision-making, facilitate the negotiation of tradeoffs, and reduce power imbalances across sectors (Weitz et al., 2017a). Real-word nexus applications, including the perspective of diverse disciplines, should be carried out to advance generic knowledge and improve WEF-integrated planning and modeling capabilities (Cai et al., 2018; Miralles-Wilhelm, 2016). Applying qualitative methods is necessary to capture contextual information and enhance understanding of the formal and informal rules and practices that structure social interactions (Bernard et al., 2017; Treuer et al., 2017).

### 1.2.2 Sustainability Science

Concerns with the increased consumption and depletion of crucial life-support systems have made sustainability a topic for discussion in the scientific community and political arena (Wu, 2013). The report Our Common Future, published in 1987 by the United Nations (UN) World Commission on Environment and Development, paved the way for a new field of sustainability science striving to co-create knowledge with various stakeholders to inform dynamics that support human development while fostering environmental integrity as well as intra- and inter-generational equity. (W. Clark & Dickson, 2003; Kates et al., 2001; Wu, 2013). Sustainability science has emerged as an integrative field that combines diverse disciplines and collaboration with 'non-academic" stakeholders as well as diverse ways of knowing when defining sustainable development pathways. Kates (2011) proposed and revised the core questions to guide the

sustainability field, including managing human-environment systems toward a sustainability transition, identifying, and resolving trade-offs between human well-being and the natural environment, and promoting adaptability and resilience. Arguing that sustainability science should go further from problem-driven to solution-oriented research, Miller et al. (2014) posited the need for studies examining how systems could be guided toward sustainable pathways and translating visions into action. Furthermore, Ives et al. (2019) criticized sustainability scholarship for rarely focusing on individuals' experiences and assumptions, limiting the understanding of their decisions and capacity to drive change toward sustainability.

Many normative perspectives, frameworks, and approaches have been deliberated to frame, conceptualize, and operationalize sustainability (Hopwood et al., 2005; Mino & Kudo, 2020). In 2015, sustainability challenges were negotiated among UN member nations and outlined as the 17 Sustainable Development Goals (SDGs) and 169 targets to integrate sustainable development into formulating and implementing national policies (Stephan et al., 2018; UN General Assembly, 2015). SDGs are intended to urgently redirect development trajectories diminishing the viability of a sustainable future for all. The global pursuit of sustainability is described as universal but contextually dependent because, according to Kates et al. (2001), most of what sustainability attempts to integrate and explain has a regional character. Wu (2013), for instance, argued for sustainability place-based research at the regional scale where sustainability synergies and trade-offs are most operational. Because the multi-scale interactions raise uncertainties and external drivers and externalities could exist beyond certain regions, UN member nations

committed to "share knowledge, expertise, technology, and financial resources" in support of achieving the SDGs (Stephan et al., 2018). Hence, dialogue among the North and South scientific communities needs to continue to connect science to the political agenda for sustainable development (W. Clark & Dickson, 2003; Kates et al., 2001).

## 1.3 CASE DESCRIPTION

### 1.3.1 The South American Republic of Uruguay

Uruguay is the third smallest country in South America, with about 3.5 million inhabitants (CDNU, 2019). Since 2005, the country has experienced significant economic growth and social reforms (Singh et al., 2015). The country holds economic and political stability with an established democracy and flourishing institutions. Uruguay has the highest GDP per capita, lowest income inequality, and poverty rate in Latin America (Singh et al., 2015). Human development indicators such as life expectancy, literacy rate, and health system capacity rank Uruguay at the region's top. Also, Uruguay has high living standards close to many developed countries (Singh et al., 2015). The World Justice Project (2021) rated the country at the top in the region regarding the rule of law. Since 2012, Transparency International has consistently ranked Uruguay as the least corrupt country in the Latin American region (Buquet et al., 2012). During the COVID-19 pandemic, Uruguay's strengths made the country one of the best prepared in Latin America to respond with a comprehensive online learning platform and testing methodologies developed nationally (Taylor, 2020; The World Bank, 2021).

Concerning the 2030 Agenda for Sustainable Development, Uruguay is committed and has submitted four voluntary national reports in 2017, 2018, 2019, and

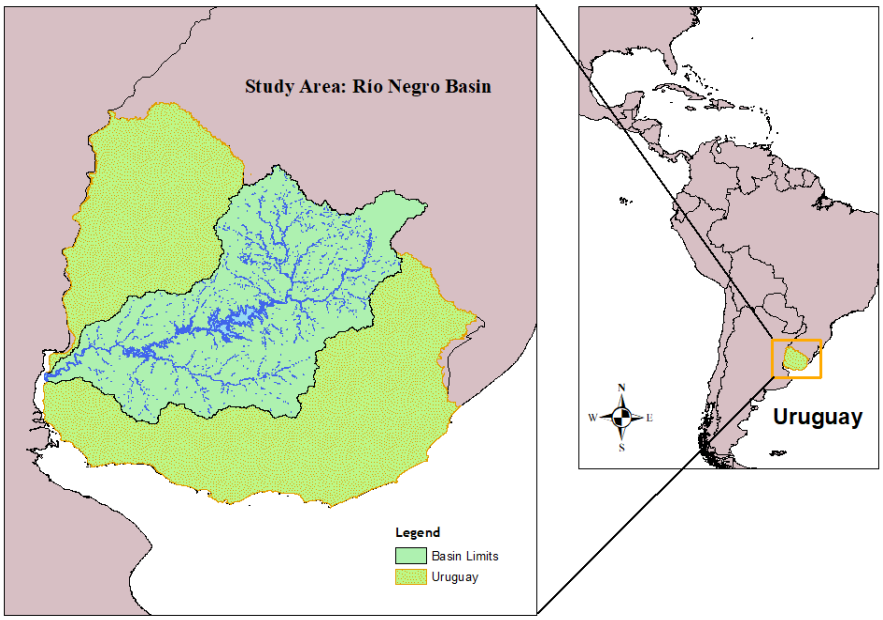
2021. Uruguay's 2021 SDGs report draws on Sachs et al. (2019) to propose six "SDG Transformations" and help map out an operational strategy for the country. The SDG Transformation framework focused on six integrated SDG themes to achieve sustainable development: 1) education, gender, and inequality, 2) health, well-being, and demography, 3) energy decarbonization and sustainable industry, 4) sustainable food, land, water, and oceans, 5) sustainable cities and communities, and 6) digital revolution for sustainable development. Uruguay performed well in almost all the SDG transformations except for strategy four, focusing on Sustainable Food, Land, Water, and Oceans. The Uruguay 2021 Sustainable Development Report acknowledged that challenges remain in managing significant trade-offs and coordinating efforts to align agricultural production with biodiversity conservation and restoration, water quality in rivers, and resilience to climate change. Uruguay's low performance on the SDG transformation strategy for Sustainable Food, Land, Water, and Oceans results from increased agricultural and livestock productivity (SDSN & IBD, 2021).

Expanding agricultural activities supports Uruguay's export-oriented economy, where 70 percent of the total exports come from this sector (FAO & UNDP, 2017). The agriculture sector and associated activities compromise up to 25 percent of Uruguay's gross domestic product (GDP) (SDSN & IBD, 2021). The country's agriculture sector feeds around eight times its current population, and the goal is to intensify production to supply global food demand and feed 50 million people by 2050 (SDSN & IBD, 2021). According to the United Nations Food and Agriculture Organization (FAO), Uruguay's agricultural sector is highly vulnerable to climate change, climate variability, and extreme

events such as frequent floods, droughts, and heatwaves. The agricultural sector accounts for approximately 75 percent of Uruguay's total GHG emissions, significantly more than half from methane (FAO & UNDP, 2017). The agricultural sector's rapid growth and intensification depend highly on local resource-intensive activities, adversely impacting the country's biodiversity, ecosystems, and water quality (MVOTMA & SNA, 2019). Therefore, when downscaling to the regional scale, most of the country's water bodies face challenges in managing nutrient concentrations exceeding the eutrophic level (MVOTMA, 2017).

**Figure 1**

*Study Area: Rio Negro Basin in Uruguay*




Shapefiles source: National Environmental Observatory

Ministry of Environment of Uruguay

### 1.3.2 Rio Negro Basin, Uruguay

The Rio Negro Basin (RNB) is an international inland watercourse situated 96% in Uruguay and 4% in Brazil (MVOTMA, 2018). The river originates in Brazil and crosses Uruguay from East to West, located in the central region of Uruguay and dividing the country into two areas: North and South. The watercourse discharges into the Rio Uruguay, then into the Rio La Plata and the South Atlantic Ocean. RNB has a surface area of 70,714 km² covering 40% of the territory of Uruguay and a total population of 387,034 inhabits in 2011 (MVOTMA, 2018). Figure 1 shows the limits of the basin. The river is considered a critical inland watercourse in Uruguay as it is where the hydroelectric is produced in the country (Patrone, 2014). Three dams positioned in cascade along the river were built primarily for hydropower generation: Rincón del Bonete, Baygorria, and Palmar. In addition, the river serves different purposes such as irrigation, aggregate extraction, agriculture and livestock, tourism, bathing, fish farming, artisanal, and sport fishing. Almost 100% of the RNB area is used for productive purposes, mainly livestock farming (MVOTMA-DINAMA, 2018). Eight intendancies or regional governments compromise the basin: Durazno, Rivera, Tacuarembó, Cerro Largo, Flores, Florida, Río Negro, and Soriano. The effluents of the intendancies also discharge into the river.

### 1.3.3 Case Selection

Although the sustainable development agenda is established globally, most of what sustainability pursues has a regional character (Kates et al., 2001). Scholars have argued for sustainability place-based research at the regional scale, where sustainability

synergies and tradeoffs are most operational (Wu, 2013). This research focuses on the South American country of Uruguay because of the country's commitment to the 2030 Agenda for Sustainable Development. The country acknowledges the urgent need to address the challenges of managing significant trade-offs and coordinating efforts within the agricultural, water, and energy sectors (SDSN & IBD, 2021). The Rio Negro Basin (RNB) is selected as the regional unit of analysis because it is one of the most concerning cases to the Uruguayan authorities and local actors. The National Environmental Directorate (DINAMA by its acronym in Spanish) reported that from 2009 to 2017, the river had a high accumulation of nutrients, leading to eutrophication and several episodes of algae blooms (MVOTMA-DINAMA, 2018). As a highly productive region where agriculture, water, energy, and other sectoral priorities compete, the RNB is ideal for examining the governance processes embedded in basin development to address an urgent sustainability problem worsened by climate variability. This case is a great example of a water, energy, and food (WEF) "nexus hotspot" where the agriculture, hydropower, and water sectors interact, generating synergies and tradeoffs (Mohtar and Daher 2016). According to the Economic Commission for Latin America and the Caribbean, good practices and lessons should be identified and disseminated to advance the SDGs in the Latin American region while applying a WEF nexus approach (Embid & Martín, 2018). The case study of the RNB provides an opportunity to contribute lessons while examining the notions of integrated planning and sustainability on the regional scale.

## 1.4 INTELLECTUAL MERIT

This dissertation advances the WEF nexus and sustainability science literature by shedding light on the implications of the research trend to support the SDGs as well as reframing and appraising a persistent water quality problem to support sustainable development. Since adopting the 2030 Sustainable Development Goals, research attention has been directed toward the water, energy, and food (WEF) nexus approach for sustainable development (Opejin et al., 2020). To date, no study has explicitly examined the extent to which the WEF nexus research has generated knowledge supporting the SDGs implementation. The first research study in this dissertation addressed this gap, and two contributions were made. First, I developed an operational codebook by synthetizing the sustainable development goals on food, energy, and water resulting in eleven cross-cutting themes. The codebook is a specific contribution to WEF nexus and SDG literature, which other scholars can adopt. Second, I applied the codebook to assess the contributions from the WEF nexus literature and answer three sub-questions about the alignment of the WEF nexus studies with the SDGs, the aims, and the geographical locations of empirical studies.

The present research also contributed to the established research agenda on sustainability science by examining trade-offs and how systems could be guided to more sustainable pathways (Miller et al., 2014, Kates, 2011). Even though the water-energy-food (WEF) nexus approach has notably contributed to reframing problems from siloed to interdependent among sectors to help manage synergies and trade-offs, little is known about the underlying systemic causes preventing effective cross-sectoral governance

responses. This study employs the systemic and agent-focused Transformational Problem-Solving (TPS) framework to reframe the water quality problem in a WEF nexus hotspot in Uruguay. While examining this case study, the present research makes several contributions to the literature. First, this study explored the causal relationship of the WEF nexus interactions creating a water quality problem, an issue that has been the "missing dimension" in the WEF nexus literature (Heal et al., 2021; Arnbjerg-Nielsen et al., 2022). Second, limited research has focused on the governance aspects of the WEF nexus (Newell et al., 2019; Opejin et al., 2020), and the study of the conditions for cross-sectoral coordination and collaboration has emerged in recent years (Weitz et al., 2017a, 2017b). This study contributes to the recent scholarly aims to enable effective governance and decision-making by understanding root causes and causal relationships and identifying intervention points (Arnbjerg-Nielsen et al., 2022; Kellner, 2023). Finally, this research contributes to closing a governance gap remaining in the WEF nexus research regarding the elaboration of overarching guiding principles to facilitate outcomes negotiation and reduce power imbalances across WEF nexus institutions and actors (Weitz et al., 2017b) by employing the well-established sustainability principles from the sustainability sciences (Gibson, 2006; Shah & Gibson, 2013).

## 1.5 BROADER IMPACT

According to the Economic Commission for Latin America and the Caribbean, linkages among the WEF sectors with the SDGs and prioritization criteria are needed to identify good practices and lessons to be disseminated in Latin American countries (Embid & Martín, 2018). Like other agriculture-exporting regions, the South American

country of Uruguay faces sustainability challenges driven by growing global food and commodities demands, generating increased pressure on local water, energy, and food (WEF) resources. Uruguay's agricultural sector feeds around eight times its current population (28 million people), and the goal is to intensify production to feed 50 million people by 2050 (SDSN & IBD, 2021). The case of the Rio Negro Basin (RNB) is of particular interest for sustainable outcomes because it compromises 40% of the Uruguayan territory and is a highly agriculturally productive area where the main country's hydroelectric production concentrates, along with other concurrent social and economic activities. This research is taking place at the same time the RNB became home to the country's largest foreign investment in history (El País, 2023). This study's findings shed light on the local perspectives about basin development and have the potential to impact ongoing decision-making on institutional and managerial practices. The case of the RNB in Uruguay may be relevant for other basins where agriculture intensification takes place in response to global food and commodities demands while impacting local livelihoods.

# CHAPTER 2

# A SYSTEMATIC REVIEW OF KNOWLEDGE ADVANCES IN SUPPORT OF THE SUSTAINABLE DEVELOPMENT GOALS FROM THE WATER-ENERGY-FOOD NEXUS LITERATURE

## 2.1 INTRODUCTION

In 2015, the United Nations member nations negotiated and outlined 17 Sustainable Development Goals (SDGs), 169 targets, and 231 unique indicators to foster sustainable development in national policy formulation and implementation (Pahl-Wostl, 2019; Srigiri & Dombrowsky, 2021; United Nations General Assembly, 2015; Weitz et al., 2017b). The SDGs aim to urgently redirect development trajectories toward a sustainable future for all. The 2030 Sustainable Development Agenda includes goals specific to food (SDG 2 zero hunger), energy (SDG 7 affordable and clean energy), and water (SDG 6 clean water and sanitation). Although set separately, the SDGs are not mutually exclusive, generating coupled benefits and trade-offs among them (International Council for Science, 2017; Liu et al., 2018). However, the sectoral targets and indicators do not address the conflicts and synergies created among the SDGs' goals on food, water, and energy (Arnbjerg-Nielsen et al., 2022).

Adopting the SDGs raised research attention to the water, energy, and food (WEF) nexus approach for sustainable development (Opejin et al., 2020). The WEF nexus approach seeks to augment collaboration among the involved sectors to manage synergies and trade-offs (Lele et al., 2013). Although WEF nexus studies date back to the late 1980s (Newell et al., 2019), the SDGs renewed interest in integrative nexus thinking.

Several scholars consider the WEF nexus approach as a bridge or platform to collaborate and implement the individual SDGs (Gallagher et al., 2016; Stephan et al., 2018). Pahl-Wostl (2019) stated, "without adopting a WEF nexus approach, the SDGs on water, energy, and food will not be achieved, which would as well have implications for all other SDGs." The WEF nexus approach may, direct or indirect, create a ripple effect on archiving other SDGs (Liu et al., 2018). However, according to Liu et al. (2018), from many quantitative methods developed to analyze the WEF nexus interactions, only "some indices in nexus studies overlap with SDGs indicators" (e.g., Karnib, 2017).

The potential of the WEF nexus approach to support the SDGs is contested because the WEF nexus and the SDGs plausibly have different emphases and motivations (Allouche, 2017; Leese & Meisch, 2015; Simpson & Jewitt, 2019). Scholars have argued that the WEF nexus exegesis is driven by narratives of resources scarcity, security, and risk impacting the economy, while the SDGs were designed based on the efficient use and equitable redistribution of resources for all (Allouche et al., 2019; Leese & Meisch, 2015). Several authors have raised concern that the WEF nexus analysis often neglects the sustainability emphasis, for instance, on distributional justice (Leese & Meisch, 2015), gender (FAO, 2018), and livelihood (Wichelns, 2017). In its report for the UN High-Level Political Forum, the Food and Agriculture Organization of the United Nations (FAO) stated that despite the substantial gender aspects in the WEF sectors, the nexus approach often overlooks gender concerns (FAO, 2018). Leese & Meisch (2015) argued that the over-focus on the WEF nexus security omits unequal access to resources globally, blurring distributional justice.

The potential linkages between the WEF nexus approach and the SDGs remain unclear. It is necessary to evaluate whether the sustainability focus adopted when using the WEF nexus functions as a bridge for integrating across SDGs. This systematic literature review identifies, examines, and synthesizes the WEF nexus studies that explicitly focus on the SDGs. To my knowledge, no systematic review has assessed the knowledge advance generated by the WEF literature supporting the SDGs implementation. Previous systematic literature reviews have focused on research trends, methods, and case studies (e.g., Albrecht et al., 2018; Hejnowicz et al., 2022; Taguta et al., 2022). Little research has investigated the scientific evolution supporting any SDGs on food, energy, and water (e.g., Basu & Dasgupta, 2021, focused on SDG 6 on water).

Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Liberati et al., 2009; Moher et al., 2009), this study searched, collected, and analyzed peer-reviewed studies, book chapters, and conference papers over a span of eight years (2015 – 2022) to investigate the extent to which the WEF nexus literature has generated new knowledge enabling the SDGs achievement. PRISMA is a transparent and reproducible methodology, rarely found in the WEF nexus studies (e.g., Fernandes Torres et al., 2019; Taguta et al., 2022). A codebook was designed to identify the cross-cutting themes within the SDGs on food, energy, and water. The primary research question guiding this study is: What are the knowledge advances in the FEW nexus literature that supports sustainable development goals? The following three research sub-questions guide the scope of this systematic literature review:

1. To what extent are the sustainability themes present in the WEF nexus literature aligned with the SDGs on water, energy, and food?
2. Which WEF studies have explicitly employed the SDG themes in an empirical approach? What is the geographical focus of these studies?
3. What are the aims of the empirical studies in the WEF nexus literature linked to the SDGs?

## 2.2 METHODS

This systematic literature review is conducted following the protocol of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Liberati et al., 2009; Moher et al., 2009). PRISMA is a robust and systematic methodological approach to conducting and reporting a systematic literature review since it provides guidelines for setting a literature search strategy, selecting criteria, and data extraction processes when searching in a database. Following PRISMA guidelines improves rigor and transparency in the methodology.

**Table 1**

*Terms searched in the Scopus database*

| Search topic (first row) | Search (second row) | Search topic (third row) | Records Identified | Search topic (third row) | Records Identified |
|---|---|---|---|---|---|
| food, energy, water | AND nexus | AND sustainability OR sustainable | 194 | AND sustainable development goal | 26 |
| food, water, energy | | | 53 | | 8 |
| water, food, energy | | | 110 | | 19 |
| water, energy, food | | | 424 | | 79 |
| energy, water, food | | | 53 | | 4 |
| energy, food, water | | | 12 | | 4 |
| | | Total | 846 | | 140 |

### 2.2.1 Literature Search Strategy

A systematic literature search was performed using Elsevier's SCOPUS database. SCOPUS is the largest interdisciplinary database with a range of content coverage suitable for the goal of this study (Falagas et al., 2008). Two main database searches were performed to illustrate the increased interest in sustainability within the WEF nexus literature. One focused on "sustainability or sustainable," and the other narrowed the search to "sustainable development goal." The first search string included a combination of the keywords "food, energy, water" AND "nexus" AND "sustainability" OR "sustainable" and several variations of the searched "food, energy, water" terms as detailed in Table 1. The second search string was narrowed to the keyword "sustainable development goal." SCOPUS searches for these terms in the titles, abstracts, and keywords. The search was limited to English-language publications, including peer-reviewed articles, book chapters, and conference papers between 2015 through 2022 (data accessed: 2/15/2023). The year 2015 was selected as the starting date because the 2030 Agenda for Sustainable Development was adopted that year, boosting the interest in the WEF nexus approach for sustainable development (Opejin et al., 2020). Book chapters and conference papers were included in the search criteria to access more literature and emergent perspectives.

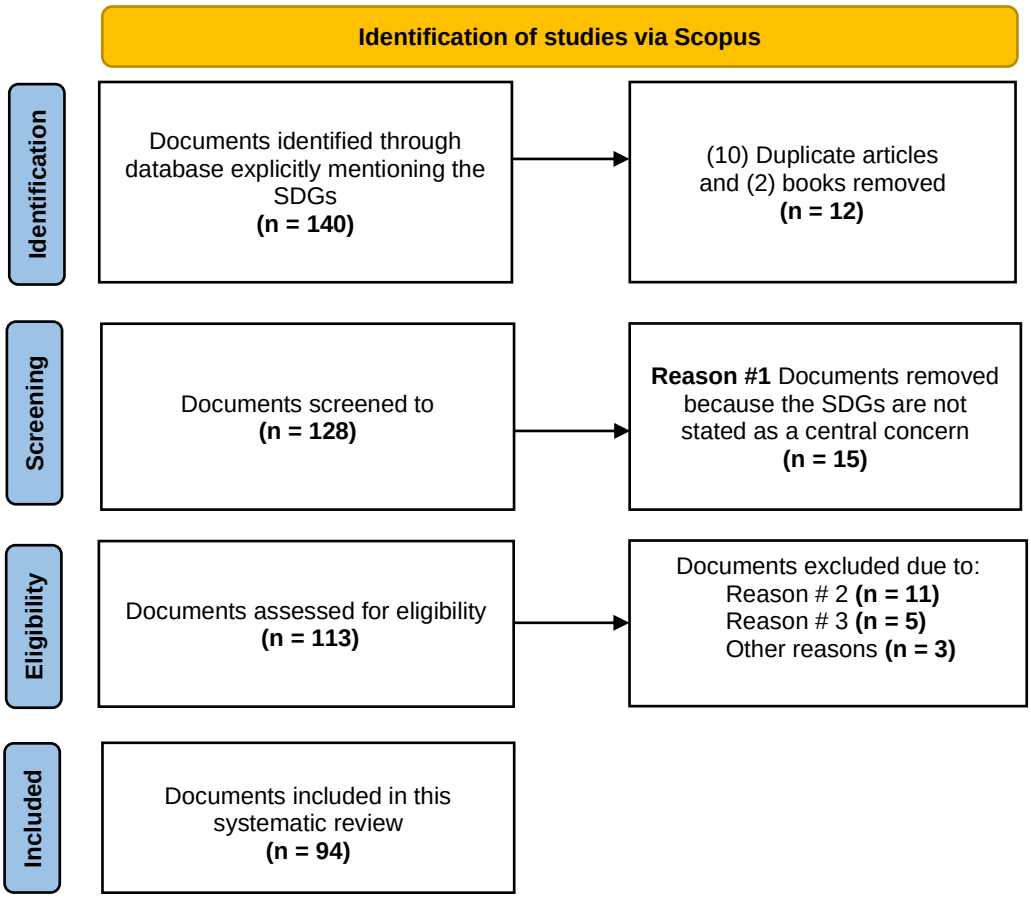
### 2.2.2 Selection criteria for the studies

Any piece of literature included for analysis in this systematic literature review must meet three inclusion criteria. First, the publication must explicitly state the Sustainable Development Goals (SDGs) as a central concern. Second, the publication

must focus on the three sectors in the water, energy, and food (WEF) nexus, and not only on two sectors, such as food-water, energy-water, and energy-food (viz. Reason #2). Third, the publication must not be a literature review, including systematic literature reviews, bibliometric analyses, and meta-analyses (viz. Reason #3). Three records were excluded for other reasons. After exhausting all potential supply sources, two records with inaccessible documents were excluded from the analysis. One record was a not English-language publication. These exclusions in criteria limit the results to any publication of conceptual or empirical research, situating the SDGs in the WEF nexus literature.

**Figure 2**

*PRISMA flow diagram of selecting the literature for analysis*




### 2.2.3 Data collection process

The 140 records retrieved from the search term “sustainable development goal” were combined to facilitate the removal of the duplicate. Figure 2 provides the flow diagram of the process of selecting the literature for analysis. Duplicated pieces of literature were identified manually, and two full-text books were found on the data and removed. After this first step of identification, 128 records remained for screening. The screening consisted of manually examining the scope of the work by glancing at the main

sections of the paper. Documents were removed if they did not explicitly address the Sustainable Development Goals (SDGs) within the WEF nexus. The two additional inclusion criteria (Reason #2 and Reason #3, as stated in the previous section) were applied to reduce the number of documents. All the previous steps were manually screened and sorted. A total of 94 articles complied with the present study criteria focused on the SDGs within the WEF nexus literature and were included in this systematic literature review.

### 2.2.4 Data Analysis

I developed a codebook based on the targets and indicators of the 2030 Sustainable Development Goals (SDGs) on food (SDG 2 zero hunger), energy (SDG 7 affordable and clean energy), and water (SDG 6 clean water and sanitation). These SDGs were examined to generate a set of cross-cutting themes that represent them operationally. The development and use of an SDGs operational framework and cross-cutting themes were intended to examine the contribution to all elements of the target statements. To illustrate, accessibility to food (Target 2.1) requires this food to have adequate nutrients and be sufficient and diverse (Target 2.1 and 2.5). In addition, better access to food requires increased agricultural productivity (Target 2.4 and 2.a) and sustainable agricultural practices (Target 2.4). The results of the SDGs analysis resulted in 11 cross-cutting themes, coded as accessibility, affordability, adequacy, diversification, efficiency, productivity, governance, international cooperation, target population, finance, and environmental protection. However, it is important to note that these cross-

cutting themes are not mutually exclusive or have rigid boundaries. Studies may fall into a cross-cutting theme as a central premise but also address others peripherally.

Each cross-cutting theme is designated as a code name. Table 2 shows the code name, exemplar targets, and the search terms used to facilitate the analysis of the documents. The codebook was developed in MAXQDA 2022 mixed method software, and all the documents were imported. The analysis entailed three steps. First, the documents were screened to verify compliance with the reasons stated in the inclusion criteria. Second, drawing from the classification of the publication applied by Apetrei et al. (2021), each document was classified as conceptual, empirical, and conceptual/empirical study. Conceptual publications are those making an original conceptual contribution, such as frameworks, concepts, research agendas, commentaries, and argumentations. Empirical publications have little conceptual work and focus on collecting evidence to study a phenomenon in a specific context. Conceptual/empirical publications make original conceptual contributions and use empirical evidence to illustrate the phenomenon in a specific context. Third, the text search function in MAXQDA was used to autocode the terms searched. Fourth, autocoded segments were examined and recoded if they were related to the cross-cutting theme—the previous steps classified literature based on the covered themes.

**Table 2**

*Overview of the operational codebook*

| Codes | **Exemplary Targets** | **Term Search** |
|---|---|---|
| **ACCESSIBILITY** | | |
| Target 2.1 access to food | | access, accessibility, accessible, unequal, equal, inequality, equality, equitable, fair, just, justice |
| Target 2.5 access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge | | |
| Target 2.3 secure and equal access to land, other productive resources, and inputs | | |
| Target 6.1 access to drinking water | | |
| Target 6.2 access to sanitation and hygiene | | |
| Target 7.1 access to energy services | | |
| **AFFORDABILITY** | | |
| Target 2.c limit extreme food price volatility | | afford, affordable, affordability, price, cost |
| Target 6.1 affordable drinking water | | |
| Target 7.1 affordable energy services | | |
| **ADEQUACY** | | |
| Target 2.1 safe, nutritious, and sufficient food | | adequate, safe, nutritious, soundly managed, sufficient, safely managed, reliable, modern, safety |
| Target 2.5 soundly managed diversified seed and plant banks at the national, regional, and international levels | | |
| Target 6.1 safely managed drinking water services | | |
| Target 6.2 adequate and safely managed sanitation services | | |
| Target 7.1 reliable and modern energy services | | |
| **DIVERSIFICATION** | | |
| Target 2.5 maintain the genetic diversity of seeds and plants | | diversity, diversify, diversification seeds, diverse, sources, renewable energy, energy, solar, wind, eolic, geothermal, thermal, hydropower, hydroelectric, ocean, wave, bioenergy, biofuel |
| Target 7.2 increase the share of renewable energy | | |

| | |
|---|---|
| **EFFICIENCY** | |
| Target 6.4 increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity | efficiency, conservation, save, saving, water efficiency, energy efficiency, withdrawals, supply, scarcity |
| Target 7.3 double the global rate of improvement in energy efficiency | |
| **PRODUCTIVITY** | |
| Target 2.4 increase agricultural productivity and production | productivity, production, productive |
| Target 2.a enhance agricultural productive capacity in developing countries | |
| **GOVERNANCE** | |
| Target 6.5 implement integrated water resources management at all levels, including transboundary cooperation | governance, integrated water resources management, integrated management, transboundary, cooperation, participation, local communities |
| Target 6.b support and strengthen the participation of local communities | |
| **INTERNATIONAL COOPERATION** | |
| Target 2.a enhanced international cooperation | international cooperation, capacity-building, capacity building, support |
| Target 6.a expand international cooperation and capacity-building support to developing countries | |
| Target 7.a enhance international cooperation | |
| **TARGET POPULATION** | |
| Target 2.1 in particular the poor and people in vulnerable situations | population, poor, vulnerable, vulnerability, children, adolescent, girls, pregnant, lactating, women, older, elderly, producers, indigenous, family, farmers pastoralists, fishers, developing countries, small island developing states, landlocked |
| Target 2.2 children under 5 years of age, adolescent girls, pregnant and lactating women and older persons | |
| Target 2.3 small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers | |
| Target 2.a in particular least developed countries | |
| Target 6.2 paying special attention to the needs of women and girls and those in vulnerable situations | |
| Target 6.4 substantially reduce the number of people suffering from water scarcity | |
| Target 6.a expand support to developing countries | |

| | |
|---|---|
| Target 7.b for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries | |
| **FINANCE** | |
| Target 2.a increase investment in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks | Investment, invest, agricultural research, extension services, technology development, plant gene banks, livestock gene banks, commodity market, food reserves, food price volatility, clean energy technology |
| Target 2.b elimination of all forms of agricultural export subsidies and all export measures with equivalent effect | |
| Target 2.c ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility | |
| Target 7.a promote investment in energy infrastructure and clean energy technology | |
| **ENVIRONMENTAL PROTECTION** | |
| Target 2.4 ensure sustainable food production systems and implement resilient agricultural practices, that help maintain ecosystems, which strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality | environmental protection, sustainable production, agricultural practices, ecosystems, protect, restore, climate change, adaptation, extreme weather, drought, flooding, disasters, land and soil quality, mountains, forests, wetlands, rivers, aquifers, lakes, clean fuels, clean technology, wastewater, hazardous, pollution, untreated, recycling, safe reuse |
| Target 6.3 improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse | |
| Target 6.6 *By 2020,* protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes | |
| Target 7.1 primary reliance on clean fuels and technology | |

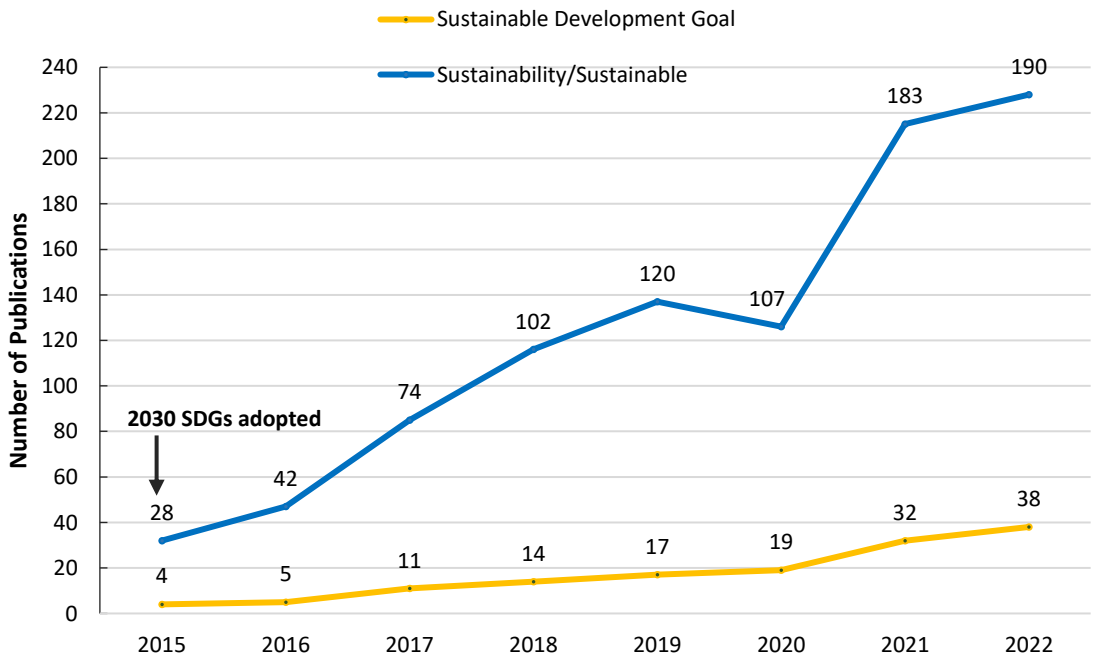
Adapted from: United Nations, Goals 2, 6 and 7. Source: https://sdgs.un.org/goals

## 2.3 RESULTS

The results obtained from the literature search in SCOPUS show an increased interest in the WEF nexus literature on sustainability, with more than half the literature (480 out of 846) published after 2020. In contrast, the number of publications retrieved from the search term "sustainable development goal" was significantly lower (140) than those recovered (846) from using "sustainability or sustainable." The number of studies retrieved from the search term "sustainable development goal" is low and shows a slow increase between 2015 and 2020. Figure 3 shows the number of publications per year retrieved while searching the term "sustainability or sustainable" (blue line) or "sustainable development goal" (yellow line) through the SCOPUS database.

**Figure 3**

*WEF nexus literature centered on sustainability versus the SDGs per year*



### 2.3.1 Alignment of the WEF nexus literature with the SDGs

The first question of this research was to identify if the sustainability themes in the WEF nexus literature aligned with the SDGs. A total of 94 peer-reviewed articles, book chapters, and conference papers aligned with the developed SDGs cross-cutting themes within the WEF nexus literature. Figure 4 shows the frequency with which the SDG cross-cutting themes were addressed in the literature. The 11 cross-cutting themes that emerged from the data fell in 37% (35 out of 94) governance, 20% (19 out of 94) environmental protection, 10% (9 out of 94) efficiency, 9% (8 out of 94) diversification, 6% (6 out of 94) accessibility, 5% (5 out of 94) finance, 3% (3 out of 94) adequacy, 3% (3 out of 94) target population, 3% (3 out of 94) productivity, 2% (2 out of 94) international cooperation, and 1% (1 out of 94) affordability. Governance is the most frequent theme, followed by environmental protection and efficiency. The least frequent themes were affordability and international cooperation. It is important to note that studies may focus on a cross-cutting theme as a central concern but also address others peripherally. The top ten peer-reviewed journals where these research studies were published based on frequency are detailed in Table 3.

**Table 3**

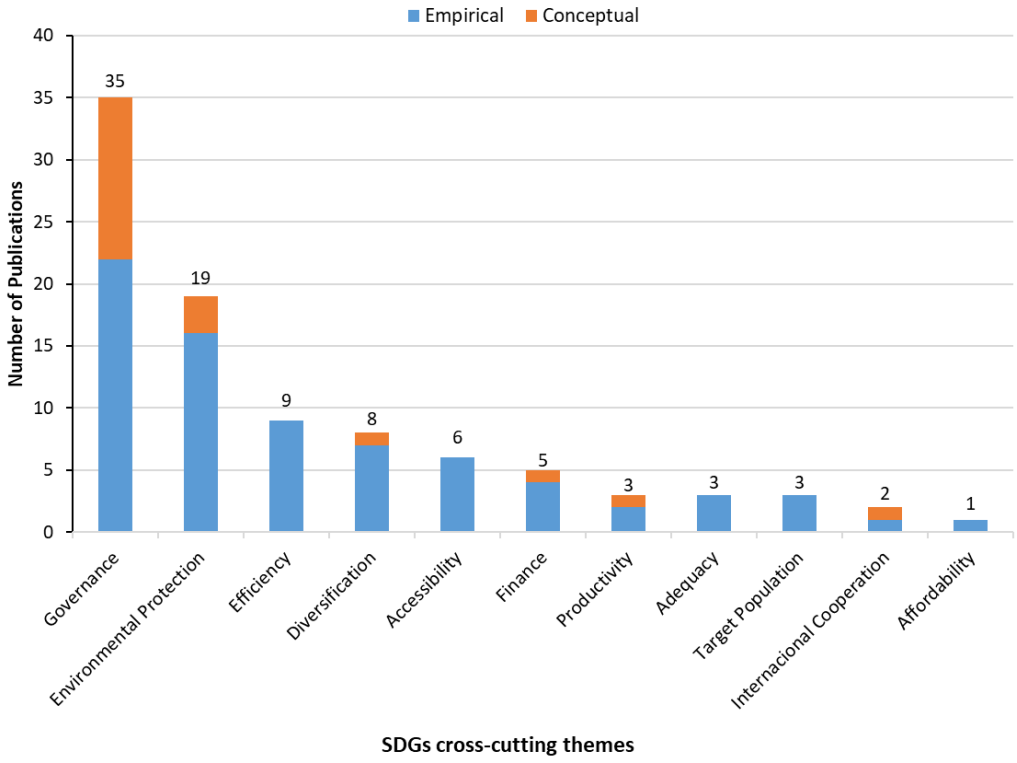
*Top ten journals where the WEF nexus studies focused on the SGDs*

| Journal Names | Publisher | Frequency | Impact Score (2021) |
|---|---|---|---|
| Sustainability (Switzerland) | MDPI | 5 | 4.17 |
| Resources, Conservation, and Recycling | Elsevier | 5 | 12.68 |
| Science of the Total Environment | ScienceDirect | 5 | 10.15 |
| Environmental Science and Policy | ScienceDirect | 4 | 6.53 |
| Agricultural Water Management | ScienceDirect | 3 | 6.53 |

| | | | |
|---|---|---|---|
| Frontiers in Sustainable Food Systems | Frontiers Media S.A. | 3 | 4.49 |
| Frontiers in Water | Frontiers Media S.A. | 3 | 1.2 |
| Journal of Cleaner Production | Elsevier | 3 | 9.29 |
| Sustainable Production and Consumption | ScienceDirect | 3 | 9.06 |
| Water (Switzerland) | MDPI | 3 | 3.47 |

**Figure 4**

Frequency of the SDGs themes addressed in the WEF nexus literature



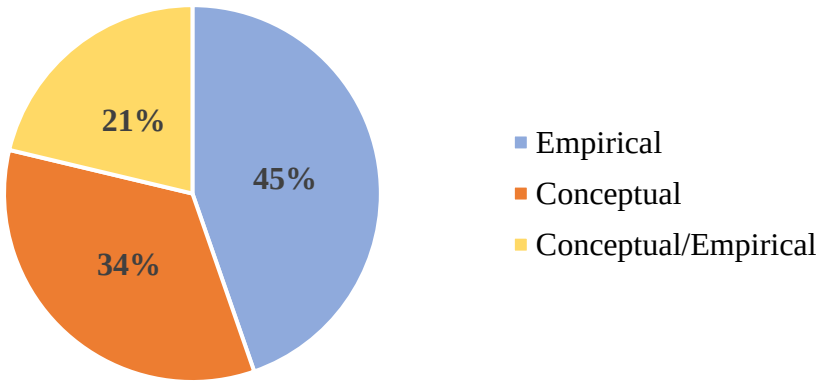

### 2.3.2 WEF nexus empirical studies addressing the SDGs and geographical locations

The second question in this research aimed to identify which studies have used SDG cross-cutting themes with an empirical approach and their geographical locations. Figure 5 presents the percentage for each type of publication: conceptual, empirical, and

conceptual/empirical. From the 94 peer-reviewed articles, book chapters, and conference papers focused on the SDGs within the WEF nexus literature, 45% (42 out of 94) were empirical studies, 34% (32 out of 94) were conceptual/empirical studies, and 21% (20 out of 94) were conceptual publications. Of the 94 records included for analysis, 79% (74 out of 94) of studies made an empirical contribution addressing the SDGs in specific countries.

**Figure 5**

*Percentage of types of research studies*




This second question also aimed to identify the geographical locations where empirical studies have been conducted. According to the data, empirical studies have been presented for 124 countries. Some studies have presented more than one country as a study region or case study. Countries were classified as developed countries, developing countries, or countries in transition, based on the World Economic Situation and Prospects 2022 prepared by the Economic Analysis and Policy Division of the Department of Economic and Social Affairs of the United Nations Secretariat (UN DESA, 2022). Figure 6 presents the percentage of empirical studies based on this

development classification. Studies included 67% (83 out of 124) developing countries, 27% (33 out of 124) developed countries, 6% (7 out of 124) countries in transition, and 1% with global scope. The top developing countries with the most empirical studies are China (14), India (10), South Africa (10), and Bangladesh (7). The top developed countries with the most empirical studies are Italy (5), Spain (4), Sweden (4), Germany (4), and Greece (4). Studies also have been conducted for countries in transition, such as Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan (e.g., Hao et al., 2022). Figure 7 illustrates a global choropleth map of countries where the WEF nexus literature had contributed empirical studies linked to the SDGs.

**Figure 6**

*Percentage of empirical studies by development classification*

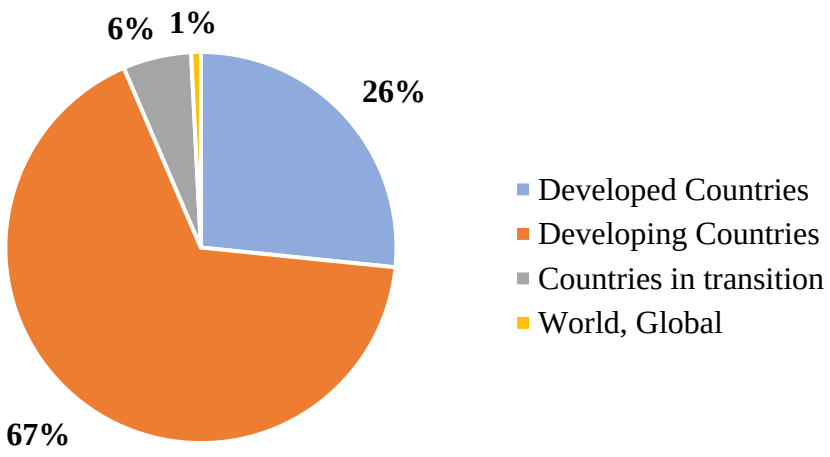
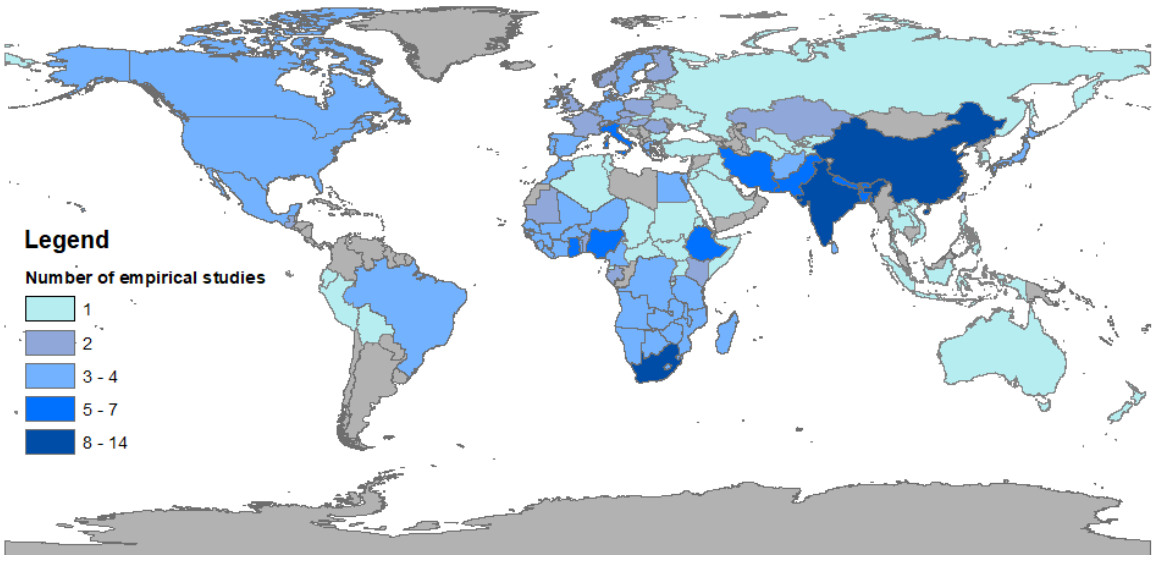


**Figure 7**

*Global choropleth map displaying the countries that empirical studies*




Darker colors represent high frequency, while lighter colors correspond to less frequency.

### 2.3.3 Aims of the WEF nexus empirical studies within the SDGs themes

The third question in this research focused on identifying the aims of the WEF nexus empirical studies motivated by the SDGs. Figure 8 compares the counts of SDGs cross-cutting themes in the WEF nexus empirical studies. The counts range from 22 (governance) to 1 (international cooperation). The 11 cross-cutting themes that emerged from the empirical studies fell in 30% (22 out of 74) governance, 22% (16 out of 74) environmental protection, 12% (9 out of 74) efficiency, 9% (7 out of 74) diversification, 8% (6 out of 74) accessibility, 5% (4 out of 74) finance, 4% (3 out of 74) adequacy, 4% (3 out of 74) target population, 3% (2 out of 74) productivity, 1% (1 out of 74) affordability and 1% (1 out of 74) international cooperation. Governance is the most

frequent theme, followed by Environmental Protection and Efficiency. The least frequent themes were affordability and international cooperation. Table 4 highlights exemplars of empirical research for each of the SDGs' cross-cutting themes. Summaries of exemplars contributions made from empirical studies are also included.

**Figure 8**

*Frequency of the SDGs themes in WEF nexus empirical studies*

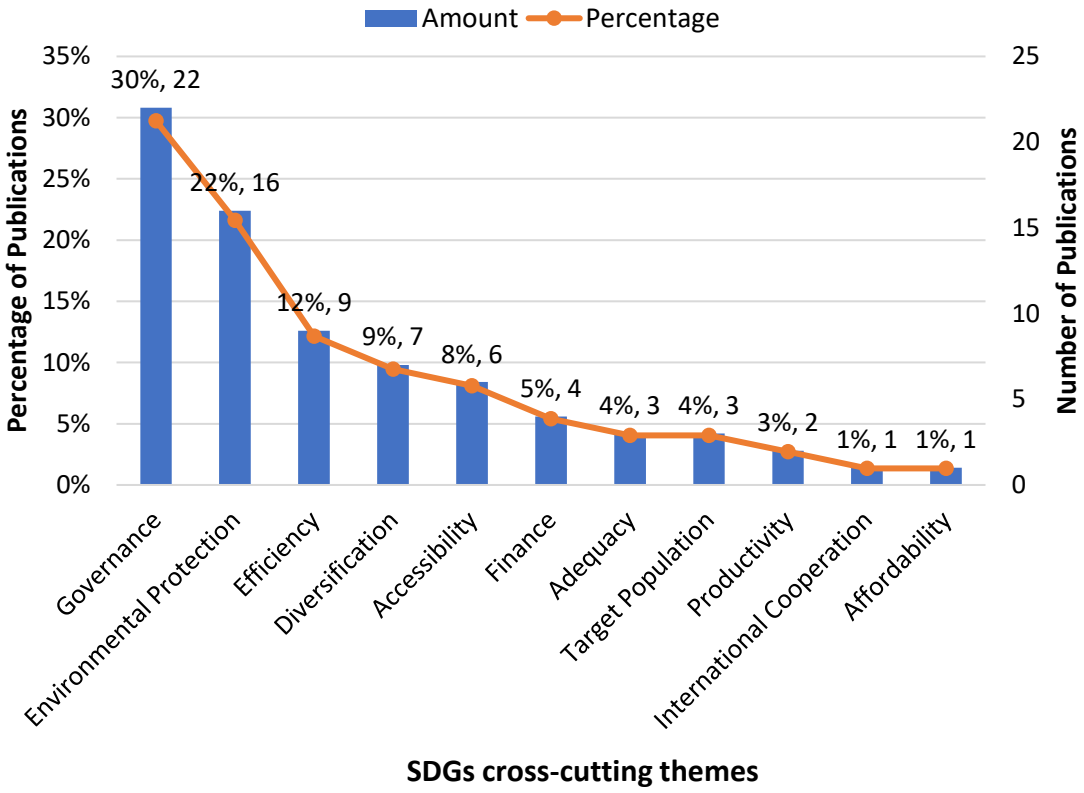


**Table 4**

*Exemplars empirical research for each of the SDG cross-cutting themes*

| SDG Theme | Focus (Cite) |
|---|---|
| Governance | Local perceptions of WEF security and livelihood consequences of two dams for hydropower and irrigation purposes in Ethiopia (Gebreyes et al., 2020) |
| Environmental Protection | Ecological response to the increased productivity of WEF resources in nine well-developed countries in Africa (Muhirwa et al., 2022) |
| Efficiency | Potential conflict between the promotion of the WEF nexus (SDG2, SDG6, SDG7) and planetary boundaries (Hua et al., 2020) |
| Diversification | Comparative analysis of two coal-depended countries: Germany and South Africa, for a just energy transition (Hägele et al., 2022) |
| Accessibility | Sustainability performance of urban agriculture network in the food–energy–water nexus based on governance structures for food access in a Metropolitan area in the United States (Valencia et al., 2022) |
| Finance | A cost-benefit analysis of a hydropower dam considering the WEF nexus and environmental, economic, and social aspects (Tajziehchi et al., 2022) |
| Adequacy | Optimal production of food of vegetable and animal origin based on the minimum essential nutrients per person per day (Naja et al., 2018) |
| Target Population | Gender perspectives on the WEF nexus in Ethiopia (Villamor et al., 2020) |
| Productivity | Optimal cropping patterns to minimize water and energy consumption at the watershed scale in Iran (Sadeghi et al., 2020) |
| Affordability | The gap between electricity supply and demand and the payment capacity of rural villagers in Mozambique (Uamusse et al., 2019) |
| International Cooperation | International Network Governance for the SDGs (Kapucu & Beaudet, 2020) |

### 2.3.4 Examples of knowledge contributions from empirical studies

#### *2.3.4.1 Studies focusing on governance*

Almost one-third of the empirical studies (22 out of 74) fell into the governance cross-cutting theme. The governance theme refers to studies focused on implementing integrated water resources management at all levels, including transboundary cooperation

(Target 6.5) and supporting and strengthening the participation of local communities (Target 6.b). Studies addressing integrated management within the WEF nexus and a nexus perspective on the SDGs are reported in this cross-cutting theme. Within this area of investigation, considerable research attention has been directed toward the creation of frameworks, indicators, indexes, or models for WEF-integrated management (e.g., Akinsete et al., 2022; Dhaubanjar et al., 2021; Hao et al., 2022; Lazaro et al., 2021; Nhamo et al., 2020; Rasul & Neupane, 2021; Yue & Guo, 2021, among others).

To illustrate, Giupponi & Gain's (2017) research presented a comprehensive approach for the WEF spatial assessment with indicators based on the SDGs, then aggregated the indicators in a single WEF security index. This indicator-based approach is intended as a tool to monitor and compare progress among different geographical areas, focusing on synergies and trade-offs. The proposed approach has been employed at the global scale and in two river basins: the Ganges–Brahmaputra–Meghna River Basin in Asia and the Po River Basin in Europe. Another research was conducted by Zhang et al. (2022) emphasizing the "lack of a systematic and quantitative analysis of how the nexus approach could promote achieving SDGs." Authors contributed an expanded WEF nexus framework from the lens of SDGs and quantifying the two-way interactions between sectors. The framework was applied to the case study of China. Zhang et al. concluded that the SDGs indicators could not capture the real links between the WEF sectors.

Two specific empirical studies in the WEF nexus literature have sought to support and strengthen the participation of local communities (Target 6.b). For instance,

Gebreyes et al. (2020) examined the perception of WEF security of the people whose livelihoods are directly affected by two newly constructed dams in Ethiopia for hydropower and irrigation purposes. A survey was conducted in 549 households around the two large-scale dams. An interesting finding was that despite the presence of these two large dams, local people perceive minimal access to energy and irrigation. Another study by Almulla et al. (2022) introduced a WEF-integrated stakeholder-driven and model-supported nexus decision-making framework. The authors applied this decision-making framework to the case study in the Souss-Massa basin Morocco because of its significance for the agricultural sector.

#### *2.3.4.2 Studies focusing on Environmental Protection*

Environmental protection is the second cross-cutting theme that received the most research attention. 22% (16 out of 74) of the empirical studies focused on the environmental protection theme. This theme encompasses, for instance, sustainable food production systems and resilient agricultural practices (Target 2.4), pollution reduction (Target 6.3), and ecosystem protection and restoration (Target 6.6). For instance, in the article "Environmental sustainability and footprints of global aquaculture," Jiang et al. (2022) created a food-energy-water-carbon (FEWC) composite sustainability index (0–100) to assess the sustainability and footprints of global aquaculture production systems. Given the role of aquaculture for global food and nutrition security and other SDGs, these aquaculture production systems have proliferated worldwide, raising concerns about environmental impacts. The results obtained from the assessment show that the average sustainability score of global aquaculture is low (26), with most countries scoring

between 0–50 (low sustainability score) and none scoring 75 or greater (high sustainability score).

The studies of Muhirwa et al. (2022) and Rasul (2016) converged in stating the need to assess the environmental impacts of achieving the WEF security nexus and the SDGs. Rasul (2016) focused on South Asian countries such as Bangladesh, Nepal, and Pakistan. Muhirwa et al. (2022) focused on nine well-developed African countries, such as Algeria, Egypt, Tunisia, Mauritius, Ghana, Cameroon, and Gabon. Rasul (2016) stated the fact that "with less than 5% of the earth's land area, South Asia has to feed about one-fourth of the world's population (1.6 billion people)." Incentives like subsidizing water and energy for increased food production have led to inefficient use and overexploitation of resources. The authors offered an extensive list of cross-sectoral impacts with implications for sustainability, the SDGs, and alternatives to managing trade-offs and enhancing synergies. Muhirwa et al.'s study aimed to assess the sustainability of the high increase demand for WEF resources, using three indicators: ecological footprint (EF), ecological biocapacity (EBC), and eco-balance. The authors argued this approach could help policymakers and practitioners determine the best types of resources to adopt to decrease the ecological response of increased WEF resources productivity.

#### *2.3.4.3 Studies focusing on efficiency*

The efficiency cross-cutting theme sought for studies focused on the prudent and efficient use of resources across all sectors. For instance, water efficiency and sustainable water withdrawals (Target 6.4) and energy efficiency rates (Target 7.3). A 12% (9 out of 74) of the empirical studies were classified under the efficiency theme. An interesting

article is “Identifying priority biophysical indicators for promoting water-energy-food nexus within planetary boundaries” by Hua et al., 2020**.** This article states that “the efficiency of biophysical resource utilize is the ratio between the quantity per capita of biophysical resource utilization and the threshold per capita of the planetary boundaries for each indicator of the WEF nexus.” The authors conducted a global study to, among other objectives, explore the potential conflict between the promotion of the WEF nexus (SDG2, SDG6, SDG7) and planetary boundaries. Hua et al. employed global datasets of official SDG statistics and 15 indicators to monitor the progress of the WEF nexus in 156 countries. In summary, Hua et al. found significative differences in the performance of the WEF nexus between countries and that “the massive resource consumption associated with the promotion of the WEF nexus can severely transgress multiple planetary boundaries.”

In line with ensuring sustainable water withdrawals, Moraes-Santos et al. (2021) aimed to quantify the exploited water flows against the capacity of aquifer systems in five municipalities located in the northeastern region of the Paraíba do Sul River Basin in Brazil. The authors employed data on groundwater concession and use related to the electricity consumption of the water supply systems and food production in the five Brazilian municipalities. Moraes-Santos et al. found a lack of knowledge of the total extraction of water from the aquifers and that “only 13% of the total water used and granted is used for public use, so it is important to consider that, in the event of water crises, the greatest damage and restrictions on access to water reflect on the population, that is, the public use of water resources.” Because of the key role of irrigation in global

food production, Campana et al. (2022) investigated the range of irrigation efficiency of photovoltaic water pumping systems, which intrinsically present WEF nexus interdependencies. Case studies of photovoltaic water pumping systems for irrigation projects were discussed in China, Spain, Portugal, Italy, and Morocco.

#### *2.3.4.4 Studies focusing on diversification*

The diversification cross-cutting theme refers to studies focused on using or having the alternative to use various sources. For instance, maintaining the genetic diversity of seeds, cultivated plants, farmed and domesticated animals, and their related wild species (Target 2.5) and increasing the share of renewable energy (Target 7.2). A total of 9% (7 out of 74) of the empirical studies focused on diversification, particularly renewable energy (Hägele et al., 2022; Kylili et al., 2021; Neupane et al., 2022; Schwanitz et al., 2017). For instance, through the comparative analysis of Germany and South Africa, both coal-depended countries, Hägele et al. (2022) investigated how governments design and implement solutions for a just energy transition that synergistically addresses the Paris Agreement and the 2030 Sustainable Development Agenda. The authors developed a just energy transition framework, applied it to the two case studies, and described the challenges in overcoming the coal phase-out's environmental, economic, and social burdens on the Water-Energy-Food-Land nexus (SDGs 2, 6, 7, 15).

The studies of Neupane et al. (2022) and Matthews & McCartney (2018) had a similar focus on examining the function of hydropower in achieving the SDGs on food, energy, and water. Neupane et al.'s study focused on South Asia countries such as

Afghanistan, Bangladesh, Bhutan, India, Nepal, and Pakistan. Matthews & McCartney (2018) focused on the countries of Zambia and Laos. Drawing from Zarfl et al. (2015), Matthews & McCartney (2018) highlighted that approximately 3700 hydropower dams with a capacity of more than 1 MW were under planning (83 %) or construction (17 %) worldwide in 2014. According to these authors, the proliferation of hydropower dams is driven by "the global shifts towards renewable energy and changes in how large-scale projects are financed, especially the rapid expansion of Public-Private Partnerships (PPPs)." Acknowledging that the socio-ecological impacts associated with dams resulted in a decline in construction worldwide in the past, Matthews & McCartney (2018) examined the challenges, trade-offs, and risks associated with hydropower dams and the WEF nexus. The authors provided a series of lessons learned based on case studies to improve decision-making toward social-ecological resilience. Neupane et al.'s study, argued for the underutilization of the potential of renewable energy, especially hydropower, in South Asia countries. According to the authors, this hindered the WEF security of the South Asia people. The authors discussed policy, financing barriers, and research gaps on socio-economic and bio-physical factors.

#### *2.3.4.5 Studies focusing on accessibility*

Only 8% (6 out of 74) of the studies using an empirical approach focused on the accessibility theme. The accessibility cross-cutting theme refers to studies centering on access to food (Target 2.1, land and other productive resources and inputs (Target 2.3), drinking water (Target 6.1), sanitation and hygiene (Target 6.2), and energy services (Target 7.1). One of the most widely used WEF nexus indices for resource availability

and accessibility is Pardee Rand Food – Energy – Water (PR-WEF) Security Index (Willis et al., 2016). The PR-WEF Security Index is based on two sub-indicators for integrated WEF resources availability and accessibility referenced as WEF security. In summary, availability refers to local resources meeting the needs of individuals, and accessibility refers to individuals having access to them (Nkiaka et al., 2021). This index was the subject of several empirical research (e.g., Mohammadpour et al., 2019; Nkiaka et al., 2021; Venghaus & Dieken, 2019). For instance, Nkiaka et al. (2021) used PR-WEF Security Index to conduct a quantitative and spatial analysis in 47 sub-Saharan Africa (SSA) countries, showing that 41 countries in SSA are WEF insecure.

Although Mohammadpour et al. (2019) criticized the PR-WEF Security Index because of its limitations in exploring regional variations, authors draw on this index to analyze (WEF) security at regional levels in South American countries Ecuador, Peru, and Bolivia. The authors enhanced the existing PR-WEF Security Index to ensure its applicability at the regional scale. They found a wide variation in the calculated indices for regions within these countries. Likewise, Cansino-Loeza et al. (2020) mentioned the PR-WEF Security Index and other indices for their lack of applicability in measuring WEF nexus security at any scale. Therefore, Cansino-Loeza et al. proposed an index to assess the progress in WEF security of any region based on the SDGs on food, water, and energy. This index was applied to the case of the state of Sonora, Mexico, producing several sustainability indicators for the state. The authors asserted that this index is replicable to other regions if accurate data for the WEF resources exist.

#### *2.3.4.6 Studies focusing on finance*

The finance cross-cutting theme refers to, for instance, studies that focus on investment in infrastructure, research, and technology development (Target 2.a, Target 7.a) as well as the proper functioning of the world food commodity markets (Target 2.b, Target 2.c). A total of 4 out of 74 (5%) studies focused on the finance theme. To illustrate, Siderius et al. (2022) characterized the trade-offs and synergies between water, energy, and food-related SDGs in the Ganges–Brahmaputra–Meghna River basin system. The Ganges–Brahmaputra–Meghna River basin included the countries of Bhutan, Bangladesh, India, and Nepal, including a large part of South Asia's 'wheat basket' and 'rice bowl.' Using multi-objective optimization of SDGs, the authors quantified the linkages between the profitability of food production. This study found that "the trade-off between food production and agricultural profit is strong [and] the amount of people fed would be reduced by more than two-thirds [when] profitability [is] maximized."

Another example is the article "A Cost-Benefit Analysis of Bakhtiari Hydropower Dam Considering the Nexus between Energy and Water." In this study, Tajziehchi et al. (2022) modified the SimPacts, and HECAM models investigated the long-term profitability of hydropower by considering the environmental, economic, and social aspects of the cost-benefit analysis of constructing hydropower dams. Then, the HECAM II model (upgraded version) was validated in the Bakhtiari hydropower dam in Iran. The HECAM II model included SDGs 2, 6, and 7 by adding consideration to the agricultural, fishery, water transmission, and hydropower generation. The HECAM II model demonstrated that "the Bakhtiari Dam can positively interfere with the development

problems [and] the project should be evaluated as a long-term solution to the complex sustainability problem in this region."

In the line of investment in technology development, Udugama et al. (2020) examined the aspects of commercializing technologies for resource recovery in a circular economy aligned with the SDGs. Four case studies were presented to illustrate the circular economy of technologies that directly convert food waste, waste energy, or wastewater into valuable raw materials. The case studies selected are affiliated with the Process and Systems Engineering Center at the Technical University of Denmark. As discussed by the authors, the financial aspect is key to advancing technology development; still, funding from government programs (EU and regions) is limited and depends on private investors.

#### *2.3.4.7 Studies focusing on adequacy*

Only three empirical studies (3 out of 74) fell into the adequacy cross-cutting theme, which refers to how acceptable the supplied resources are in both quality and quantity. For instance, adequacy includes safe, nutritious, and sufficient food (Target 2.1), safely managed drinking water services (Target 6.1), adequate and safely managed sanitation services (Target 6.2), and reliable and modern energy services (Target 7.1). For instance, Naja et al. (2018) and Cansino-Loeza et al., 2021 are two empirical studies tackling Target 2.1 on safe, nutritious, and sufficient food. On the one hand, Cansino-Loeza et al. (2021) developed a mathematical model aiming for the optical mix of technologies to supply the energy, water, and food needs of disadvantaged rural communities. The optimal production of food of vegetable and animal origin is

determined based on the minimum essential nutrients per person per day. This model was tested in a case study in a rural community in Mexico. On the other hand, Naja et al.'s (2018) study examined Lebanese adults' dietary patterns (viz., Western, Lebanese-Mediterranean, and High-Protein) and the Environmental Footprint and greenhouse gas (GHG) emissions of food consumption based on nutrition. This study offered "evidence for the notion that what is healthy for people may also be healthy for ecosystems and highlight the need for nutrition recommendations to take into consideration the nexus of water, food, energy, in addition to health."

#### *2.3.4.8 Studies focusing on target populations*

Only 4% (3 out of 74) of the empirical studies fell into the target population cross-cutting theme. This theme sought for studies focused on developing countries (Target 2.a, Target 6.a, Target 7.b), poor and people in vulnerable situations (Target 2.1, Target 6.2, Target 6.4); children under 5 years of age, adolescent girls, pregnant and lactating women and older persons (Target 2.2); small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers (Target 2.3); small island developing States, and land-locked developing countries (Target 7.b). As presented in Figure 6, studies included 83 developing countries, and 7 countries in transition. Therefore, most of the empirical studies comply with the criteria for the target population theme based on geographical locations. While most of the empirical studies focused on developing countries, only three empirical studies focused on the target population besides being in a developing country (viz. Nhamo et al., 2020, Mabhaudhi et al., 2022, Villamor et al., 2020). Other studies fell in the peripheral of the target population as

cross-cutting themes interfaced (e.g., Uamusse et al., 2019 in affordability; Wade et al., 2022 in productivity; Cansino-Loeza et al., 2021 in adequacy).

For instance, Nhamo et al. (2020) presented an integrated WEF nexus analytical model for building resilient communities and then applied it to evaluate resource availability, distribution, use, and management at the Sakhisizwe Local Municipality in South Africa. The population in the Municipality is 61% rural communities, where smallholder farmers face challenges to be productive and secure food because of unproductive land, old farming practices, and climate change. The study aimed to inform strategies and guidelines on improving the livelihoods of resource-poor rural communities attaining the SDGs by understanding the socio-economic and environmental interactions. In another study, Mabhaudhi et al. (2022) applied a WEF nexus analytical livelihoods model to assess rural livelihoods to manage resources, build community resilience, and measure performance on the SDGs. This study focused on southern Africa (viz. Angola, Botswana, Comoros, Democratic Republic of Congo (DRC), Lesotho, Madagascar, Mauritius, Malawi, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe), where 60% of the population lives in rural areas "with limited access to basic services and amenities such as clean and safe water, affordable and clean energy, and balanced and nutritious diets."

In a noteworthy article, "Gender Specific Differences of Smallholder Farm Households Perspective of Food-Energy-Land Nexus Frameworks in Ethiopia," Villamor et al. (2020) was the only study applying a gender-specific lens to assess the differences between men's and women's perspectives on the food-energy-land nexus from a

smallholder farm household perspective in rural Ethiopia. The authors adopted the conceptual framework of Actors, Resources, Dynamics, and Interactions (ARDI) to co-develop a mental model of the nexus concept combined with focus groups and statistical analysis. The study suggested that WEF nexus trade-offs may arise from gender-specific differences (e.g., gender-specific productive roles, access to a broader spectrum of actors, and decision-making regarding resource utilization, including time allocation).

#### *2.3.4.9 Studies focusing on productivity*

Only 3% (2 out of 74) of the empirical studies fell into the productivity theme, which primarily focuses on increasing agricultural productivity or enhancing productive capacity, particularly in developing countries (Target 2.4 and 2.a). To illustrate, Sadeghi et al. (2020) used a WEF nexus approach to investigate the balance in supply and demand of resources to identify the optimal cropping patterns for the Shazand watershed in Iran. According to the authors, the optimization approach is rarely used at the watershed scale. Using this approach, Sadeghi et al. studied 14 crops planted in the orchard, irrigated, and rain-fed farms between 2006 and 2014, targeting the water-energy-food nexus index (WEFNI) maximization. They found that minimizing water and energy consumption and maximizing benefit is not possible in the Shazand Watershed. Authors recommended cultivating horticultural crops rather than crash crops like onion, potato, and sugar cane.

Posited as a strategy to mitigate precipitation seasonality, Wade et al. (2022) developed a hydro-economic model to assess the role of irrigation in supporting the food system. The authors applied the hydro-economic model to assess irrigation scenarios in a highly productive agricultural region in the Pacific Slope of Guatemala. Authors found

that if irrigation infrastructure is expanded with bioenergy, the agricultural output may increase between 3.4% and 18.4% relative to current levels under current climate conditions. The authors also stated the disparities related to land ownership and irrigation in the region. For instance, even though smallholder farmers own more than 50% of the land, they have limited capacity to finance irrigation infrastructure, and 65% of the irrigation is dedicated to large-scale crops for exports. The authors asserted that this study shows "evidence that the marginal benefit from increased irrigation access to smallholder farmers is nearly equal to that received by large-scale industrial, agricultural producers."

#### *2.3.4.10 Studies focusing on affordability*

Only one empirical study (1 out of 74) fell into the affordability theme. Uamusse et al. (2019) studied the electrification rates in small rural villages in Mozambique. Even though Mozambique has a plentiful supply of energy resources, it is one of the poorest countries in the World, and electrification rates are low. Using a WEF nexus approach, the authors studied the viability of small hydropower plants and affordability for poor rural villagers. According to the authors, the payment capacity of villagers has been estimated to be approximately 50 USD annually (out of 300 USD annual income) per household/year in Mozambique. However, the result of this study indicates that the real payment capacity for rural villager households is between 8 and 19 USD per year.

#### *2.3.4.11 Studies focusing on international cooperation*

Only one empirical study (1 out of 74) fell into the international cooperation cross-cutting theme. This theme sought empirical studies on understanding international cooperation (Target 2.a, Target 6.a, Target 7.a) for the SDGs achievement and the

capacity-building support directed to developing countries (Target 6.a). In the article "Network governance for collective action in implementing united nations sustainable development goals," Kapucu & Beaudet (2020) conducted a network analysis and visualization to investigate if international organizations were working in coordination toward the SDGs, with a particular look at the goals within the WEF nexus, and concluded that "numerous programs, funds, and specialized agencies are working together through collective action partnerships."

## 2.4 DISCUSSION AND CONCLUSION

The present study was designed to assess knowledge generated from the WEF nexus literature in support of the 2030 Sustainable Development Agenda on food (SDG 2 zero hunger), energy (SDG 7 affordable and clean energy), and water (SDG 6 clean water and sanitation). Eight years of scholarly articles were examined since the SDGs adoption (2015-2022) within the WEF nexus literature. The motivation for this study came from the contested perspectives of whether the WEF nexus approach may or may not blur the sustainability emphasis in the SDGs; and the fact that seven years remain before the intended deadline of 2030. The main question in this study sought to determine the knowledge advances contributed by the WEF nexus literature in support of the SDGs. This research was undertaken to answer this main question, and two contributions were made while exploring the WEF nexus literature role in support of all elements of the SDGs target statements. First, I developed an operational codebook by synthesizing the sustainable development goals on food, energy, and water resulting in eleven cross-cutting themes. The codebook is a specific contribution to WEF nexus and SDG

literature, which other scholars can adopt. Second, I applied the codebook to assess the contributions from the WEF nexus literature and answer three sub-questions about the alignment of the WEF nexus studies with the SDGs and the aims and geographical locations of empirical studies.

Through the codebook application, this study determined the count of studies focused on the SDGs 11 cross-cutting themes—accessibility, affordability, adequacy, diversification, efficiency, productivity, governance, international cooperation, target population, finance, and environmental protection. Overall, the sustainability themes in the WEF nexus studies aligned with the SDGs. A total of 94 peer-reviewed articles, book chapters, and conference papers aligned with the developed SDGs cross-cutting themes within the WEF nexus literature (Figure 4). The results show that governance and environmental protection themes have received the most research attention. In contrast, aspects of the SDGs, such as affordability and international cooperation, have received less attention. A possible explanation for the dominance of governance cross-cutting theme is that previous studies reported governance being neglected in the past (Weitz et al., 2017b), contributing to an observed increase in this area of research which coincides with the years of this study (Pahl-Wostl, 2019; Srigiri & Dombrowsky, 2021). Another possible explanation is that the governance cross-cutting theme includes developed frameworks, indicators, and models for integrated management, which fall into quantitative methods that have dominated the WEF nexus literature (Albrecht et al., 2018). A possible explanation for environmental protection is the second cross-cutting with more research attention might be that studies from the environmental science field

have dominated over the social sciences field, as found by Newell et al. (2019). Further data collection could be extended to non-English publications to examine the contributions of the WEF nexus literature on other languages.

In accordance with the present results, WEF nexus studies have used the SDG cross-cutting themes with an empirical end in diverse geographical locations. This result is promising because, according to Liu et al. (2018), more empirical studies for integrated management and governance were needed in the WEF nexus literature. In fact, 74 out of 94 (79%) studies made an empirical contribution addressing the SDGs in specific countries. Empirical studies have been presented for 124 countries, as illustrated in the map of countries in Figure 7. Studies focused on 67% (83 out of 124) developing countries, 27% (33 out of 124) developed countries, 6% (7 out of 124) countries in transition, and 1% with global scope. These results may also raise a question for further research about why the majority of the WEF nexus studies focused on the SDGs in developing countries and why is the reason fewer studies focused on developed countries.

Even though most of the empirical studies comply with the criteria for the target population theme based on the geographical locations, the empirical studies focused on the target population besides being in a developing country were scant. Only one empirical study (1 out of 74) addressed gender-specific differences in smallholder farm households' perspective of the food-energy-land nexus (Villamor et al., 2020). This result accords with earlier observations by the Food and Agriculture Organization of the United Nations (FAO) that the WEF nexus approach often overlooks gender concerns within the SDGs (FAO, 2018). In general, the lack of studies focused on vulnerable populations,

children, women, the elderly, small-scale farmers, and indigenous people is concerning. These results further support the argument that less emphasis is put on distributional justice (Leese & Meisch, 2015) and livelihood (Wichelns, 2017).

Concerning the aim of the WEF nexus empirical studies motivated by the SDGs, it was found that governance and environmental protection cross-cutting themes have received most of the research attention. In contrast, aspects of the SDGs, such as affordability and international cooperation, have received less attention. These results display a slight difference from the analysis results that included non-empirical studies in Figure 4. It is interesting to note that very few empirical studies were found in the literature on the finance (4 out 74) and affordability (1 out of 74) cross-cutting themes, given that the sustainability studies have been criticized because of the overemphasis on the economic aspects when dealing with trade-offs (Berke & Conroy, 2000; Coffman & Umemoto, 2010). Further studies investigating the finance and affordability cross-cutting theme could experiment with using ProQuest's ABI/INFORM Collection, a business and trade database with English-language publications worldwide. As mentioned, some studies were found to interface within more than a cross-cutting theme. This finding is promising since the comprehensiveness of the intended SDG targets is considered.

Returning to the main research question, it is now possible to state that the WEF nexus literature appears to be generating knowledge that contributes to understanding the linkages between the SDGs for water, energy, and food. Taken together, these results provide strong evidence of the role of research and the potential contribution the WEF nexus literature can enable to understand the conditions on which the SDGs could be

implemented in different contexts. Despite these promising results, there is a need to revisit the scope of research to direct more attention from the WEF nexus literature to the SDGs cross-cutting theme with less research, such as finance, adequacy, target population, affordability, and international cooperation. Further research should be undertaken to investigate, for instance, the interface of access and affordability and integrated management and adequacy. Pursuing the 2030 Sustainable Development Agenda and the WEF SGDs is one of our society's biggest aspirations. Applying the proposed codebook could lead to a fundamental change in how research is conceived to be easily transferred and become actionable for those who need the knowledge for better decision-making. Now that the potential of using this operational codebook to assess the contribution towards the SDGs has been tested, this codebook could be repeated with other SDGs to assess future research trends and help address concerning gaps, such as the lack of research attention given to vulnerable groups and distributional justice.

# CHAPTER 3

# IMPROVING GOVERNANCE RESPONSES BY REFRAMING THE WATER QUALITY PROBLEM IN A WATER-ENERGY-FOOD NEXUS HOTSPOT FOR SUSTAINABILITY

## 3.1 INTRODUCTION

Declining global water quality is a significant problem threatening human well-being and ecosystem integrity (Kates & Parris, 2003; Srinivasan et al., 2012). The 2030 Agenda for Sustainable Development explicitly targets water quality under Sustainable Development Goal 6 - Target 6.3, which aims to reduce pollution, halve untreated wastewater discharges, and restore water-related ecosystems. Pursuing Sustainable Development Goals (SDGs) is complex because each goal engages in multiple objectives and generates synergies and trade-offs with other goals (International Council for Science, 2017; Liu et al., 2018). For instance, pursuing SDG 2 - Target 2.4 for increased agricultural production may generate more nutrient discharges and pollute water bodies. Understanding these interactions, therefore, could facilitate prioritizing points of intervention to manage trade-offs systematically (Reddy et al., 2018).

Addressing water quality as a sustainability challenge requires analytical approaches that consider cross-sectoral interactions and uncover the underlying causes to enhance the problem-solving capacity (Arnbjerg-Nielsen et al., 2022; Kellner, 2023). This involves problem reframing to include broad aspects in the problem description (Pahl-Wostl, 2019; Wiek, 2015). Framing is a widely used concept to explain how people understand and explain a particular problem, who the responsible people are, and what

collective actions should be taken (Benford & Snow, 2000). Framing approaches in sustainability generally encompass and structure the dynamics and causal relationships within complex systems (Ness, 2020; Ness et al., 2010). When complex systemic problems are studied and reframed, the places with the potential to intervene and shift the system for the better could be identified (Meadows, 1999). Reframing from a normative sustainability perspective built up the understanding of the problem to incorporate elements to orient the issue toward a sustainable solution (Mino & Kudo, 2020).

The most popular approach to analyzing how the SDGs can be achieved in integrated ways is the water-energy-food (WEF) nexus. The WEF nexus approach intends to overcome silo thinking, which refers to setting sectoral goals without reflecting on the interactions with other sectors (Covarrubias, 2019). While water quality is present in many WEF nexus cases, water quality has been the "missing dimension" within WEF nexus studies, given that previous research has been mainly restricted to water quantity (Heal et al., 2021). Water quality has been widely studied, but limited research is investigating water quality from a WEF nexus perspective (e.g., Reddy et al., 2018; Tong et al., 2021). Scholars agree that meeting the water goals using the WEF nexus without water quality considerations will not be possible in cases where it is the main issue at stake (Arnbjerg-Nielsen et al., 2022). Therefore, the WEF nexus studies must examine water quality, especially in areas considered WEF nexus hotspots (Heal et al., 2021; Mohtar & Daher, 2019).

Likewise, limited research has focused on the governance aspects of the WEF nexus (Newell et al., 2019; Opejin et al., 2020), and the study of the conditions for cross-

sectoral coordination and collaboration has emerged in recent years (Weitz et al., 2017a, 2017b). Noteworthy is the study of Jones & White (2022), shedding light on barriers to collaborative WEF nexus governance in practice. Greer et al. (2020) illustrated the importance of effective communication to identify and negotiate trade-offs through an empirical study. Drawing from the integrative environmental governance literature, Weitz et al. (2017b) highlighted the need for identifying actors and analyzing their cognitive frames present in formal technical documents underpinned in assumptions, norms, and principles. Other research has posited using different analytical tools to understand the underlying causes preventing effective governance of the WEF systems. For instance, Kellner (2023) conceptualized a WEF nexus case using analytical tools such as the Networks of Action Situations (NAS) approach linked with system thinking. Since effective decision-making may be enabled by understanding causal relationships (Arnbjerg-Nielsen et al., 2022), Kellner's (2023) research is valuable in paving the way to introduce the study of root causes and intervention points to improve existing WEF nexus governance.

This study aims to provide insights into the underlying causes of the water quality problem in the Rio Negro Basin in Uruguay by employing the systemic and agent-focused Transformational Problem Solving (TPS) framework (Wiek, 2015). The TPS facilitated revealing the cause-effect structure in the WEF nexus interactions and making explicit stakeholders' activities with the end of identifying points of intervention to improve governance responses (Wiek, 2015; Wiek & Larson, 2012). The case of the Rio Negro Basin is a FEW nexus hotspot and illustrates the challenges of pollution

prevention unfolded by development goal interactions of energy generation (Goal 7), increased agricultural productivity (Goal 2), and water use (Goal 6). The 2021 Uruguay Sustainable Development Report stated that significant and increasing challenges persist in managing trade-offs and coordinating efforts focused on sustainable food production and water resources management (SDSN & IBD, 2021). A case-study method is applied to the challenges in the Rio Negro Basin to examine two theoretical propositions (Yin, 2018) and answer the following research questions:

1. What systemic-causal structure of immediate and root causes drives the water quality problem? Who are the involved actors?
2. How are the silo-thinking and focus on the adverse effects shaping the problem-solving capacity?
3. What potential alternative intervention points could improve governance responses for change toward sustainability?

## 3.2 THEORETICAL PROPOSITIONS

Research in sustainability sciences and WEF nexus recommend reframing governance challenges to investigate cross-sector, cross-scale interactions and manage trade-offs by integrating different knowledge systems (Matson et al., 2016; Pahl-Wostl, 2019). The WEF nexus approach substitutes work in silos with sectoral interdependencies, and sustainability science dissects the systemic-causal structure to reveal what makes the issue complex, harmful, and urgent (Larson et al., 2013; Pahl-Wostl, 2019; Wiek, 2015). Reframing a problem employing both nexus and systemic

thinking from a sustainability perspective may reveal aspects of the WEF nexus governance that are overlooked by only reframing from silos to interdependencies.

### 3.2.1 Proposition 1, based on the water-energy-food nexus: silo-thinking persists in management and planning

The food, energy, and water (WEF) nexus is an approach to studying the existing interconnections within WEF systems through, for instance, natural processes, input-output interdependence, overlapping infrastructures and management, and competing objectives at different scales (Cai et al., 2018; Pahl-Wostl, 2019). The WEF nexus approach underlines that the preferences and actions of one sector could compromise the security, resilience, and sustainability of other sectors (Stephan et al., 2018). The assumption is that knowing the interconnections among sectors will generate cooperation to overcome the sectoral approach when managing the WEF systems, namely silo-thinking (Covarrubias, 2019). Overcoming silo-thinking is complex as each sector's institutional characteristics are constrained and require significant analytical and reflection efforts in cooperation (Pahl-Wostl, 2019). Despite many methods and tools developed to understand cross-sectoral interdependencies (Albrecht et al., 2018), the WEF nexus studies have shown modest progress in practice in replacing silo-thinking with integrated governance (Weitz et al., 2017a).

Based on the goal of overcoming the silo-thinking in the WEF nexus literature, the first case study proposition is as follows:

Proposition #1: Despite being a WEF nexus hotspot where interactions among the WEF systems are evident and create a persistent water quality problem that must urgently be addressed, silo-thinking persists in management and planning.

### 3.2.2 Proposition 2, based on framing sustainability challenges: immediate causes overshadow root causes

Sustainability is comprehensive and complex, as it proposes cross-sectoral, cross-scale, and intergenerational considerations to tackle humanity's challenges. Comprehending these challenges requires multiple perspectives and disciplines, namely transdisciplinarity. Bringing different fields into dialogue requires systemic approaches and methodologies that are robust and transparent to help overcome single-disciplinary thinking and structure sustainability challenges. For complex problems, scholars have asserted that reframing sustainability challenges by accounting for the root causes (drivers) generating the adverse impacts will improve collective problem-solving capacity (Jerneck & Olsson, 2011; Ness, 2020; Ness et al., 2010). For instance, (Matson et al., 2016) stated that the precision in the problem diagnosis could improve governance responses. However, Meadows (1999) warned that the system's deeper drivers rooted in existing rules, goals, and people's operation modes are not easy to intervene.

Based on the literature arguing for identifying and addressing root causes leading to impacts, the second case study proposition is as follows:

Proposition #2: Deeper root causes are less acknowledged, and the focus is on the immediate causes and adverse effects.

## 3.3 METHODS

Three types of public documents are examined as they are instrumental in synthesizing public interest information about the state of the basin. The study methods are structured as follows. First, the study region in Uruguay is presented. Second, the data collection strategy is detailed. Third, the data analysis procedures using the Transformational Problem Solving (TPS) - Step 2 framework as a methodological approach and analytical codebook are explained.

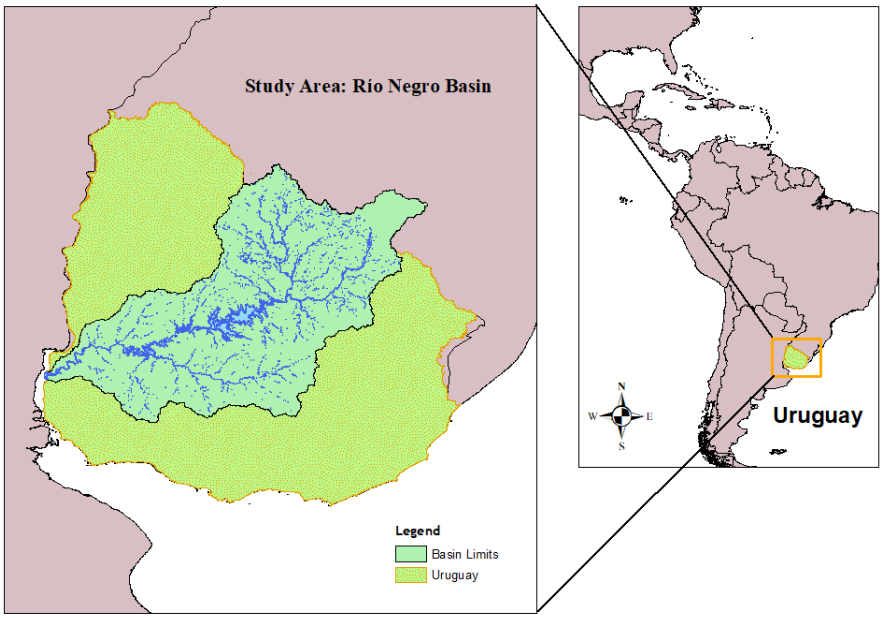
### 3.3.1 Case Study: Rio Negro Basin in Uruguay

The Rio Negro Basin consists of a transboundary river starting upstream in Brazil's territory (4% of the area), sited largely in the central region of Uruguay (96% of the area), and downstream discharging into the Rio Uruguay. Figure 9 shows the location of the Rio Negro Basin in Uruguay. The basin comprises 40% of the Uruguayan territory and is home to the three most important dams in the country: Rincón del Bonete (1070 $km^2$), operating since 1948; Baygorria (100 $km^2$), in function since 1960; and Palmar (320 $km^2$), operating since 1981. The territory is almost entirely under some productive agricultural activity, in particular livestock farming. Up to now, the river has experienced significant water quality problems, mainly resulting from human activities such as agriculture, industry, and effluent discharges from the departments on its margins. According to the Uruguayan norm (Decree 526 of 1979), the water's Total phosphate (TP) concentration should be less than 0.025 mg/L. The TP concentration in the Rio Negro recorded values between 0.078 and 0.126 mg/L between 2009 and 2018, which means the river did not meet the water quality criteria. High levels of nutrients, such as

phosphorus, led the river to eutrophication conditions and algae blooms. Currently, concerns also exist given the addition of a new pulp mill facility in the middle area of the basin, which will bring more effluent discharges to the river. In the report, Calidad Ambiental de la Cuenca del Río Negro 2009 – 2017 by the DINAMA recommended starting collaborative work with local farmers, producers, and institutions to develop best practices to improve the water quality conditions. In 2018, the Rio Negro Basin Commission was established, consisting of representatives from the government, civil society, and water users in general, as enacted by the 2009 National Water Policy and the 2004 constitutional reform.

**Figure 9**

*Location of the Rio Negro Basin in Uruguay*




Shapefiles source: National Environmental Observatory

Ministry of Environment of Uruguay

### 3.3.2 Data collection

A case study method is employed to investigate the challenges in the Rio Negro Basin in Uruguay and frame them with a normative focus on sustainability to reveal underlying causes (Yin, 2018). A case-study method allows a deeper insight into the effect-cause relationship within the WEF nexus interactions via two theoretical propositions drawn from the literature to orientate the data analysis and facilitate the interpretation of the findings (Yin, 2018). The data collected for analysis include fourteen public documents (Table 5), the first seven meeting minutes of the Rio Negro Basin Commission (Table 6), and the prognosis findings of the media content analysis examining seventy news articles published on Ojeda-Matos et al. ***in review***.

*3.3.2.1 Public Documents*

The Uruguayan government has a policy of Open Access Data, allowing free access to local public databases and documents. Primarily, I collected public records (reports, presentations, and atlases) from the National Environmental Observatory (NEO) database on the Ministry of Environment website (accessed: 3/2022). The document search through the NEO database was limited to those discussing aspects of the agriculture, energy, and water sectors and within the Rio Negro Basin. Table 5 shows a list of the documents downloaded and included for analysis. These public documents are written in Spanish, the official language for government affairs. The term searched was "Cuenca del Río Negro" in Spanish. I also established the following criteria for a public document to be included in the analysis. The selection criteria include that the documents must:

- Match the spatial scale of the area under study (Rio Negro Basin and Uruguay)
- Be relevant to one or several of the agriculture, energy, and water sectors
- If there are two versions of a document, the most recent version is selected
- Comprehensive documents covering a variety of topics were preferred
- Have been published between 2001 - 2021

The time frame was limited from 2001 - 2021 to capture the effects of Uruguay's economic recovery strategy focused on agriculture following the 2002 economic collapse (Redo et al., 2012), as well as the implementation of the first water quality monitoring systems in the Rio Negro Basin in 2008 (MVOTMA-DINAMA, 2018). The initial search resulted in 1300 documents. However, upon review, it became evident that these documents were not restricted to the Rio Negro Basin because the database did not combine the words in "Cuenca del Río Negro" when searching. Therefore, I manually evaluated the title of each document and downloaded 54 to be included for the next assessment and data cleaning. Data cleaning was conducted using the above selection criteria, and 14 documents were included for analysis. Then, I consulted with a government official and active member of the Rio Negro Basin Commission (RNBC) about the documents found and asked if other relevant documents should be included in the selection. No additional documents were recommended to be included in the analysis. The documents were organized chronologically and classified by document type (e.g., reports, atlas), year of publication, and main theme (Table 5).

**Table 5**

*List of documents collected from the National Environmental Observatory*

| ID | Document Theme | Date Published | Document Type | Document Name |
|---|---|---|---|---|
| D1 | Water Quality Monitoring | 2011 | Report | Monitoreo y evaluación de calidad de agua, plan para la definición de una línea de base del Río Negro |
| D2 | Water Quality Monitoring | 2012 | Report | Monitoreo calidad del agua del Río Negro (Período 2009 a 2011) |
| D3 | Water Quality Monitoring | 2015 | Plan | Plan de Monitoreo de Río Negro - Informe de datos de calidad de agua |
| D4 | Wetlands Inventory | 2015 | Report | Proyecto Inventario Nacional de Humedales - Producto 2 - Inventario para la Cuenca del Río Negro |
| D5 | Water Quality Monitoring | 2016 | Report | Monitoreo calidad del agua del río Negro - Informe 2015 |
| D6 | Water Quality | 2018 | Report | Calidad ambiental de la cuenca del Río Negro (2009 - 2017) |
| D7 | Water Quality | 2018 | Report | Monitoreo de Calidad del Agua Río Negro - Informe 2016 |
| D8 | Land Cover and Land Use | 2018 | Cartography Guidelines | La Elaboración de un Mapa de Uso/Cobertura del Suelo de la Cuenca del Rio Negro: Proceso Técnico - Científico |
| D9 | Maps and facts | 2019 | Atlas | Atlas de la cuenca del Río Negro |
| D10 | Water Quality Improvement Plan | 2019 | Plan | Plan de Acción para la Mejora de la Calidad del Agua de la Cuenca del Río Negro, Iniciativa para el Río Negro |
| D11 | Water Quality Improvement Plan | 2019 | Plan Presentation | Iniciativa para el Río Negro |
| D12 | Land Cover and Land Use | 2019 | Cartography | Mapa de Uso/Cobertura del Suelo de la Cuenca del Rio Negro – 2019 |
| D13 | Water Quality Monitoring | 2020 | Report | Monitoreo de Calidad del Agua Río Negro - Informe 2019 |
| D14 | Land Cover and Land Use | 2021 | Cartography | Cartografía del Uso y Cobertura del Suelo de la Cuenca del Rio Negro 2020/2021 |

*3.3.2.2 Meeting Minutes*

The meeting minutes of the Rio Negro Basin Commission (RNBC) were collected from the institutional website of the Uruguayan Ministry of Environment on a webpage designated for the public availability of the Commission documents. The meeting transcripts are publicly available and can be downloaded along with the materials presented during the meetings. The RNBC has been active since December 2018, and at the time the data set was downloaded for this study, seven meeting minutes and transcriptions were made publicly available (accessed: 03/2022).

*3.3.2.3 News articles*

The media articles were collected from the Nexis Uni® database, which is widely used in social sciences to access news articles in the U.S. and abroad. A detailed description of the data collection procedure of the seventy news articles was published by Ojeda-Matos et al. ***in review***.

**Table 6**

*Overview of the Rio Negro Basin Commission meetings*

| No. | Date | Meeting Theme |
|---|---|---|
| 1 | 12/12/2018 | Formation of the Rio Negro Basin Commission |
| 2 | 03/13/2019 | Commission bylaws approval, Presentation of the Rio Negro Initiative |
| 3 | 07/28/2021 | Presentations of various projects by the Ministries |
| 4 | 10/28/2021 | Status of the Rio Negro Initiative, National Waste Management Plan |
| 5 | 12/02/2021 | Presentations of various projects by diverse actors |
| 6 | 04/20/2022 | Status of the Rio Negro Initiative by the Ministries |
| 7 | 07/01/2022 | Competitive Fund of the Rio Negro Initiative and jury selection |

### 3.3.3 Data analysis

The data analysis was guided by an analytical codebook applying the TPS framework elements, including the root and immediate causes, the positive and negative effects, and the causing, benefiting, and affected stakeholders (detailed in the following section). In addition, linguistic connectors were included in the codebook to facilitate the document analysis. Finally, the three data sources were triangulated, prioritizing the goal of digging into the problem to link effects and causes and identify alternative intervention points for improved governance responses.

### 3.3.4 Transformational Problem-Solving (TPS) framework

The TPS is a problem-solving framework that step-by-step identifies and analyzes a sustainability problem toward a solution vision and strategy (Wiek, 2015). The framework is rooted in sustainability principles and employs a systemic reframing approach to provide insights on potential intervention points to orient the solution strategy (Gibson, 2006; Jerneck & Olsson, 2011; Meadows, 1999; Wiek, 2015). The TPS framework - Step 2 is a pragmatic approach to analyzing the problem and facilitating a problem-solving effort aided by a systemic problem map (Wiek, 2015). The framework includes sufficient details to understand the cause-effect links of the problem and serves multiple objectives, such as accounting for people's activities and identifying trade-offs and potential intervention points to inform governance responses and effective solutions (Wiek, 2015).

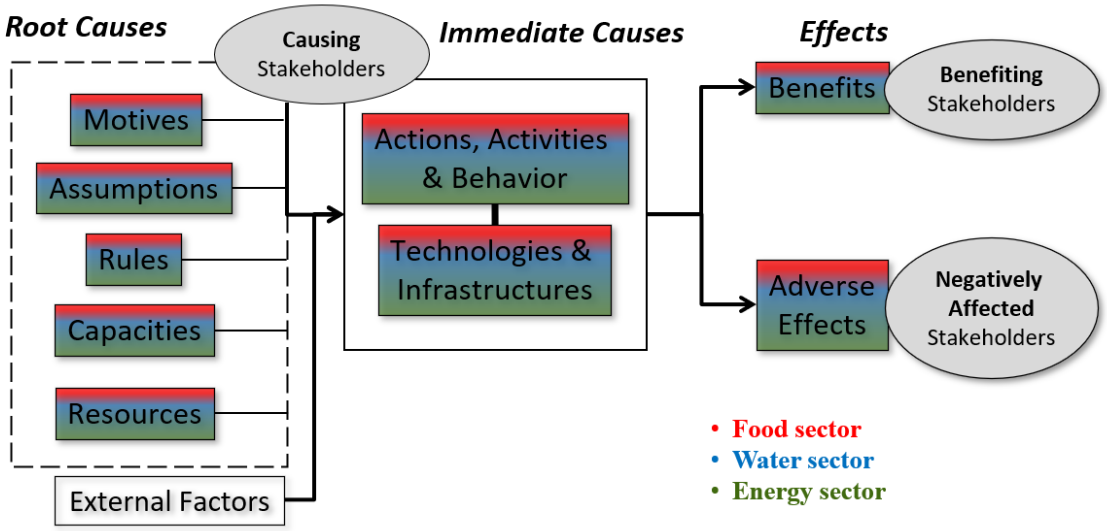
Analyzing and describing the problem in this practical way offers an overall perspective of the immediate causes and root causes and the benefits and adverse effects,

along with identifying causing, benefiting, and affected stakeholders. Immediate causes are more easily identifiable intervention points because they possess material characteristics such as infrastructure and people's actions. In contrast, root causes are less accessible because they are intangible such as people's motives, needs, capacities, and resources. Table 7 presents all the elements of the TPS framework – Step 2, which were adapted in an analytical codebook (more details in Wiek, 2015). This framework is remarkable in using a plain and accessible language, facilitating knowledge transferability to practitioners in the WEF systems.

The analysis using the TPS framework begins backward, taking the adverse effect and the affected stakeholders as an entry point for the problem analysis. Figure 10 shows the structure of the TPS framework - Step 2. The negative effect is drawn back to the immediate causes, which are people's actions, activities, behavior, and the technologies and infrastructures they use. At the same time, these immediate causes are generating benefits for people. The next step is to identify those benefits and the people benefiting. Recognizing the adverse effects and the benefits opens the possibility for more explicit discussions regarding trade-offs. Finally, the immediate causes are traced back to six types of root causes or drivers: motives, assumptions, rules, capacities, resources, and external factors; and causing stakeholders are also identified. The objective is to clarify how and why the problem exists and who may be able to address the issue.

**Figure 10**

*Transformational Problem-Solving framework – Step 2*




Adapted from: Wiek, 2015.

To guide the document analysis, the analytical codebook includes each code name, its short and detailed definitions, and examples of coded segments (Bernard et al., 2017; MacQueen et al., 1998). Table 7 summarizes the codebook showing the code name and the short definitions. The analytical codebook also includes guidelines to identify linguistic connectors, as presented by Bernard et al. (2017, p.108-109). Linguistic connectors are words or phrases indicating a causal, conditional, or time-oriented relation or explaining provenience. Since the TPS framework - Step 2 is intended to identify the cause-effect links, the document analysis was primarily guided by identifying linguistic connectors linking causes and effects. The linguistic connectors presented by Bernard et al. (2017) served as a basis to create a list of potential words and phrases to look for, which were then translated into Spanish. While conducting the document analysis,

several new linguistic connectors emerged from the text and were classified and included in the analytical codebook. Finally, an intercoder reliability assessment was performed with the help of a Spanish-speaking research assistant who analyzed 10% of the coded segments in the public documents to validate the codebook (O'Connor & Joffe, 2020). After two rounds of coding, the codes reached the required threshold between 0.80 to 1, which indicates an almost perfect agreement according to the formula by Cohen's Kappa (O'Connor & Joffe, 2020). Then, the validated codebook was used to code all documents.

**Table 7**

*Analytical codebook based on the TPS framework and linguistic connectors*

| Codes | **Code Short Description** |
|---|---|
| **Effects** | |
| Adverse or Negative Effects | The adverse or negative effects involve death, decay, collapse, and extinction generating harmful conditions hindering the possibility of a sustainable status. |
| Benefits or Positive Effects | The (perceived) benefits are the advantage or profit gained from the same adverse effects making the problem persist. |
| **Immediate Causes** | |
| Causing Actions, Activities & Behavior | Describe people's actions, activities, and behavior, including individual and collective pursuits. |
| Causing Technologies & Infrastructures | People's actions and activities negatively affect others and the environment as they are linked to technical systems, technologies, and infrastructure. |
| **Root Causes** | |
| Motives, needs, values and preferences | A strong driver for activities, actions, and behavior is people's individual or collective motives, needs, preferences, values, intentions, desires, and so forth. |
| Assumptions | Certain assumptions and beliefs are considered accurate and have certain levels of approval to guide or misguide people's actions, activities, and behavior. |
| Rules, norms, laws | To varying degrees, rules influence and regulate people's actions, activities, and behavior. Formal rules are usually written in the law, and informal rules are shared in a collective. |
| Capacities | Capacities, abilities, capabilities, skills, and competence have the potential to enable what can be done. |

| | |
|---|---|
| Resources | Resources availability allows the materialization of what can be accomplished. This may include money, time, property, natural resources, trust, or a social network. |
| External factors | External factors or forces influencing actions from the outside, with limited options to change them directly. |
| **Stakeholders** | |
| Causing Stakeholders | People responsible for the roots and immediate causes |
| Benefiting Stakeholders | People that benefit from the positive effects |
| Negatively Affected Stakeholders | People that have been affected by the adverse effects |
| **Linguistic Connectors** | |
| Causal relation | Words or phrases connecting a clause with a cause or reason of the event in the main clause. |
| Conditional relation | Words or phrases used when the occurrence of one thing is conditional to another thing. For example, if one thing (A) occurs, then another thing (B) will occur as a result of (A). |
| Time-oriented relation | Words or phrases two events together, based on the time they occur. For instance, the word "after" may express when an event occurred following a determined circumstance in time. |
| Provenience | Words or phrases used to express what is the source of something. For example, the use of words such as "come," "origins," or "motive." |

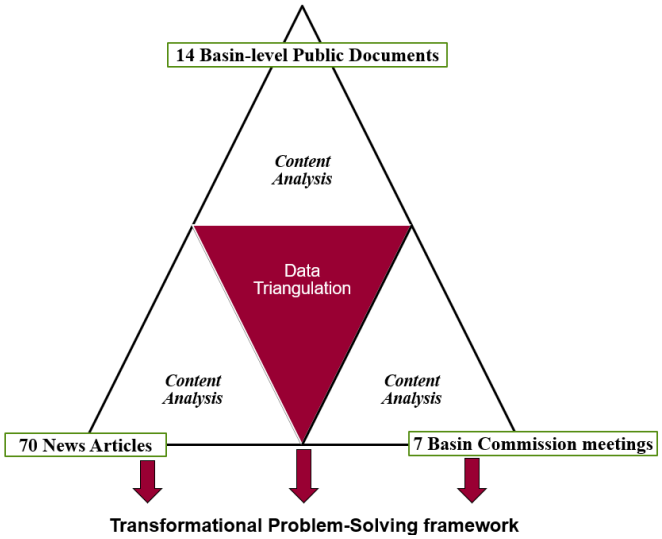
To perform the analysis, the documents were imported to MAXQDA mixed method software program, and a code system was created using the analytical codebook. Document analysis entails an analytical deductive process of "finding, selecting, appraising, and synthesizing data contained in documents" guided by the analytical codebook (Bowen, 2009, p.28). Since the analysis focused on coding the text segments indicating an effect-cause relationship to populate the TPS framework, the analysis on MAXQDA followed two steps. First, the text search function in MAXQDA was utilized to autocode the linguistic connectors. Second, the coding strategy focused on evaluating autocoded segments and recoding if they pointed out any causal-effect relationship

related to the TPS framework elements. Linguistic connectors facilitated document analysis by identifying points of interest in the documents.

Since degraded water quality is identified as the main adverse effect leading to environmental, social, and economic detrimental impacts in the river basin, it is used as an entry point for the analysis using the TPS framework. To produce the results, data triangulation is employed (Carter et al., 2014; UNAIDS, 2010; Yeasmin & Rahman, 2012). Data triangulation combines multiple data sources to examine an issue and overcome any information deficiency (Carter et al., 2014; Yeasmin & Rahman, 2012). Figure 11 shows the data sources triangulated. Instead of drawing conclusions from a single data source, the goal of data triangulation is to look more extensively and in-depth at the problem to link effects and causes and identify alternative points of interventions for improved governance responses. The analysis does not aim to be exhaustive but to obtain results that are consistent through triangulation. The more relevant results to this goal are prioritized and presented in the next section (UNAIDS, 2010).

**Figure 11**

*Data Sources Triangulated*




## 3.4 RESULTS

Three data sources were analyzed and triangulated to deepen and widen the understanding of the causal effect relationship of the WEF cross-sectoral interactions creating the water quality problem in the Rio Negro Basin in Uruguay (Figure 11). Data points from the meeting minutes of the RNB Commission are referenced as RNBC1 to RNBC7, the media content is referenced as U1 to U70, and the public documents are cited as D1 to D14 (ID in Table 5). The results section is organized by first reporting the findings for each component of the TPS framework supported by empirical evidence. Second, the responses to the case study's two theoretical propositions are presented. Third, the potential alternative intervention points on immediate and root causes are described (Table 8).

### 3.4.1 Adverse Effects

The primary adverse effect identified by local actors is water pollution, which triggers episodes of eutrophication and cyanobacteria blooms (D1; RNBC1; U60). The reframing from a sustainability perspective shows that water quality degradation has complex and dispersed effects touching diverse sectors and actors in the basin area and beyond – i.e., the other ecosystems and sectors depending on water resources, such as local tourism, fishing, public health, and livestock farming, are impacted. This section addresses the additional adverse systemic effects (secondary and tertiary effects) created through eutrophication and cyanobacteria.

The viability and integrity of ecosystems are compromised as soil degradation endures (U10a; U35). Moreover, cattle and fish populations present high levels of toxins resulting from cyanobacteria to the extent that there are now "localized risks in certain areas where it is not recommended that livestock drink directly from the watercourse," as acknowledged in the public media by the DINAMA (U10a; U35). Contaminated water harms human and social well-being because of the water humans and pets in contact with or consuming the water (U10A). Specifically, cyanobacteria accumulation in the reservoirs reached levels that put at risk the health of those who use their water for bathing (U10A), as revealed by studies conducted by the Faculty of Chemistry of the University of the Republic at the request of the National Administration of Power Plants and Electrical Transmissions, known as UTE. While cyanobacteria usually represent a moderate or low risk to human health, skin irritation, mucous membranes, or allergic

reactions can still occur in people in contact with water (U51), as cautioned by the Ministry of Health of Uruguay in January 2019.

Livelihood opportunities are negatively impacted as algae bloom limits the activities in the river and downstream beaches, affecting the fishing and tourism industries. There is an inter-regional problem because the downstream communities in the capital of Montevideo and Rio Uruguay's water are adversely impacted. In 2019, "the largest cyanobacteria blooming in history" even reached beaches in the metropolitan area of Montevideo, negatively impacting tourism there. Furthermore, fish mortality has been reported at the Palmar dam as water damming increases nutrient concentration and reduces the oxygen available for fish viability (RNBC2). In addition, the presence of cyanobacteria in watercourses from where water is withdrawn has increased the price and difficulty of treating drinking water, according to expressions from the president of OSE (Obras Sanitarias del Estado) (U51). The rural population dispersed in the territory lacks access to safe drinking water and sanitation, affecting the sanitation in rural schools (RNBC1: MVOTMA, 2018). The difficulty of accessing a safe source of water and sanitation in schools translates into a potential health risk for teachers and children. The water quality problem seems to have now become an urgent and chronic problem: while “the cyanobacteria have been [there] since the reservoirs were made, the issue is that it is no longer sporadic, but constant and prolonged until winter" as stated by an academic from the Faculty of Science of the University of the Republic (U60).

### 3.4.2 Benefits or Positive Effects

Relatively little is discussed about the benefits or positives of the basin's current activities and development trajectory. One occasionally discussed benefit is the role of this basin in Uruguay's development since generating hydropower has been the backbone of the energy supply. Hydroelectricity generation in the Rio Negro, along with the Salto Grande dam (binational dam located on the Uruguay River and shared with Argentina), has historically constituted the basis of the country's electricity supply (D4). In contrast, today, it contributes a smaller portion of electricity generation and supply, given that demand has grown and is supplied with other energy sources. A second benefit is how the water contributes to agriculture, which generates economic activity while supplying local food demand and exporting globally. The basin's annual volume of water per user-type is 86% for irrigation, 3% for industrial use, 2% for human consumption, 1% for other agricultural uses, and 8% for other uses (RNBC1). Thirdly, establishing the new forestry-pulp mill brings foreign investment to the area, generating local economic activity and jobs as well as promoting the repair of aging infrastructure. The dilemma is that these benefits result from the same activities creating adverse effects, and this interdependency is not explicitly discussed or balanced against. Statements about the benefits associated with local food security were not found.

### 3.4.3 Immediate Causes

#### *3.4.3.1 Causing Technologies & Infrastructure*

Three hydroelectric dams cause problems, such as disrupting river connectivity, affecting flood regime, and increasing nutrient concentration (D4; U12). The National

Administration of Power Plants and Electrical Transmissions, known as UTE, is Uruguay's government owner-operator of these three hydroelectric dams: Rincón del Bonete (upper basin), Baygorria (middle basin) and Palmar (lower basin) (D1; D4; RNBC1). These dams were primarily built to generate hydroelectric power and currently have multiple uses, such as irrigation and fishing (D1). Nutrient discharge peaks have been registered for Total Nitrogen (TN) and Total Phosphorus (TP) directly related to the operation of the Rincón del Bonete and Palmar reservoirs. For example, TP loads have presented higher values at the outlet than at the inlet of the reservoirs (D6). TP levels have reached five times the maximum value permitted by regulation in the Palmar reservoir. (U35). The dam operation also conflicts with other local uses. For instance, the lack of co-management has led to important biodiversity loss as the opening of dam gates does not consider fish spawning of the *tarariras* (native fish of the Rio Negro) (RNBC2).

Human settlements on the river's negative margins impact water quality because they lack infrastructure for adequate wastewater treatment. Significant investments are needed to improve the existing infrastructure in the cities located in the basin. Some cities have treatment systems, such as the City of Paso de los Toros, but they are partial and do not cover the whole city. Current systems need expansion and remodeling; existing plants should be improved with tertiary treatments to reduce the nutrient discharges into the river. In addition, there are 120 discharge sites in the basin (data from 2015-2016), of which only 43 are regulated by the DINAMA. Industries account for 72% (31) of regulated discharges, including meat, dairy, mineral extraction, wood, chemical, and

agricultural production. The domestic and sanitation sector accounts for 28% (12) of the regulated effluents (D6).

*3.4.3.2 Causing Actions, Activities & Behaviors*

Among the main human activities that cause the water quality problem are urban waste discharges (domestic and industrial), land use change, and the current agricultural practices (U48). The basin population in the Uruguayan part of the basin is 387,034 inhabitants, mostly located in the departmental capitals and in the intermediate and small localities (Census 2011) (MVOTMA, 2018). The drinking water service reaches 98% of the population, while the sanitary sewer network reaches 47.8% (MVOTMA, 2018). Land cover in the basin is 66.52% natural field, 16.33% agricultural, 8.92 % afforestation, 5.27% native forest, 2.58 % water bodies, and 0.14% urban (D12). The natural field (66.52%) is destinate mostly for livestock farming. Land cover changes and water quality degradation are expected to continue because of the addition of the new pulp mill (UPM Paso de los Toros). The forest area may increase as eucalyptus afforestation is the main input for this agro-industrial chain (D14). In addition, eucalypt afforestation has already claimed 20% of the river water available (U35).

Most of the Total Nitrogen (92%) and Total phosphorus (96%) discharge from the basin comes from diffuse sources (D6). The basin is divided into upper, middle, and low basins. In the upper zone, the primary land uses are rice crops, eucalyptus afforestation, and livestock, and it is the zone receiving the water effluents from the Brazilian part of the basin. In the middle zone, extensive livestock and cereal and oilseed crops predominate. The lower zone is the largest producing crops such as soybeans and corn

(D6). Water quality monitoring stations show higher nutrient values in the upper and lower areas of the basin (D6). Water quality is impacted due to agrochemical dumping and erosion that comes through surface runoff (D12). Farmers' behavior has been pointed out because fertilizer has been applied more than twice permitted, ignoring that after a certain level of fertilization, soil productivity does not increase (U4). Also, it has been mentioned that cultural change is needed on how phosphorus is handled, which should be inside the soil and not above the ground (RNBC2). Direct seeding causes the first layers of the soil to be supersaturated with nutrients that easily run off directly to the watercourses (U60).

### 3.4.4 Root Causes

#### *3.4.4.1 Motives, needs, values, and preferences*

What motivates actors to develop and use the basin's resources had to be distilled from little discussions about the benefits received. However, these benefits are not directly referred to as motives or preferences but perhaps as needs. The country's need for productive development and energy generation caused today's river conditions (RNBC2). Hydroelectric production for the country's development came from this basin. Both energy production and agricultural development have benefited the populations that have settled in the basin and the entire Uruguayan society (RNBC3). Therefore, the status quo to act upon the main causes of the water quality problem may be motivated by economic development, as hydropower generation and agriculture create economic opportunities and improved living standards for Uruguayans. Several goals, such as the Agricultural Plan, may motivate and frame decision-making now—for instance, the goal for

agriculture intensification to feed 50 million people by 2050 (SDSN & IBD, 2021).The data analysis, particularly from the Commission, does not present public discussion about preferences or guiding values for basin development. The data analysis, particularly from the Commission, does not present a public discussion about what preferences and values should guide the basin development. However, a strong motivation to address water pollution now may be the negative impacts reaching up to the Capital of Montevideo and Punta del Este, as stated in a public discussion at a meeting of the RNBC (RNBC2).

*3.4.4.2 Assumptions*

The documents analyzed do not clearly state the assumptions guiding what the actors do. However, some assumptions could be distilled from the practices in place. For example, a farmer fertilizing twice what is needed may be part of the assumption that twice phosphorus increases soil productivity but also increases food production (U4). The government delaying an early intervention and response to local concerns about pollution may be part of the assumption that the river system could handle the contaminants and the problem would not extend beyond the basin. There is an underlying assumption that more knowledge and institutional capacity are needed to address a well-known problem, evidenced by the prioritization of more technical studies and the establishment of a new Minister of the Environment. UTE has adopted dam operating rules based on its technical expertise, indicating that UTE assumes that they are not responsible for the social and environmental impacts that lack of co-management creates.

*3.4.4.3 Rules, norms, and laws*

Uruguay has numerous approved acts and plans that regulate water quality, basin development, and public participation. Water quality is determined through Decree Nº 253 of 1979 for Water Pollution Prevention through physical, chemical, and biological variables (D1). Although water quality has been regulated for decades, it has been poorly enforced in the Rio Negro over time and violates established standards. According to Decree Nº 253/979, the TP concentration in natural water bodies in Uruguay must be less than 0.025 mg of phosphorus per liter (25 µg P/l). This value is not met in the Rio Negro (RNBC3). However, a proposal is to update the guide value for TP concentration to be less than or equal to 0.1 mg phosphorus per liter (100 µg P/l) (D1). In addition, the dam operation rules employed by UTE are not well-communicated to other water users. As a result, a co-management strategy has not been reached that, for instance, allows biodiversity to flourish. In 2017, a new Irrigation Act was enacted to enable the operation of new private irrigation reservoirs. This legislation was highly contested as the government may not have the capacity to monitor their operation, and these private reservoirs may be a new source of pollution (U42A).

Participatory and comprehensive water management, with diverse members from the government, civil society, and water users, was enacted through the 2004 constitutional reform. In 2009, the National Water Policy was approved, which implemented the constitutional reform of 2004. The National Water Policy established regional councils and basin commissions as participatory spaces (RNBC1). Decree 298 of 2018, operationalized through the Rio Negro Initiative, aims to establish measures to

prevent, control, stop and reverse the process of water quality deterioration of the Rio Negro, with emphasis on sustainable development (D11). Land use is regulated through the Territorial Planning and Sustainable Development Act, a regulatory framework for territorial planning and sustainable development established in 2008. This Act provides for regional or basin management, with specific actions for land use. At the Rio Negro Basin, land use plans are now under preparation, such as the Plan Corredor Logística de Ruta N°5 in the department of Rivera, Plan Centenario in Durazno, Plan local de Paso de los Toros in the department of Tacuarembó, among others (RNBC3). Other national plans, such as the National Environmental Plan and Climate Change Adaptation Plan, are to be implemented at the national level with expected translated actions on basins (RNBC1). In 2020, the Urgent Consideration Act created a new Ministry of Environment, considered affirmative action by the executive toward environmental policies (RNBC3).

*3.4.4.4 Capacities*

A diversity of expertise and knowledge to address the water quality issue exists within the Rio Negro Basin Commission as it is constituted through representatives from the government, civil society, and users. Government officials hold bachelor's or higher degrees. Local competencies are developed in scientific research, water monitoring, and management. A university degree in Agro-Environmental Engineering to build local expertise in water resources management, irrigation, effluent management, and research laboratories has recently been developed by local universities, such as La Universidad Tecnológica (RNBC1). Water quality issues have been published in several technical and

scientific reports on the Rio Negro; in addition, a new state of affairs report is in progress, which was shared in the first section of the Commission (see draft: MVOTMA, 2018). The government has established several agreements with academia to research and generate knowledge about river conditions. However, the scientific evidence at times is sometimes not considered for the basin's development decision-making. Additionally, despite the local expertise and knowledge capacities, there is a lack of intervention capacity diligently address the problem by the respective national authorities. For example, the water quality of the Rio Negro has been permanently monitored with a quarterly frequency since 2009, with 15 monitoring stations located from the river entrance from Brazil to the river mouth into the Rio Uruguay (D6; RNBC1). However, the Uruguayan government failed to invest in water protection and in enforcing compliance with environmental regulations (U4). Despite the government's recent, albeit slow response to pollution (U4), local actors, neighbors, and producers have informed the problem for over 15 years (U56).

*3.4.4.5 Resources*

Resources to address the extent of the water quality problem are lacking in the departments. At the departmental level, a Deliberative Committee of the Rio Negro exists, consisting of councilors (Ediles in Spanish) of the Departmental Boards who advocate for the river's water quality. However, it was not until the algae bloom reached the beaches of the Capital of Montevideo and Punta del Este, impacting tourism activity in the area, that some action was initiated by the Ministry of Environment as stated by a representative of this Deliberative Committee in the second section of the Commission

(RNBC2, p. 24). At the National level, plenty of resources to address the water quality problem have been acquired by the Rio Negro Initiative (RNI), including allocating funds ($15M) and personnel. The Rio Negro Initiative was established by the Minister of Environment as required by the 2009 National Water Policy, but particularly to facilitate implementing the new pulp mill (UPM Paso de los Toros). The RNI has also received funds ($3.5M) from the foreign developer of the new pulp mill (UPM Paso de los Toros). Additionally, as part of this RNI, UTE contributed to a facility in the Rincon del Bonete dam to create a regional center that would serve as a logistics center, storage, sample preparation, and logging for the technicians (RNBC2). The amount of resources allocated to the Rio Negro seems unprecedented; however, these are non-recurring funds, and they mainly respond to an initial agreement to implement the new pulp mill (UPM en Paso de los Toros). The availability of natural resources, especially eucalypt afforestation, is an advantage used to attract this type of foreign investment to the country. As an emergent economy, Uruguay may lack the resources to opt for a not natural resource-based sustainable development.

*3.4.4.6 External factors*

External drivers influencing the problem cause-and-effect structure are climate variability, global food demand, and energy demand from neighboring countries. Uruguay experiences high climate variability, manifesting as periodical floods and droughts in the basin. Both flood and drought stress the system and exacerbate the water quality problem as low water level raises the concentration of nutrients (U58). Floods wash fertilizers into the watercourse and move cyanobacteria to areas beyond the basin.

Droughts also impact rainfed agriculture (U2). In addition, meteorological factors such as higher temperature (particularly in summer) and solar radiation influence the exponential growth of cyanobacteria per a study by the Faculty of Sciences of the University of the Republic (U48; U60). Geographical and soil factors have also been identified as potential drivers that are considered external to the influences of humans. For instance, it has been proposed to revise the phosphorus and nitrogen standards to adapt them to the region's soil conditions, which seem to have a higher phosphorus level, similar to Brazil and Argentina (U13). The growing global food demand is another factor influencing the problem, as Uruguay plans to increase agricultural productivity. Uruguay's agriculture sector feeds around eight times its current population (28 million people), and the goal is to intensify production to feed 50 million people by 2050 (SDSN & IBD, 2021). Furthermore, Uruguay's electrical grid is interconnected with Argentina and Brazil, exporting energy to these neighboring countries.

### 3.4.5 Causing, Benefitting, and Negatively Affected Stakeholders

Overall, actors could be causing, benefiting, and adversely affected simultaneously or at different temporal-scale, so they are encountering their present and future trade-offs. At first glance, it seems that the primary actor who has a stake and can act upon the resolution of the water quality problem is the Rio Negro Basin Commission, and one could identify actors through the membership of the Rio Negro Basin Commission. However, some key actors may not be part of this Commission. To illustrate, fishers with an evident stake in addressing the problem are absent from the Commission. The Minister of Environment's National Directorate of Environment (NDE)

convenes, organizes, and facilitates the Commission (Act No. 17.283). The Ministry's primary responsibility is to formulate, implement, supervise, and evaluate plans to measure and assess the quality of water resources and ecosystems. The NDE is a causing actor because of the lack of top-down enforcement of environmental regulations and slow response to local actors' concerns, resulting in a lasting problem (U4; U56).

UTE, Uruguay's government owner-operator of the hydropower dams, benefits from the sale of hydropower energy and causes part of the problem due to the inability to operate the reservoirs in a way that is compatible with other uses. Another example is OSE, which supplies the drinking water and sewage service and is responsible for the lack of infrastructure to manage untreated water effluents from the cities and localities (RNBC2). OSE benefits from drinking water sales but is also negatively affected by cyanobacteria in watercourses that increase the price and difficulty of treating drinking water (U51). Individuals living in the human settlements on the river's margins are responsible for contributing to the untreated wastewater effluents, but the recreational use of the river is limited due to health concerns.

At the local level, farmers who benefit from the increased agricultural productivity are also causing actors due to the overuse of fertilizers. At the national level, Uruguay's inhabitants benefit from the hydroelectricity generation, agricultural productivity, and the economic activity the basin's ecosystem services have supported. At the transboundary level, users from the basin's part in Brazil benefit from productive activities. Still, they are also pointed out as contributors to water quality degradation, particularly in the upper basin. Finally, on a global scale, international consumers benefit

from using Uruguay's resources to produce commodities that are exported worldwide. An example is the new pulp mill in the middle basin (UPM Paso de los Toros), a foreign investment from Finland that brings economic activity but discharges its effluents into an already polluted river.

### 3.4.6 Response to theoretical propositions

*Proposition #1:* Despite being a WEF nexus hotspot where interactions among the WEF systems are evident and create a persistent water quality problem that must urgently be addressed, silo-thinking persists in management and planning.

The results obtained from the analysis supported the first proposition. The overall picture from the findings is that the silo-thinking prevails over integrated management when considering the WEF systems interactions creating the water quality problem in the basin. There is a certain acknowledgment that the solution to the problem encompasses actions from different sectors, as evidenced by inviting diverse actors to present their perspectives and plans on the river basin at the RNBC meetings. However, there is not an open discussion on how these individual actions relate to others and the effect on the overall sustainability problem beyond the water quality problem. The governance of the WEF systems goes along in fragmented and parallel instead of in an integrated way. For instance, the Ministry of Livestock, the Ministry of Industry, Energy, and Mining, and the Ministry of Environment are in the conversation for the Rio Negro Initiative, displaying certain multi-sector collaboration but not across sectors. Basin-level documents are mainly descriptive and water-related and not cross-sectoral-oriented. Another important

piece of evidence is the lack of co-management hindering integrated actions across WEF systems and other users.

*Proposition #2:* Deeper root causes are less acknowledged, and more focus is put on the immediate causes and adverse effects.

*Rival explanation 2**:*** Root causes such as adopting rules and generating knowledge receive great emphasis, even though this does not lead to sustainability problem-solving actions.

The results obtained from the analysis partially supported the second proposition. The problem reframing showed a better understanding of the immediate causes, although there is no dialogue for integrated co-management of the reservoirs. Significant emphasis has been on adopting new rules and plans, capacity building through new knowledge generation, and resource allocation. The national government has made efforts to build capacity. It has collected data for more than ten years but even now maintains the focus on the water quality effects and not on the long-term sustainability of the basin. As a result, there is less emphasis on exposing the assumptions, motives, needs, and perceived benefits associated with the activities that create the water quality problem.

### 3.4.7 Alternative intervention points for changes toward sustainability

Reframing the water quality problem facilitated the identification of potential alternative intervention points to support local problem-solving capacity and sustainable development, which are set out in Table 8. Seven alternative intervention points were identified regarding benefits or positive effects, immediate causes, and root causes. The

implications of intervening in these points and potential changes toward sustainability are examined in the discussion section.

**Table 8**

*Potential alternative intervention points for changes toward sustainability*

| | ID | Intervention Point | Intervention Description | Potential changes toward sustainability |
|---|---|---|---|---|
| | P1 | Benefits | Discussing the benefits relative to the impacts | Bases for a trade-offs analysis |
| Immediate Causes | P2 | Causing Technologies and Infrastructure | Communicating the hydropower dam operating rules | Co-management to protect biodiversity and local livelihood for other users such as fishers |
| | P3 | Causing Actions, Activities, and Behaviors | Training on how to handle fertilizers, and regulation enforcement | Pollution reduction and prevention |
| Root Causes | P4 | Capacities | Improving intervention capacity | Water resources carrying capacity |
| | P5 | Rules | Integrating Plans | Cross-scale planning and sustainable development |
| | P6 | Assumptions | Activating the role of the national government in regulation enforcement | Overcome institutional inertia for WEF system changes |
| | P7 | Motives, needs, and preferences | Visioning Exercise | Increase engagement with the integrated planning process |

## 3.5. DISCUSSION

The present research study triangulated grey literature, such as government reports, basin commission meeting minutes, and news articles, to deepen and widen the understanding of the causal effect relationship creating a chronic water quality problem in the case of Rio Negro Basin (RNB) in Uruguay. While examining this case study, the

present research makes several contributions to the literature. First, this study explored the causal relationship of the WEF nexus interactions creating a water quality problem, an issue that has been the “missing dimension” in the WEF nexus literature (Heal et al., 2021; Arnbjerg-Nielsen et al., 2022). Second, limited research has focused on the governance aspects of the WEF nexus (Newell et al., 2019; Opejin et al., 2020), and the study of the conditions for cross-sectoral coordination and collaboration has emerged in recent years (Weitz et al., 2017a, 2017b). This study contributes to the recent scholarly aiming to enable effective governance and decision-making by understanding root causes and causal relationships and identifying intervention points (Arnbjerg-Nielsen et al., 2022; Kellner, 2023). Third, this study empirically shows a discrepancy between addressing root causes, such as adopting formal rules and generating knowledge, and the intervention capacity for sustainable problem-solving actions.

The RNB is an example of a WEF nexus hotspot where water quality is the main issue at stake (Heal et al., 2021; Mohtar & Daher, 2019). The basin is a highly agricultural productive area, especially livestock farming and crops such as soybean, rice, and corn. Three dams are placed along the river for hydropower generation and irrigation. All the current activities generate a compound effect that has led the river to eutrophication conditions and algae blooms. In 2019, "the largest cyanobacteria blooming in history" impacted diverse sectors and actors in the basin area and beyond, reaching the beaches of the Capital of Montevideo and Punta del Este. The current problem framing guides the current institutional work by government actors that focuses on alleviating the direct effects of the water quality problem. Using the water quality problem as an entry

point, the problem reframing from a sustainability perspective demonstrates that the WEF nexus interactions generated other negative and dispersed effects on other sectors depending on water resources, such as tourism, fishing, and swimming. Currently, some of the negatively impacted actors, such as fishers, are absent from the Commission. Hence, adequate framing is important to improve governance responses (Ness, 2020; Wiek, 2015; Ness et al., 2010).

The first objective of this case study sought to reveal the systemic causal structure of immediate and root causes driving the water quality problem and who are the involved actors that can intervene and act upon the deeper drivers of the problem. The immediate causes sought for infrastructure and people's actions contributing to the problem. The causing infrastructure in place is the three-hydropower dams operated by UTE that disrupt the river connectivity, affecting its flood regime and increasing nutrient concentration. The human settlements on the river's margins impact water quality because they lack infrastructure for adequate wastewater treatment; OSE oversees this infrastructure and services. The causing actions are primarily performed by local actors such as the government, farmers, residents, and industries. For instance, farmers have been pointed out because fertilizer has been applied more than twice what is permitted. Water quality is impacted because of agrochemical dumping and erosion that come through surface runoff. The government is a causing actor because of the lack of enforcement of environmental regulations and slow response to local actors' concerns, resulting in a lasting problem.

The root causes are sought for intangible aspects such as people's motives, needs, capacities, and resources. Results show greater emphasis on addressing drivers focused on adopting new formal rules and generating knowledge and less emphasis on perceived benefits to facilitate trade-off analysis against actions generating the water quality problem. For instance, the case of RNB exhibits the peculiarity that Uruguay has many approved acts and plans that regulate water quality, basin development, and public participation. Since 1979, water pollution has been regulated by Decree Nº 253. Participatory and comprehensive water management has been enabled since the 2009 National Water Policy was approved, which implemented the constitutional reform of 2004. Furthermore, a regulatory framework for Territorial Planning and Sustainable Development has been established since 2008. In addition, the water quality issue has been studied, several technical and scientific reports have been published, and more are in preparation.

The second question in this study aimed to determine if the silo-thinking and focus on the adverse effects were conditioning the problem-solving capacity. The evaluation of the theoretical case study propositions indicated that bringing FEW actors together to address the main issue at stake has not been proven to break the siloed approach and the focus on the direct effect of the water quality problem. This result is evidenced by the fact that the RNBC has been a convergence space where the local actors meet; however, there is no open discussion on how their plans could be integrated into others. The governance of the WEF nexus systems is fragmented and parallel instead of in an integrated way, with few instances displaying certain multi-sector collaboration but

not across sectors and root causes such as motives and assumptions. Basin-level documents are mainly descriptive and water-related and not cross-sectoral-oriented. These results are likely to be related to White et al.'s (2017) findings, which empirically demonstrated the practical limitations of an integrated approach, such as the specific functions each actor must serve.

The third aim of this research was to determine potential alternative intervention points to improve governance responses for change toward sustainability. Based on the new understanding of the problem resulting from the reframing with a sustainability perspective, seven alternative intervention points were identified and set out in Table 8. As the WEF sectoral interdependencies can bring benefits and trade-offs, the TPS framework facilitated the identification of perceived benefits and adverse effects. However, the data show relatively little about the benefits associated with the basin's development trajectory. Therefore, the first potential alternative intervention point (P1) suggested is opening the public discussion to the benefits of the same activities creating adverse effects, enabling a trade-off identification and analysis. The FEW nexus literature constantly states trade-off analysis as a central concern. Prior research has focused on describing the biophysical nature of the trade-offs in different contexts (McCornick et al., 2008; Newell et al., 2019; Pahl-Wostl et al., 2021). Nevertheless, performing such a trade-off analysis may not be possible without a clear association of the sectoral benefits and dispersed adverse effects.

The proposed alternative intervention points in the immediate and root causes should be interpreted thoughtfully. Immediate causes are more straightforwardly

identifiable because they possess material characteristics such as infrastructure and people's actions. Root causes are less accessible because they are intangible such as people's motives, needs, and capacities. Meadows (1999) warned that the system's deeper drivers rooted in existing rules, goals, and people's operation modes are not easy to intervene in. Still, while examining the changes that can shift the FEW interactions towards sustainability, the next essential intervention point suggested is conducting a visioning exercise (P7) to increase engagement with the integrated planning process and long-term commitment (P5). Visioning is widely used in the planning process, where key actors with public involvement can build consensus about the basin's future development. The visioning exercise could be the basis for scenario planning using decision-support tools (Alamanos et al., 2022). Using the same TPS framework, Wiek (2015) recommends creating a sustainability solution vision (Step 3). In addition, it provides the opportunity to discuss guiding values because if they are incompatible, Covarrubias (2019) found them to be a barrier to bringing together actors to set common goal-visions for the WEF nexus.

Intervening in potential points for change toward sustainability will not come with any cost. For instance, hydropower generation and irrigation use seem to have a priority role in the current country's development. Still, a potential intervention point is to UTE starting to communicate the hydropower dam operating rules protecting biodiversity and local livelihood for other users such as fishers and bathers (P2). The dam operation conflicts with other local uses. A possible explanation for the lack of co-management could be related to sectoral power asymmetric. Further study could be undertaken to

examine any power imbalances across sectors making actors perceive the possibility for FEW nexus collaboration differently (Jones & White, 2022). In addition, training for farmers could be required on how to handle fertilizers (P3) properly. The national government needs an active role in intervening to enforce environmental regulations and overcoming the institutional inertia for FEW systems changes (P3, P4, P6), given that weak intervention and enforcement capacity may hinder the cross-sectoral collaboration to solve the water quality problem given that FEW sectoral may perceive the lack of collective commitment for change.

Integrating sectoral plans and actions may also be essential for a potential change toward sustainable development (P5). The path for such integration is not clear or easy. Scale and sector mismatches have been identified as the main barriers to collaborative FEW nexus governance (Jones & White, 2022; Pahl-Wostl et al., 2021). Despite these challenges, formal rules that enable water quality protection, territorial and sustainable development, and public participation are important first steps toward advancing systemic and integrated governance and further linking rules across the WEF systems (Olawuyi, 2020). Scholars have suggested that perhaps when water quality is the issue at stake, an ecosystem health and services perspective will be needed (Heal et al., 2021; Arnbjerg-Nielsen et al., 2022). de Strasser et al. (2016) and Pahl-Wostl (2019) have contributed methodologies with an ecosystem perspective in the FEW nexus literature. For instance, Pahl-Wostl (2019) proposed an analytical framework identifying FEW sector interactions by linking actors via ecosystem services to identify governance deficits.

## 3.6 CONCLUSION

The primary aims of the present study were to examine the underlying systemic causes preventing effective cross-sectoral governance responses and identify alternative intervention points for potential changes toward sustainability. This study found that the operation of hydropower dams and fertilizers management are immediate causes of the water quality problem, and the insufficient consideration of motives, assumptions, and capacities are the root causes. Results show more significant emphasis on addressing deeper drivers focused on adopting new rules and generating knowledge and less emphasis on perceived benefits to facilitate trade-off analysis against actions causing the water quality problem. These results lead to suggestions on alternative interventions points on (1) discussing the benefits relative to the impacts to create the bases for a trade-offs analysis, (2) communicating the hydropower dam operating rules to protect biodiversity and local livelihood for other users such as fishers, (3) training on how to handle fertilizers, and enforcing regulation for pollution reduction and prevention, (4) conducting a visioning exercise to increase engagement with the integrated planning process and long-term planning, (5) the national government taking an active role to overcome institutional inertia for WEF system changes, (6) improving intervention capacity to guard water resources carrying capacity (7) integrating plans for cross-scale planning and sustainable development. This research has provided empirical evidence on the analytical benefits of reframing the problem with nexus thinking and a systemic and agent-focused approach to support problem-solving capacity.

# CHAPTER 4

# "WE ARE NOT BUYING IT": LOCAL PERSPECTIVES ON THE RIO NEGRO BASIN IN URUGUAY THROUGH A SUSTAINABILITY APPRAISAL OF THE WATER-ENERGY-FOOD NEXUS

## 4.1 INTRODUCTION

Sustainable development has been conceived as a global agenda, but its goals have an inherent regional character (Kates, 2001). One main challenge of the sustainability agenda is contextualizing the implementation strategies on different scales, particularly on the regional scale, where many sustainability synergies and trade-offs are operationalized (Wu, 2013). This study tests the potential of downscaling the sustainability aims to a regional area through a sustainability appraisal of the current activities and initiatives occurring in the Rio Negro Basin (RNB) in Uruguay, where water, energy, and food (WEF) systems strongly interact. The extent to which sustainability is pursued on the regional scale has been said to depend on how national objectives align with sustainable development (George, 2001). In that case, the Uruguayan Government has voluntarily committed to the 2030 Sustainable Development Agenda. It has started several initiatives on the regional scale, particularly in the main river basins, to manage synergies and trade-offs, currently setting back the country on the sustainable development strategy of food, land, water, and oceans (SDSN & IBD, 2021). The RNB case is of particular interest for sustainable outcomes because it compromises 40% of the Uruguayan territory and recently became home to the country's largest foreign investment in history (El País, 2023).

The water, energy, and food (WEF) nexus approach is posited as the most suitable analytical lens to interconnect sectoral decision-making for sustainable development (Liu et al., 2018). The last few years of research attention have been directed toward the governance challenges at the core of the WEF nexus (Jones & White, 2022; Pahl-Wostl, 2019; Srigiri & Dombrowsky, 2022), particularly in response to previous scholarship stressing how little is understood about qualitative institutional capacities and the conditions for cross-sectoral coordination and collaboration (Lele et al., 2013; Opejin et al., 2020; Weitz et al., 2017b). Drawing from the integrative environmental governance (IEG) literature, Weitz et al. (2017a) stated that one governance gap remaining in the FEW nexus literature is elaborating overarching guiding principles to facilitate outcomes negotiation and reduce power imbalances across WEF nexus institutions and actors. Connecting the WEF nexus literature with the well-established sustainability principles in the sustainability sciences (Gibson, 2006), this research attempt to fill this gap by conducting a sustainability appraisal as an overarching guiding tool (Weitz et al., 2017a).

In research and practice, sustainability appraisal has been used as a decision-support tool to integrate social, environmental, and economic considerations into the planning processes to foster sustainable development (Bond & Morrison-Saunders, 2009; Gibson, 2017). The case of the RNB presents a unique opportunity to examine a WEF nexus hotspot where numerous interactions occur between the agricultural, water, and energy systems, and sustainability is a local concern due to a water quality problem (Mohtar & Daher, 2016). Although there is no one-fit-all application of sustainable principles (Shah & Gibson, 2013), this study contributes a case study for the WEF nexus

studies, providing a new perspective on how to guide systems toward sustainability. The present study aims to answer the question of how the activities and initiatives enhance or diminish the overall sustainability of the RNB. Applying sustainability principles may avoid jumping prematurely into trade-offs that respond to a particular concern without an explicit justification (Coffman & Umemoto, 2010; Gibson, 2005). Results may provide first insights on how to counterbalance decision-making toward sustainability and could be used as a guide for decisions on the basin development and project level (Shah & Gibson, 2013).

## 4.2 THEORETICAL BACKGROUND

### 4.2.1 Sustainability Sciences

The literature on sustainability sciences has shifted to emphasize how systems could be guided toward sustainable pathways and translating visions into action (Miller et al., 2014). However, what does it mean to steer systems toward sustainable pathways? How to incorporate sustainability in development plans has long been a question of great interest in the field. One widely used approach to ensure that systems are driven to sustainable pathways is conducting a sustainability evaluation (e.g., sustainability assessment or appraisal). In research and practice, sustainability evaluation has been applied as a decision-support tool that integrates proposed actions' environmental, social, and economic effects to foster sustainable development (Bond & Morrison-Saunders, 2009; Gibson, 2017). Sustainability assessments and appraisals have been conducted in many parts of the world (Gibson, 2006; Gibson, 2017). In the UK, for example,

sustainability appraisal has been a key instrument for planned development (Thérivel & Minas, 2002).

A sustainability appraisal aims to ensure that the planning process does not overlook sustainability criteria (George, 2001). It may serve as a second opinion or peer review of the process that could inform a future more complex planning process (George, 2001). Opportunities for change are more likely to be identified if an external party conducts the appraisal (Thérivel & Minas, 2002). The assumption is that integrating an appraisal in the planning process could more effectively introduce changes toward sustainability since each step of the planning process can be checked against sustainability criteria (George, 2001; Thérivel & Minas, 2002). Another assumption is that better information supports better decision-making (Bond & Morrison-Saunders, 2009). An ideal appraisal should be iterative while linked to the planning process aiming for sustainable outcomes (George, 2001). Involving appraisers with different backgrounds and specializations could enhance the appraisal results (Thérivel & Minas, 2002).

Some precautions are advised when carrying out a sustainability appraisal. Since sustainability appraisal came to include social and economic aspects in the earlier environmental assessment, a note of caution is due to the over-focus on the social and economic aspects while undermining the environmental concerns (Morrison-Saunders & Fischer, 2006). George (2001) argued that sustainability appraisal should not deemphasize the environment. In contrast, Ravetz (2000) warned: “that improved environments do not necessarily lead to quality of life or vice versa” (p.32). As expected,

the normative focus adopted when making decisions to foster sustainability has been critically evaluated for the idea of balancing dimensions and criticized for pursuing economic sustainability as the main criteria to assess trade-offs (Coffman & Umemoto, 2010; Berke & Conroy, 2000). A sustainability appraisal may not be a panacea but may facilitate managing the increased impacts while promoting outcomes satisfying the environmental, social, and economic goals (Morrison-Saunders & Fischer, 2006; Ravetz, 2000).

The challenges of balancing the economy, society, and environment are indeed underestimated (Coffman & Umemoto, 2010; Gibson, 2005). Thus, scholars have proposed adopting sustainability principles for a more consistent application (Gibson, 2005; Haughton, 1999). In 2006, Gibson argued for a comprehensive adoption of a set of applicable generic sustainability criteria and trade-off rules based on "two decades of deliberations and experience with sustainability assessments initiatives" (Gibson, 2006, p.171). As posited by Gibson, the primary purpose of sustainability evaluation should be to compare alternatives and avoid the most significant adverse effects. Nowadays, Gibson's sustainability assessment is the most widely used method in sustainability science for alternative pathways deliberation and trade-off decision-making. A range of studies has applied this methodology to appraise water governance (Wiek & Larson, 2012), identify water sustainability framing (White, 2013; White et al., 2019), assess large river basin infrastructure (Shah & Gibson, 2013), and appraise disaster recovery initiatives (Brundiers, 2018). More recently, Gibson (2017) compiled studies applying sustainability assessment to cases such as Senegal's energy and agricultural systems and

Brazil's energy transition to sugarcane ethanol production. Sustainability assessment has demonstrated the potential to facilitate the overall burdens of deliberation in decision-making while evaluating empirical studies and practice at different scales.

### 4.2.2 Water-energy-food (WEF) nexus

The WEF nexus is considered an ideal approach to tackling sustainable development challenges. In the past decade, there has been an increase in the literature focused on sustainable development (Opejin et al., 2020). However, the overall picture is that much of the current literature on the WEF nexus pays more attention to technical and environmental issues and less to governance (Newell, 2019; Opejin et al., 2020). Governance is an extension to management and decision-making in which the Government does not decide and act in isolation, but rather actors impacting or impacted by those decisions participate in the decision-making process (Weitz et al., 2017b). The WEF nexus has effectively identified the management and decision-making problem of isolated actions generating unintended consequences, but the governance dictates if this knowledge is implemented (Weitz et al., 2017a). The governance issues within the WEF nexus studies range from multi-level governance structures to including the diverse actors' perspectives (Kliskey et al., 2021; Pahl-Wostl, 2019; Pahl-Wostl et al., 2021).

There have been few instances of qualitative studies of the FEW nexus studies that capture contextual information and actors' decisions driving change (Albrecht et al., 2018; Treuer et al., 2017). Kliskey et al. (2021) assessed the practice of stakeholder involvement in WEF nexus studies and reported that only 20% of the examined publications mentioned that other individuals outside the research team were involved.

Little is known about essential factors to achieve integrated policy, governance, and decision-making, such as norms, politics, and power relations (Weitz et al., 2017b). More research examining the role of human decisions is essential to understand trade-off mediation and adaptation preferences across WEF sectors (Faeth & Hanson, 2016). The limited research incorporating actors' perspectives posits a risk for policy and plan implementation because of the level of public contribution and engagement with proposed solutions (Díaz et al., 2017; Kliskey et al., 2021).

## 4.3 METHODS

### 4.3.1 Study Area: Rio Negro Basin in Uruguay

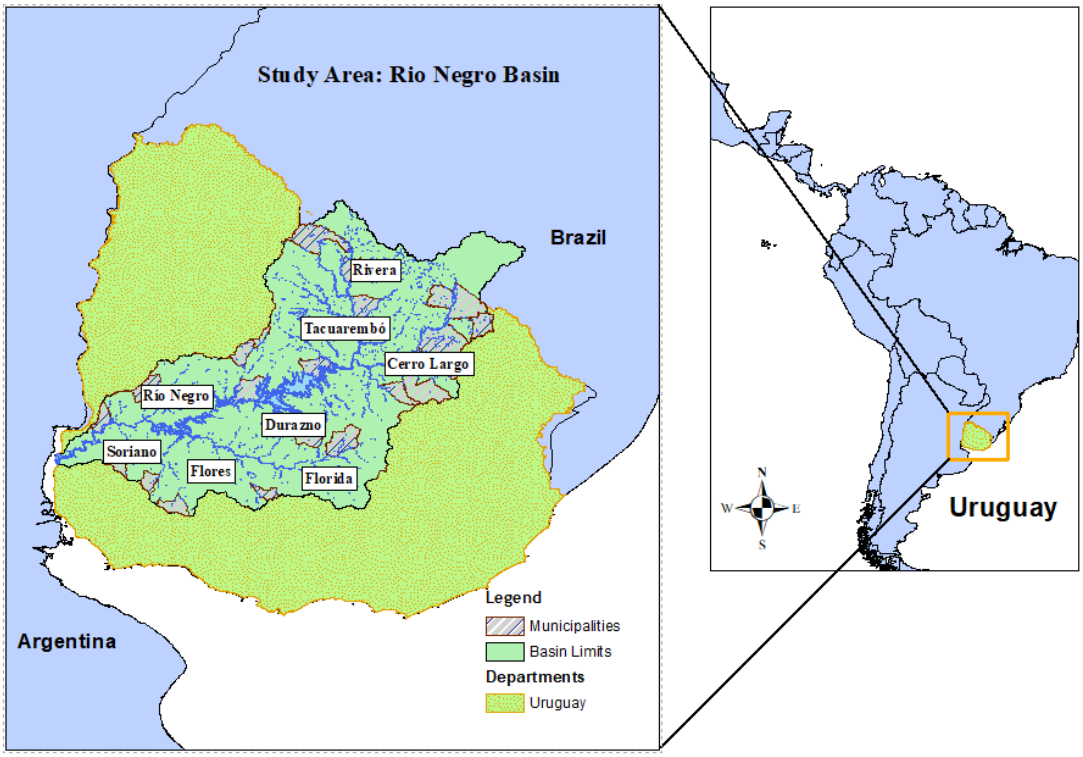
The Rio Negro Basin (RNB) is a critical riverine area in Uruguay, as it comprises 40% of the country's territory and is home to three hydroelectric dams (Figure 12). The basin region has strong interlinkages between agriculture, energy, and water, as most of the land has productive activities, mainly livestock farming. The river serves primary purposes, such as hydropower production, agricultural irrigation, and receiving the effluents of the human settlements and industries settled on its margins. Various activities occur on the river, such as aggregate extraction, tourism, bathing, and commercial, artisanal, and sport fishing. Soon the operations of a new pulp mill will be added to the activities in the basin's middle area, near the Baygorria dam. Finnish forestry group UPM has established a second pulp mill (UPM2) in Uruguay, and operations are about to start in the first quarter of 2023. UPM2 is the largest foreign investment in the history of Uruguay (El País, 2023). All these activities compete for and generate increased pressure

on local water, land, and energy resources, establishing it as a “WEF nexus hotspot” (Mohtar and Daher, 2016).

The Rio Negro has undergone a persistent water quality problem in the past decades. In 2018, the Government of Uruguay enacted Decree No. 298/018 and developed an Action Plan referred to as the “Rio Negro Initiative” to improve the quality of the river waters. The Initiative is the first stage in planning for the basin’s sustainable development and the Rio Negro Basin Plan. This Initiative has taken place over three years and has 34 immediate projects encompassing actions in 5 thematic axes and four cross-cutting programs focused on drinking water and sanitation, biodiversity protection, local capacity building, sustainable production management, and information gathering about the basin ecosystems. Decree No. 298/018 also mandates the establishment of the Rio Negro Basin Commission (the RNB Commission—from now on) to share information, deliberate, and respond to basin conditions. The Commission is a tripartite space comprising representatives of the Government, civil society, and water users; it has held meetings since December 2018.

**Figure 12**

*Location of the Rio Negro Basin in Uruguay*




Shapefiles source: National Environmental Observatory

Ministry of Environment of Uruguay

### 4.3.2 Data collection

Two main data sources of evidence were used to conduct the sustainability appraisal: semi-structured interviews and meeting transcripts of the Rio Negro Basin Commission (RNBC). The meeting transcripts were collected from the Uruguayan Ministry of Environment's website, where they are publicly available. The Rio Negro Basin Commission meetings included actors from the Government, civil society, and water users, as classified by the Uruguayan Ministry of Environment. Government includes national and departmental governments, including the Minister of National Defense. Civil society includes academia, national laboratories, non-profits, and professional

organizations such as the Inter-American Association of Sanitary and Environmental Engineering. Water users include the water and power utilities, farmers and producers' associations, and the Chamber of Industries of Uruguay. Hence, these meeting transcriptions allow access to the perspective of the key stakeholders involved in the ongoing dialogues about the Rio Negro Basin planning and implementation processes. More details of this data set are included in Tables 9 and 10. The typical sample size in case studies ranges from six to ten interviews or from three to five for in-depth interviews (Hernández Sampieri et al., 2014). A total of six semi-structured interviews were conducted with participants of the government, civil society, and water users represented in the Commission between October 2022 and February 2023. Four commission meetings occurred while these interviews were being conducted.

**Table 9**

*Overview of attendance at the Rio Negro Basin Commission meetings*

| Meeting No. | Meeting Date | Attendees | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Government | | Civil Society | | Users | | Others |
| 1 | 12/12/2018 | 38 | 67% | 8 | 14% | 11 | 19% | 0 |
| 2 | 03/13/2019 | 41 | 59% | 18 | 26% | 10 | 14% | 0 |
| 3 | 07/28/2021 | 40 | 68% | 11 | 19% | 3 | 5% | 5 |
| 4 | 10/28/2021 | 35 | 70% | 9 | 18% | 5 | 10% | 1 |
| 5 | 12/02/2021 | 26 | 52% | 13 | 26% | 5 | 10% | 6 |
| 6 | 04/20/2022 | 33 | 70% | 6 | 13% | 4 | 9% | 4 |
| 7 | 07/01/2022 | 7 | 54% | 4 | 31% | 2 | 15% | 0 |
| 8 | 10/19/2022 | 17 | 59% | 8 | 28% | 3 | 10% | 1 |
| 9 | 10/26/2022 | 26 | 57% | 7 | 15% | 3 | 7% | 10 |
| 10 | 11/09/2022 | 27 | 73% | 3 | 8% | 0 | 0% | 7 |
| 11 | 11/23/2022 | 22 | 63% | 5 | 14% | 3 | 9% | 5 |
| | Average attendance | | 63% | | 19% | | 10% | |

**Table 10**

*Description of the meeting transcripts of the Rio Negro Basin Commission*

| Meeting No. | Meeting Theme |
|---|---|
| 1 | Formation of the Rio Negro Basin Commission |
| 2 | Commission bylaws approval, Presentation of the Rio Negro Initiative |
| 3 | Presentations of various projects by the Ministries |
| 4 | Status of the Rio Negro Initiative, National Waste Management Plan |
| 5 | Presentations of various projects by diverse actors |
| 6 | Status of the Rio Negro Initiative by the Ministries |
| 7 | Competitive Fund of the Rio Negro Initiative and the integration of the jury |
| 8 | Presentations of various projects by diverse actors |
| 9 | Presentations of various projects by diverse actors |
| 10 | Presentations of various projects by diverse actors |
| 11 | Presentations of various projects by diverse actors |

### 4.3.3 Data analysis

The sustainability criteria for river basin planning posited by Gibson and Shah (2013) were operationalized through a set of qualitative appraisal questions, an approach adapted from Brundiers & Eakin (2018). Arizona State University's Institutional Review Board (IRB) approved the research protocol and documents. Table 11 presents each sustainability principle and exemplary questions based on the requirements and considerations for the appraisal. During the interviews, each question prompted the interviewers to share information, knowledge, and opinion about how these sustainability principles have been put forward in basin management and planning. The interviews were the primary data to appraise the WEF sectoral interactions, activities, and initiatives taking place in the Rio Negro Basin. The RNBC meeting minutes supplemented the appraisal. The interview data were transcribed using Sonix automatic transcription software, revised by a native Spanish speaker, and imported to MAXQDA software for analysis. To guide

the analysis, codes were assigned to each sustainability criterion. For data analysis of the basin commission meetings and referenced documents, these were imported to MAXQDA software and codified to the extent that they provided information that aided the sustainability appraisal. All data sets were subject to content analysis.

**Table 11**

*Sustainability criteria for the appraisal of the river basin governance*

| Sustainability Criteria and Appraisal Questions |
|---|
| **Political commitment and accountability** |
| • Have decisions at the basin level been consistent with national sustainable development goals?<br>• Are procedures in place to hold decision-makers accountable to advance sustainability into policy and development objectives?<br>• Have actions been taken to strengthen institutional capacities for sustainable development?<br>• Have decision-makers discussed the transboundary river relationships and potential conflicts? Are there procedures in place to resolve transboundary river conflicts? |
| **Inter-system coordination and integrity** |
| • How have national social, economic, and environmental conditions influenced local scale conditions in the basin? Have these influences been considered for the Basin Plan?<br>• Have steps been taken to foster coordination between the interactions between water, hydropower, and agriculture within the basin?<br>• Are stakeholders' needs, aspirations, and expectations identified to ensure outputs that satisfy stakeholders?<br>• How are human (personnel) and financial resources allocated (e.g., coordinated and integrated) to achieve the river restoration? |
| **Democratic decision-making and social learning** |
| • Are the planning processes fair, transparent, and participatory, with special efforts to include marginalized people?<br>• During planning, do decision-makers collect and use traditional and scientific knowledge to incorporate diverse perspectives and foster social learning?<br>• Are administrative resources allocated to foster multi-sectoral collaboration, and how were responsibilities assigned? |
| **Monitoring and adaptive management** |
| • What monitoring systems are in place?<br>• Can monitoring systems detect sudden and accumulative biophysical changes? |

- Do diverse stakeholders participate in the monitoring systems activities, including local communities within the basin?
- Are learned lessons and new development processes incorporated to improve monitoring and management practices?

**Socio-ecological resiliency and integrity**

- Are development alternatives that preserve or restore habitats of threatened species and critical ecological processes endorsed?
- Can you describe what ideas exist to manage demand and supply better to lower pressures on the river?
- Are users' practices diligently chosen to mitigate potential risks associated, for example, with overuse of irrigation water, salinization, or erosion?

**Social and cultural integrity**

- How are the available resources in the basin part of the local users' everyday life? Are these resources preserved for local livelihood, poverty prevention, and their capacity to respond to disturbances (or coping with challenging situations)?
- Can you mention examples of cultural knowledge and practices that are part of the local identity and dignity? How are these practices maintained?
- How do resource users (e.g., farmers and communities) interact with the resources within the river basin? Are these interactions been considered when making plans for the basin?

**Project-affected and displaced peoples**

- Is population displacement occurring? If yes, please explain its economic, biophysical, and social costs.
- Is it ensured that affected and displaced people support or at least have no significant opposition to the plan and projects?
- Does engagement with affected and displaced people take place? Does it emphasize their long-term livelihood and lifestyle sufficiency rather than short-term needs?

**Intra- and inter-generational equity and opportunity**

- Who are more-vulnerable and less-vulnerable water users (e.g., downstream users)? How fairly and equitably do the socio-political and material alternatives address their concerns?
- Is the focus on lasting gains and cumulative effects to enhance options in the future?

**Public safety and disaster management**

- Are development alternatives aimed to lower the risk of hazardous impacts on public safety or desirable ecological and socio-economic system functions?
- Are development alternatives chosen that avoid or reduce public health risks (e.g., diseases, food safety, or generally harmful to human health)?
- Are emergency response plans widely communicated and accessible to the public? How are emergency response plans made accessible or communicated to you and others?

| **Economic and financial viability** |
|---|
| • Are economic low-risk alternatives that do not result in an excessive burden on citizens and the state selected, both now and in the future?<br>• Are development alternatives with positive financial benefits that do not have significant trade-offs in other criteria prioritized? |
| **Decommissioning and reversibility** |
| • Have decommissioning and reversibility been considered to occur without excessive cost or damage to the socio-ecological system functions?<br>• What are the associated social and environmental costs of doing it or not? |

Questions operationalized from sustainability criteria posited by Shah and Gibson, 2013

## 4.4 RESULTS

Sustainability criteria for river basin planning and management were operationalized through a set of qualitative appraisal questions, and semi-structured interviews were conducted with local actors related to the RNB in Uruguay. The appraisal was supplemented with the meeting transcripts of the RNB Commission as they allow access to other actors' perspectives from the Government, civil society, and water users.

### 4.4.1 Political commitment and accountability

Uruguay has undergone a transition toward creating environmental policies and programs over the past 15 to 20 years. Many national policies and plans have been developed for different topics, such as water protection, renewable energy, sustainable development, climate change, and circular economy. One interviewee commented:

> The change has been impressive. The environmental and sustainability topics became an agenda item, an emerging issue. It is not a buzzword but is a real and cross-cutting theme in diverse policies. […] For instance, the National Water Plan is the framework guiding the establishment of the basin commissions, and it is based on a policy developed in line with the proposed sustainable development objectives. (RNB03).

Despite having policies and plans for sustainable development, the government has made development decisions impacting the RNB that are inconsistent with these objectives. Various actors are concerned about the chronic level of water pollution and lack of control on regulations compliance. In the words of one of the interviewees:

> Pollution issues come from the lack of control; since 2009, it has been diagnosed, and water outlets continue to be installed; we diagnose that there is something here, something is there, cyanobacteria, coliforms, etc. Still, we do not have a solution; we do not have a remedy for that. Then, we become the kings of diagnosis without having the corresponding solution to clean the river […][The National Government] has all the information. […] They do not have the will to enforce. (RNB04)

A controversial affair that arose in several interviews was the establishment of the new pulp mill (UPM2) in the middle of the basin near the Baygorria dam. The establishment of UPM2 is contested due to the additional pollution from its effluents and the land use changes resulting from the agro-supply chain of eucalypts. The National Directorate of Environmental Quality and Assessment (DINACEA) evaluates and approves any company's environmental impact study to be installed in Uruguay. Talking about this issue, an interviewee said:

> Uruguay fails in the enforcement part. No one comes to see and verify [compliance], so the neighbors denounce it. [When] the technicians come, they find that the facilities are not complying, they fine them and make them fix wrong things. In that, we are failing a lot in enforcement. (RNB02)

There are some challenges and opportunities concerning the transboundary river relationship with Brazil and Argentina (where the river is born and discharges, respectively). An interviewee expressed: “when the river enters through the border, it is [already] contaminated. But from the border forward [in Uruguay] pollution with

agrotoxics has increased, lack of sanitation in cities, and everything goes directly to the river". (RNB04) Another interviewee expressed:

> Uruguay-Brazil border is very porous and has many illegal crossings. There is free movement of people, machines, and supplies. There is much communication, and many Brazilian companies are installed in Uruguay. In times of drought, areas can be crossed by walking. Rice production starts from Brazil. (RNB01)

On the third meeting of the RNB Commission, the Ambassador of Uruguay from the National Directorate of Border, Neighboring, and Maritime Affairs of the Ministry of Foreign Affairs, discussed the transboundary aspects of the Rio Negro Basin. (2021, p. 25) According to the Ambassador of Uruguay, there is no treaty or institutional mechanism with Brazil for issues on the Rio Negro. There is no binational commission that oversees the Rio Negro from the headwaters. However, other institutional mechanisms with Brazil in relation to Rio Cuareim Basin and Laguna Merín may serve as precedents. At this same meeting, a representative of the Ministry of Environment of Uruguay said:

> I think we should have a more fluid exchange with Brazil, even participate perhaps together in basin treatment. So that, so that somehow, we can have all the information. Our information is on the web; it can be shared. And well, the idea is that with Brazil, we can have this exchange in the future to discuss management in some way or the plan for the upper basin. (2021, p.15)

In this instance, the opportunities come from the existing governance bodies on the binational sides of the basin. Before the creation of the RNB Commission, there was already another body called the Deliberative Committee of the Rio Negro Basin that is made up of the councilors of all the departments on the riverbanks and the Brazilian side of the basin. According to an interviewee:

> The committee is more active than the Commission of the Executive Branch, focusing on all the issues, not only water but the basin afforestation and also sand extraction, which is being quite critical and without control over the Rio Negro. (RNB04)

Furthermore, the binational approach with Argentina exists through the Administrative Commission of the Uruguay River (known as CARU) and the Mixed Technical Commission of Salto Grande, the dam on the Uruguay River. According to an interviewee: “if there is any conflict, these are the spaces where water discharges with excessive nutrients are discussed.” (RNB03)

### 4.4.2 Inter-system coordination and integrity

In response to how have national social, economic, and environmental conditions influenced the basin development, an interviewee asserted that:

> [Decisions] are taken based not only on different scales but also based on policies that have been defined in different [pivotal] points in the country's history. The Forestry Act of 1987 allowed 1 million hectares of forestry today. So, this afforestation is a construction of the last 30 or 40 years. Then, the decision about the basin was already taken 30 or 40 years ago. Today pine [afforestation] is being replaced by eucalyptus [afforestation], with genetically [modified] improved species for increased cellulose production. (RNB01)

Land use change and eucalyptus afforestation respond to increased global pulp demand. To this end, the RNB has undergone land use changes, particularly in the Department of Tacuarembó and Rivera. Another interviewee, when asked about national influences in the basin development, said:

> Evidently, these decisions are made at the economic level, not now, from many years ago, […] when soybeans began to be planted with another type of production. Obviously, these are economic decisions to plan GMOs without control. GMOs today accept a huge amount of agrotoxics that are not accepted by natural life. These pesticides kill everything that is not transgenic and end up in the river basins with thousands of dead fish, contaminated people, dead sheep, and cattle that do not want to drink water because they know it is contaminated.

> And those are bad economic decisions made without thinking about the environment. (RNB04)

The purpose of the seventh meeting of the RNB Commission was to select the jury to analyze and define the proposals that would receive funding from the Competitive Fund of the Rio Negro Initiative. About this instance, an interviewee posited:

> The project request for the civil society was $2,000, [...] give you $2,000 to do a project. So, I think ten projects, or something, were presented, and half were selected [...] it's impossible with $2,000 to do something good, let's say. And that's where you see that sometimes when we talk about participation, we are refused participation because I never found out where the amount of $2,000 came from. Because what happens? That the money for the Rio Negro Initiative exceeds one million. It exceeds one million dollars. […] And that is why I disagree that only $2,000 is given for civil society projects. (RNB02)

Another interviewee recommended seeing a presentation where academics from the University of the Republic of Uruguay discussed the effects of establishing UPM2 in the RNB (see Estudios Rurales Tacuarembó, 2020). In this presentation (from minute 39:55), an academic argued how UPM had instrumentalized Corporate Social Responsibility (CSR) to avoid and contain conflict with other actors in the Uruguayan territory. In 2005, UPM Foundation was established, and from there, projects have been funded in rural schools, sports clubs, polyclinics, environmental entrepreneurship, etc. UPM is the first company to co-manage a national protected area (viz., Parque Nacional Esteros de Farrapos e Islas del Río Uruguay), displaying the company as environmentally friendly. According to this academic, as a mega project, UPM continues to diversify and increase its territorial control by producing cellulose, generating bioenergy, and selling it to UTE, through afforestation, beekeeping, grazing, and others.

Relating to fostering coordination and collaboration within the WEF sectors. An interviewee stated:

> Many times, some specific projects involve more than one institution. According to the theme, there are instances of coordination or co-participation in the projects. But [the RNB Commission] is like the main space, especially in which the different levels of actors participate, not only civil organizations. (RNB03)

In contrast, another interviewee stated: “there is no coordination, I have not seen coordination, rather, let’s say, there is a lack of knowledge […] the basin conditions are unknown, [for example] the current condition of fish and fishing in the Rincon del Bonete dam”. (RNB01) Another interviewee emphasized:

> I think there is a lack of real honesty and sitting down the parties. Show me. Well, what happens to you if you let the environmental flow pass? What happens to you that you lose so many millions of dollars for not generating [energy with] that water, for not damming water and being able to generate [energy]? Well. Either it is covered in some way or another. I do not know. But there must be the parties willing to let go a little, to lose and win in another. I don't think we're in it yet. In that sense, we are immature, and the Basin Commission is immature. (RNB06)

### 4.4.3 Democratic decision-making and social learning

When appraising progress towards democratic decision-making and social learning processes, an interviewee refers to the RNB Commission as that space “to follow up […] and be informed of the different activities taking place and that everyone also has access to information on the activities and initiatives that are taking place at the basin level”. (RNB03) In contrast, other interviewees differ about what the RNB Commission is for. One interviewee described that:

> The [RNB] Commission is more about the middle basin; it is more about the UPM2 area. The theme of the Commission was focused based on [UPM2]. Given the many complaints from society against UPM2, [the Commission] was created. The Commission was already required by law, but how many years were we without a basin commission? For years, we were asking for the Commission to be

> established […] until the moment that [the national government] had no choice. (RNB02)

One interviewee stated:

> The [RNB] Commission explicitly excludes the Zonal Fisheries Councils and artisanal fishers' delegates from participation. This reinforces, let's say, the convenient use of public institutions by UPM, for example, through what is called the Rio Negro Initiative, which is an economic fund used by the National Water Directorate, the National Directorate of Aquatic Resources, the National Directorate of the Environment, where a series of studies and initiatives are developed […] from the interest of the company to establish and use the resource freely. In other words, there is no room to formulate, to negotiate interests; instead, it is from the interest of the company [UPM]. (RNB01)

Related to the fishers, this interviewee also said:

> Fishing has historically been a very marginalized activity in society. There is a significant segregation of the artisanal fishing sector in inland waters, cities, and rural areas. That is, they are stigmatized as marginal people. They are often associated with crimes against property, animals, cattle rustling, and poaching. And well, generalizations are made. (RNB01)

Related to how the administrative resources are allocated to foster multi-sectoral collaboration and how responsibilities are assigned, an interviewee expressed:

> My organization made a designation based on the different basin commissions at the national level. It was distributed so that anyone is overloaded; obviously, it is one more task. The different basin commissions were designated among the participants related to issues in the area. That is how human resources are allocated. (RNB02)

Another interviewee shared:

> I actually asked for a leave of absence from my work to be able to go [to the RNB commission meetings] because I had to travel 300 kilometers (186 miles), and it took me all day. Between the time the Commission takes, last all morning, and then [driving] back, my workday is lost, but I am willing to do it, but many people would not. (RNB06)

### 4.4.4 Monitoring and adaptive management

There are several monitoring programs in the Rio Negro at the moment. First, the routine water quality monitoring carried out by the National Environmental Directorate (DINAMA, its acronym in Spanish) of the Ministry of Environment since 2009 along the river and some streams. Second, the hydrological and water quality monitoring carried out by the Faculty of Sciences of the University of the Republic for the hydroelectric utility, UTE, associated with the three reservoirs: Baigorria, Bonete, and Palmar. Third, the automatic monitoring carried out by the Technological Laboratory of Uruguay (known as LATU) for the Finnish forestry group UPM related to the required baseline studies for establishing UPM2. Three monitoring stations are located in Rincon del Bonete and Baigorria reservoirs and near Paso de los Toros, operating since late 2020. Although it is not an early warning system, the only monitoring system that can indicate changes is the automatic water quality monitoring system managed by LATU for UPM2. At the second meeting of the RNB Commission, a representative of the Ministry of Environmental asserted:

> Fifteen [monitoring stations] have been implemented recently, and these have shown a water quality situation in the Rio Negro that concerns the national government, and the [national government] understands that in the face of possible new instances and important development projects, and we said "eventual" because the case of UPM is not defined, etc. [The National government] understands that developing a preventive function is necessary to generate a baseline knowledge of the situation. (2019, p. 6)

Regarding UTE's water quality monitoring program, an interviewee warned that:

> UTE monitors, but beware! [UTE] monitors for its own interest, not because [UTE] must report to the Ministry of the Environment. No! The only thing that [UTE] reports as camaraderie is the cyanobacteria. [UTE] reported to the Ministry

> of Environment, but not because [UTE] has the obligation or because regulation requires it. (RNB06)

An interviewee said about the water quality reports: “for that reason, a citizen monitoring network was created, which goes in parallel, because sometimes [citizens] do not trust the analysis that the State provides. So, [citizens] want to do something in parallel.” (RNB02) Regarding access to UPM data, an interviewee said: “I can assure that [UPM] has as a spirit of total transparency of information, in terms of the environmental information generated.” (RNB03)

### 4.4.5 Socio-ecological resiliency and integrity

In recent decades, a significant afforestation process has been driven by the global pulp demand. According to interviewees (RNB04, RNB01), afforestation is fragmenting the territory and disrupting the adequate recharge of aquifers because there is no control of forestry plantation in the aquifer recharge areas. Concerning the preservation of habitats of threatened species and critical ecological processes, an interviewee appraised:

> Uruguay allows 100 hectares or less without environmental control. So, what do they do? They ask for authorization for 100 [hectares] that go unnoticed [...] They ask again to plant 100 more. And today, we have hundreds of thousands of hectares planted without control, which prevents the aquifers from recharging enough, leading to lower surface water. Today, for example, here we have an important lake, the Rincón del Bonete dam, which is extremely low, with historical downspout because there is no lake-aquifer interaction. (RNB04)

Another interviewee stated:

> The river modifications into man-made reservoirs are causing the decline of migratory fish species no longer found in the Rio Negro, at least in the middle and upper area of the Rio Negro, but still [these fish species] are found in the Rio Uruguay. As you know, the [fish] need to migrate, need to move along the entire river to reproduce, and having three hydroelectric dams, there is a barrier for the migration, and therefore, it has not been viable for [these fish species] to maintain over time. (RNB01)

In relation to existing strategies to manage pressures on the river, an interviewee stated:

> In the case of the hydroelectric [...] UTE is interested in the forces moving water to the turbines and with that [energy] is generated, no matter the [water] quality it has, [UTE] lets [the water] pass. [The water quality] does not affect [UTE] at all. (RNB06)

Concerning the UPM2's water use, which is a new actor in the basin, this interviewee said:

> An Executive decree forced UTE to release water through the dam [for the operation of UPM2]. That was not an agreement. There was an Executive decree that forced the release of the [minimum] flow rate. UTE protested because reserving water means reserving energy for [the hydroelectric]. So, well, there was a whole conflict. (RNB06)

### 4.4.6 Social and cultural integrity

Spending a Sunday afternoon sitting on the pier in front of the river, boating, kayaking, fishing, hunting, and tourism are some of the recreational activities in the lower area of the RNB. An interviewee mentioned, "Fishing is a cultural and ancestral practice. Hunting too. These are cultural practices that are deeply rooted in the population." (RNB02) Whereas another interviewee said, "No one takes advantage of the river as they should. Only in summer do people go to sit on the riverbank to drink mate, take a bath or walk around the bay. [The river] is not used for tourism as it should be." (RNB04)

When inquired about how the basin resources support local livelihood and poverty prevention, an interviewee stated that: "In times of economic crisis. In Paso de los Toros, around 100 families were registered who sporadically went to the river to obtain some livelihood resource." (RNB01) This interviewee also stated:

> The RNB is obviously not only formed by creeks, but by the sedimentary soils of Rivera and Cerro Largo, the Rio Negro Valley, where there are agricultural and livestock fields, the sands areas where the yield for commercial eucalyptus afforestation is excellent [...] Tacuarembó and Cerro Largo […] have also been heavily afforested, and this has affected the amount of water held in the soil, that competes with the grazing of family farmers. [...] for this other social group that is the family farmers, who are about 3000 family farmers, let's say in this situation, in this area of the Rio Negro basin, who have grazed in these fields, perhaps during 200 or 300 years. (RNB01)

### 4.4.7 Project-affected and displaced peoples

Even when this sustainability principle was inquired in a general sense, the interviewee responses about affected and displaced people converged toward the effect of the new pull mill located in Paso de los Toros in the Department of Tacuarembó. An interviewee said: “The most affected [people] are the family farmers and fishers, also the poor from Paso de los Toros, that is, the popular sectors that live in elevation 60." (RNB01) The relocation of temporary workers to build the UPM2 facility in Paso de los Toros has generated real estate speculation. In addition, the soil yields are prime for commercial eucalyptus afforestation in the Departments of Tacuarembó, Rivera, and Cerro Largo. This interviewee affirmed:

> The commercial afforestation of [UPM and others] has significantly increased the land sale and rental prices, but there is also environmental competition for water use. Both the water availability at ground level and for animal consumption. So, for up to 3000 family farmers, there is a contribution of water availability from the Rio Negro basin. With the scarcity of rains, competition with afforestation, and the high prices of the land, that [was] the social benefit that the basin gives to the family farmers, who fulfill a role simultaneously, let's say, of sovereignty in the territory. (RNB01)

The construction of a railroad between the UPM2 facility in Paso de los Toros and the Capital of Montevideo to transport cellulose to the port has also generated tensions. An interviewee said:

> That [construction] is also impacting the neighbors, the other towns, other populations, and people who live on the side of the railway route. That is to say, there are problems with access to Montevideo, the entrance, and all modifications, and that is why people sometimes feel powerless. That is the truth. That is, the problem overwhelms us. (RNB04)

### 4.4.8 Intra- and inter- generational equity and opportunity

Almost all interviewees alluded to national decisions that compromised the sustainability of present and future generations. Even with many environmental commitments, the country's natural resources are jeopardized. When inquired about who are the vulnerable water users, an interviewee said:

> The entire population. All 3 million [people]. Because the water is polluted. Water is contaminated in all waterways. Do you know what I mean? Because throughout the country, there is agricultural production. So, in all watercourses, there are agrochemicals. There's no escaping it! (RNB02)

Another interviewee said: "the water users […] the main water intake of the cities is in the Rio Negro […] There [in the cities] would be those most directly affected." (RNB03) Concerning ensuring cumulative effects to maintain and enhance future options, an interviewee pointed out that:

> The environmental dimension must be present from the outset, from the design. And that's not always the case. Then, let's see what to consider. Environmental protection measures? Impacts mitigation or remediation? Does it increase the cost? Definitely, yes. But then, as [the environmental factors] increase the costs, many times these are not carried out, and sometimes the future is being compromised for a benefit in the short term. (RNB05)

Another interviewee also pointed out:

> I believe the younger generations are becoming a little more [environmentally] conscious. Some have no conscience; that is us, who are using something that does not belong to us, that is theirs. Then, we contaminate something that belongs to them, not us. I believe they are a little more aware, but they lack much information that had been hidden from them […] evidently our generation has been disastrous, disastrous. (RNB04)

### 4.4.9 Public safety and disaster management

The water quality problem poses a public health risk due to cyanobacteria. Concerning the accessibility and wide communication of emergency response plans, an interviewee stated:

> No, it doesn't exist. To tell you more, I have had the opportunity to call the City Hall services line when I see the water with [algae bloom] conditions, and they tell me that the water is in perfect condition. But why is it in perfect condition? Because they don't study that part, they just study the part of the coliforms, which is something else. The issue of algae and cyanobacteria is not being studied. Only now [the national government] is installing buoys to check what they can work on, but nobody tells the population what that means. I have had to fight a lot for five years to put a sanitary flag that people don't even know what it is for because [the national government] didn't even report it either. It is a red flag with a green cross. That [flag] means that the water is contaminated, and they should not bathe. But [the national government] also does not explain what that flag is for. (RNB04)

### 4.4.10 Economic and financial viability

As a developing country and an emerging economy in Latin America, development decisions in Uruguay have conditioned its territorial development and natural resource conservation. An interviewee asserted that:

> Measures are poorly taken because they are not taken at the level of environmental awareness, but of economic awareness, and sometimes not everything [is done] at any cost. We must consider all these things because, in short, the intangible is unrecoverable, and then we will have many problems to recover from that, and it will be much more expensive. (RNB04)

Discussing the economic conditions in which decisions have been made, another interviewee stated:

> The economy not only of Uruguay but of Latin America depends on foreign direct investment to create conditions for these companies, corporations, to settle in our country and not in another country. Then, it is a slightly perverse logic. […] We prepare the country, so they come here. So, when do you come, the country's wealth, in our case, is the wealth of natural fields, for example, and freshwater, which are extremely scarce goods worldwide. It is compromised in the function of the corporations coming here. (RNB01)

When discussing managing trade-offs of development alternatives, an interviewee expressed:

> We still do not know how to approach it because […] we suffer the symptoms of many developing countries or whatever they want to call it, from the south. It is that agriculture and energy, selling energy gives us money, money enters the country, and the GDP increases. […] So, then you can start to see a little more of the issue of all environmental treaties, right? That is, all the transfers of environmental impacts because the impact stays here [in Uruguay]. [...] Regarding the Sustainable Development Goals, when we have those great goals of [zero] hunger in the world, of peace, any [goal], and there really is a part of social justice, of environmental justice that we are not buying it. [...] I say this because we are not so free to choose what impacts we accept and what not, because we have to eat before, because we have to deal with a lot of things, that obviously livestock and grain production, you are going to prioritize; hydroelectric, you are going to prioritize it, because if you do not have to go out and buy oil barrels that will cost you an eye from the face. [...] And there I jump to the global. I sometimes protest the Sustainable Development Goals because suddenly, our environmental agenda focused a lot on the United Nations (UN) reports with the Sustainable Development Goals. So today, we [prioritize] air emissions, but the reality is that Uruguay is not such an industrial country to make air emissions our priority. We have many obvious water problems, yet we don't have as many indicators for water quality. I understand the global issue is emissions, but we also have a gap in that, which seems to me that the environmental agendas of the south have turned a lot toward global issues and have lost local environmental agendas. Then we prioritize and do projects with respect to emissions and projects with respect to heavy metals. It's been an entire movement to remove mercury. What mercury did Uruguay have? Mercury thermometers? However, we have people who live with soil still contaminated with lead, and there is not one lead project. That is, there are studies, but they are not financed by the UN, for example. And we have arsenic in water wells. And that's not financed by the UN. (RNB06)

### 4.4.11 Procedural changes suggested for the Rio Negro Basin governance

The empirical evidence results obtained from the sustainability appraisal have been merged with lessons from the sustainability criteria for river basin planning and management, as proposed by Shah & Gibson (2013), to suggest procedural changes for the Rio Negro Basin governance (see Table 12).

**Table 12**

*Procedural changes suggested for the Rio Negro Basin governance*

| |
|---|
| Political commitment and accountability |
| Ensure institutional commitment to strengthening institutional capacity for regulation enforcement, especially water quality regulations and land use norms. |
| Ensure basin-level decisions are consistent with national sustainable development goals. |
| Establish a binational governance body to establish a plan for the upper basin. |
| Ensure the national government supports, builds, and acts upon the work and local capacity created by the RNB committee at the departmental level. |
| **Inter-system coordination and integrity** |
| Revise existing policies (e.g., The Forestry Act of 1987) to align them with the present commitment to sustainable development. |
| Increase coordination for cross-sectoral collaboration, not only through co-participation in projects but at the institutional planning and implementation level. |
| Ensure the basin commission meeting are open to a rich discussion about how the WEF sectors interact and honest trade-off analysis. |
| Communicate to the diverse actors how the inter-system coordination is planned and implemented. |
| Consider the aspiration and expectations of all actors about participating in decision-making. |
| **Democratic decision-making and social learning** |
| Ensure all actors have an overall understanding of what is the purpose of the RNB Commission. |
| Ensure the RNB Commission includes all the affected actors, with special efforts to include marginalized people such as fishers. |
| Ensure the RNB Commission is democratic and open to formulating and negotiating interests. |
| Ensure that administrative resources are allocated to foster multi-sectoral collaboration that does not represent an additional designated task. |
| Ensure the RNB commission meetings are held at alternative work schedules to accommodate the needs of the diverse actors. |
| **Monitoring and adaptive management** |
| Continue monitoring water quality to detect accumulative biophysical changes. |
| Support the citizen monitoring network to build trust and be able to detect sudden biophysical changes. |
| Ensure lessons learned are incorporated to improve monitoring and management practices. |
| **Socio-ecological resiliency and integrity** |
| Protect critical ecological processes and maintain carrying capacity. |

| |
|---|
| Ensure the hydropower operation allows biodiversity to flourish and avoid the loss of native fish species, such as the *tarariras.* |
| Protect the integrity of the territory by not allowing the same owner to have more than certain permits for eucalyptus afforestation. |
| Protect critical areas for aquifers recharge. |
| **Social and cultural integrity** |
| Ensure natural resource protection for the maintenance of socio-cultural practices. |
| Ensure resource uses for livelihood and poverty alleviation and prevention. |
| **Project-affected and displaced peoples** |
| Establish engagement with affected and displaced peoples. |
| **Intra- and inter- generational equity and opportunity** |
| Share information about development decisions with vulnerable water users and younger generations. |
| Ensure environmental protection is considered from the first phase of project design and adopt measures for mitigation or remediation. |
| **Economic and financial viability** |
| Pursue basin development that do not result in an excessive burden on the environment, citizens, and the state, both now and in the future. |
| Ensure accumulative effects maintain and enhance future options and prospects. |
| **Public safety and disaster management** |
| Ensure public health risks are widely communicated when water has unsafe levels of contaminants, in addition to the raising the sanitary flag. |
| Build on the three current institutional monitoring systems to prepare and distribute a Consumer Confidence Report (CCR) to provide the public with information about water quality reports, not only through a website. |

## 4.5. DISCUSSION

The main question this study aimed to answer was how the activities and initiatives taking place in the Rio Negro Basin (RNB) are enhancing or diminishing overall sustainability. Sustainability criteria for river basin planning and management were operationalized through a set of qualitative appraisal questions, semi-structured interviews conducted, and the RNB's meeting transcripts examined to understand local perspectives on the sustainable development of the basin. The case of the RNB is of particular interest as a WEF nexus hotspot where numerous interactions occur between

the agricultural, water, and energy systems, and sustainability is a local concern due to a water quality problem (Mohtar & Daher, 2016). Scholars have urged conducting research in WEF nexus hotspots where water quality requires critical examination (Heal et al., 2021; Mohtar & Daher, 2019). In addition, while investigating the case of the RNB, this study contributes to closing a governance gap remaining in the WEF nexus literature regarding the elaboration of overarching guiding principles to facilitate outcomes negotiation and reduce power imbalances across WEF nexus institutions and actors (Weitz et al., 2017a). Employing well-established sustainability principles from the sustainability sciences (Gibson, 2006; Shah & Gibson, 2013), this study provided a new perspective on examining the sustainable development of the WEF systems.

The present sustainability appraisal aimed to ensure that sustainability criteria for river basin planning and management are not overlooked (George, 2001; Shah & Gibson, 2013). Overall, any of the sustainability principles show a strong enhancement toward sustainability. To illustrate, sustainability principles such as political and commitment accountability and inter-system coordination and integrity show enhancement, while socio-ecological resiliency and integrity, and democratic decision-making and social learning are criteria still lagging and in need of attention. For instance, the political and commitment accountability principle has shown mixed results regarding some challenges and opportunities concerning the transboundary river relationship with Brazil (where the river is born, representing 4% of the basin). On the one hand, challenges result from the lack of binational institutional mechanisms to address transboundary river management and potential conflicts of mutual interest. In terms of communication, an interesting

finding is that a government representative understands that having information on a webpage may indicate an intention for collaboration. On the other hand, opportunities result from the existence of the RNB Committee at the departmental level, involving local actors from both sides of the Uruguay-Brazil border, which also focus on various issues beyond the water quality problem.

Even when diminished actions dominate, some positive actions continue to be the potential for introducing changes toward sustainability. The sustainability principle concerning monitoring and adaptive management exhibits slight enhancement. For instance, various monitoring mechanisms are in place to identify biophysical changes in river conditions, although UPM2 owns the only system capable of detecting sudden changes. Perhaps in the spirit of transparency, this information can be communicated, as assured by an interviewee (RNB03). Although the lack of trust in the government water quality report was the trigger, local actors exhibit an inspiring commitment to their local livelihood by creating a citizen water monitoring network and assuming some of the State responsibilities (RNB02).

The combined results of others sustainability principles are further discussed to shed light on the FEW nexus governance in practice. First, as a space for collaborative actions, the RNB Commission has brought diverse actors together who are concerned about the water quality problem and basin development in general. Still, the local perspectives are diverse about the purpose and function of the RNB Commission. For instance, for one participant, the RNB is the space to access information on the activities and initiatives taking place in the basin (RNB03). Once again, access to information is

use interchangeable with collaboration. In contrast, others perceive that the RNB Commission is a space that emerged in response to complaints against the establishment of UPM2 and that there are refused from real participation (RNB02). In the words of one of the interviewees, “there is no room to formulate, to negotiate interests,” and some actors, such as fishers, are excluded from participation.” (RNB01)

The functioning of the RNB commission illustrates the institutional capacities and the conditions for WEF cross-sectoral coordination and collaboration (Lele et al., 2013; Opejin et al., 2020; Weitz et al., 2017a). First, related to how administrative resources are allocated and responsibilities assigned to foster multi-sectoral collaboration. One interviewee stated that their organization designates people to participate, but this is an additional designated task (RNB02). Another interviewee shared the need to take a leave of absence from work to be able to participate (RNB06). These findings shed light on the practical barriers and implications of creating a collaborative space, which is not necessarily new as others have explored (e.g., the International Association for Public Participation). In addition, local perspectives are scattered regarding coordination and collaboration within the WEF sectors. One interviewee said there is occasional coordination for specific projects (RNB03), another that there is no coordination (RNB01), and another that there is a lack of real honesty from the parties to lose and win sometimes (RNB06).

Finally, another important finding is how the RNB’s cross-sectoral collaboration emerged (Weitz et al., 2017a). As mentioned before, the arrival of UPM2 as a new actor in the basin has triggered many mixed reactions. First, the national government has failed

to fully enforce the land use and water quality regulations resulting in jeopardized local livelihood, according to several interviewees. Second, at the beginning of the Commission, it was said that the establishment of UPM2 was not determined, but there was never room for deliberation (RNB01, RNB02, RNB04). These findings may help us understand that the lack of trust and common ground hinders democratic decision-making. Building trust and finding common ground and mutual benefits have been pointed out as critical for collaborative governance by other WEF actors (Jones & White, 2022). The case of the RNB has a nuance showing that further study could be carried out to look more closely at this case with a social and environmental justice lens. This research has thrown up some questions in need of further investigation. For instance, the extent to which UPM Foundation has instrumentalized Corporate Social Responsibility to avoid and contain conflicts in the context of a developing country would be worthwhile to investigate (Estudios Rurales Tacuarembó, 2020).

The main picture of the RNB case is that more activities are diminishing than enhancing overall sustainability. Despite transitioning to adopting policies and plans for environmental protection and sustainable development, the operationalization of these frameworks continues to be dominated by the pursuit of economic sustainability as the main criterion to assess trade-offs (Coffman & Umemoto, 2010; Berke & Conroy, 2000). This study's findings shed light on the significant challenges in managing trade-offs stated in the Uruguay Sustainable Development Report (IDB, 2021). The empirical evidence shows that Uruguay, like many other countries in the Latin America region, undergoes environmental-territorial changes driven by global trends and foreign

investment, albeit Uruguay has shown a noteworthy effort for this region toward sustainable development. As an emergent economy, Uruguay faces a "perverse logic," described by an interviewee (RNB01). That is the transfer of global environmental impacts against the increased gross domestic product (GDP). (RNB06)

## 4.6 CONCLUSION

Downscaling sustainability from global or national goals to regional actions is one of the major challenges that countries face when pursuing the 2030 Sustainable Agenda. As expressed by Lele et al., 2013, "governance challenges are at the heart of the nexus in each region." Therefore, the synergistic local social, economic, and environmental implications must be considered. The present study contributes to the WEF nexus literature by providing a new perspective while examining a WEF nexus hotspot embracing sustainability principles. Examining the case of the Rio Negro Basin (RNB) sheds light on how countries may not be "free to choose what impacts accept and what not," as expressed by an interviewee. The challenges remaining in the SDG strategy on local water, energy, and food will require a shift in the development trajectory in support of ecological integrity and local livelihood. Improving water quality will be especially challenging as several sectors contribute –land use, agriculture, water, urban development, and energy – and there is a lack of trust in the current collaborative space, the RNB Commission. Yet, Uruguay's willingness to pursue a sustainable development agenda may posit opportunities for smooth, positive changes toward WEF nexus sustainability.

# CHAPTER 5

# CONCLUSION

## 5.1 INTRODUCTION

The water, energy, and food (WEF) nexus approach has been posited as a bridge connecting the 2030 Sustainable Development Goals (SDGs) (International Council for Science, 2017; Liu et al., 2018). Although set separately, the SDGs can generate synergies and trade-offs, and adopting the WEF nexus approach may be critical to promote coordination and collaboration among the involved sectors (Gallagher et al., 2016; Stephan et al., 2018; Pahl-Wostl, 2019). Yet, the extent to which the WEF nexus research has generated actionable knowledge to support the SDGs implementation has not been assessed. In addition, the governance challenges for cross-sectoral coordination and collaboration are an emerging research area in the FEW nexus literature (Weitz et al., 2017a, 2017b). The purpose of this dissertation research was (i) to assess knowledge generated from the WEF nexus literature in support of the 2030 Sustainable Development Agenda on food (SDG 2 zero hunger), energy (SDG 7 affordable and clean energy), and water (SDG 6 clean water and sanitation), (ii) to examine the underlying systemic causes preventing effective WEF cross-sectoral governance responses and identify potential alternative intervention points for potential changes toward sustainability, (iii) to conduct a sustainability appraisal on a WEF nexus hotspot providing a new perspective on how to guide WEF systems toward sustainability by embracing sustainability principles. To achieve these research objectives, I conducted a systematic literature of eight years of scholarly work since the SDGs adoption (2015-2022) within the WEF nexus literature.

Then, employing a WEF nexus and systems thinking approach, I reframed a water quality problem to expose the root and immediate causes in a systemic problem constellation, while three qualitative data sources were triangulated. Finally, I conducted semi-structured interviews and examined the meeting minutes of a river basin commission to understand local actors' perspectives about how the activities and initiatives taking place in the basin enhance or diminish the overall sustainability. The rest of this concluding chapter draws together three parts. First, I presented a summary of the main findings and conclusions from chapters two, three, and four. Second, I synthesized the key takeaways resulting from this dissertation research. Finally, I explained the research limitations and identified areas for further research.

## 5.2 CHAPTER CONCLUSIONS

### 5.2.1 Chapter 2 Conclusions: A systematic review of knowledge advances in support of the sustainable development goals from the water-energy-food nexus literature

Given the growing attention to the water-energy-food nexus (WEF) approach since the adoption of the 2030 Sustainable Development Goals (SDGs) in 2015, this chapter aimed to assess the extent to which the WEF nexus research has generated knowledge in support of the SDGs on food (SDG 2 zero hunger), energy (SDG 7 affordable and clean energy), and water (SDG 6 clean water and sanitation). This research was undertaken to answer three sub-questions about to what extent the sustainability themes present in the WEF nexus literature aligned with the SDGs and the aims and geographical locations of FEW nexus empirical studies. To investigate these questions, I developed an operational codebook by synthesizing the SDGs on food,

energy, and water resulting in eleven SDGs 11 cross-cutting themes—accessibility, affordability, adequacy, diversification, efficiency, productivity, governance, international cooperation, target population, finance, and environmental protection. Second, I applied the codebook to the WEF nexus literature to assess the contributions.

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol (Liberati et al., 2009; Moher et al., 2009), eight years of scholarly articles were examined since the SDGs adoption (2015-2022) within the WEF nexus literature. Elsevier's SCOPUS database was used to search terms such as "food, energy, water" AND "nexus" AND "sustainable development goal" and its variants. The search was limited to English-language publications, including peer-reviewed articles, book chapters, and conference papers between 2015 through 2022. The initial search resulted in 128 publications screened to 94 documents, meeting the inclusion criteria of contributing knowledge to the SDGs. The documents were imported into MAXQDA 2022 mixed method software for analysis. Drawing from the publication classification applied by Apetrei et al. (2021), each document was classified as conceptual, empirical, and conceptual/empirical study. Countries where FEW nexus empirical studies were conducted were classified as developed countries, developing countries, or countries in transition, based on the 2022 World Economic Situation and Prospects (UN DESA, 2022).

A total of 94 peer-reviewed articles, book chapters, and conference papers aligned with the developed SDGs cross-cutting themes within the WEF nexus literature. The findings show that the WEF nexus literature explicitly considering the SDGs mainly

focuses on governance and environmental protection themes, with fewer studies focused on themes such as target populations and affordability. From the 94 peer-reviewed articles, book chapters, and conference papers focused on the SDGs within the WEF nexus literature, 45% (42 out of 94) were empirical studies, 34% (32 out of 94) were conceptual/empirical studies, and 21% (20 out of 94) were conceptual publications. Of the 94 records included for analysis, 79% (74 out of 94) of studies made an empirical contribution addressing the SDGs in specific countries. Studies included 67% (83 out of 124) developing countries, 27% (33 out of 124) developed countries, 6% (7 out of 124) countries in transition, and 1% with global scope. The top developing countries with the most empirical studies are China (14), India (10), South Africa (10), and Bangladesh (7).

The sustainability emphasis and motivation used in these publications were examined to shed light on the implications of the research trend in the WEF nexus literature to support the SDGs. On the one hand, some studies were found to interface within more than a cross-cutting theme. This finding is promising since the comprehensiveness of the intended SDG targets is considered. On the other hand, even though most of the empirical studies comply with the criteria for the target population theme based on the geographical locations, the empirical studies focused on the target population besides being in a developing country were scant. This result accords with earlier observations that the WEF nexus approach often overlooks the sustainability emphasis, for instance, on distributional justice (Leese & Meisch, 2015), gender (FAO, 2018), and livelihood (Wichelns, 2017). Overall, the lack of studies focused on vulnerable populations, children, women, the elderly, small-scale farmers, and indigenous

people is concerning. These results confirm the need to revisit the scope of research to direct more attention from the WEF nexus literature to the SDGs cross-cutting theme with less research, such as finance, adequacy, target population, affordability, and international cooperation.

### 5.2.2 Chapter 3 Conclusions: Improving governance responses by reframing the water quality problem in a water-energy-food nexus hotspot for sustainability

Even though the water-energy-food (WEF) nexus approach has notably contributed to reframing problems from siloed to interdependent among sectors to help manage synergies and trade-offs, little is known about the underlying systemic causes preventing effective cross-sectoral governance responses. In this chapter, I employed the systemic and agent-focused Transformational Problem-Solving framework – Step 2 to reframe the water quality problem in a WEF nexus hotspot in the Rio Negro Basin (RNB) in Uruguay. The RNB is a highly agricultural productive area where the main country's hydroelectric production concentrates, along with other concurrent social and economic activities. The WEF interactions created a persistent water quality problem in the basin, which is the focus of government actors' current public discussion and institutional work. Employing a WEF nexus and systems thinking approach, the water quality problem was reframed to expose the deeper drivers (e.g., motives, assumptions, capacities) and immediate causes (e.g., infrastructure, activities) in a systemic problem constellation. Three qualitative data sources were triangulated to deepen and widen the understanding of the causal effect relationship creating the water quality problem.

Using the water quality problem as an entry point, the problem reframing from a sustainability perspective demonstrates that the WEF nexus interactions generated other negative and dispersed effects on other sectors depending on water resources, such as tourism, fishing, and swimming. The causing actions are primarily performed by local actors such as the government, farmers, residents, and industries. For instance, farmers have been pointed out because fertilizer has been applied more than twice permitted under the assumption that more fertilizer will increase soil productivity and food production. The causing infrastructure in place is the three-hydropower dams operated by energy utility (UTE) that disrupt the river connectivity, affect its flood regime, increase nutrient concentration, and operations conflict with other local uses. The problem reframing also exposed insufficient consideration of benefits resulting from the same activities creating adverse effects; and root causes such as needs, assumptions, and capacities. Results also show a more significant emphasis on addressing deeper drivers focused on adopting new rules and generating knowledge about river conditions.

Reframing the water quality problem facilitated the identification of potential alternative intervention points to support local problem-solving capacity and sustainable development. Seven alternative intervention points were identified regarding benefits or positive effects, immediate causes, and root causes. There alternative interventions points are: (1) discussing the benefits relative to the impacts to create the bases for a trade-offs analysis, (2) communicating the hydropower dam operating rules to protect biodiversity and local livelihood for other users such as fishers, (3) training on how to handle fertilizers, and enforcing regulation for pollution reduction and prevention, (4)

conducting a visioning exercise to increase engagement with the integrated planning process and long-term planning, (5) the national government taking an active role to overcome institutional inertia for WEF system changes, (6) improving intervention capacity to guard water resources carrying capacity (7) integrating plans for cross-scale planning and sustainable development. This research provided empirical evidence on the analytical benefits of reframing the problem with nexus thinking and a systemic and agent-focused approach to improve governance responses and foster potential changes toward sustainability (Wiek, 2015; Pahl-Wostl, 2019; Kellner, 2023).

### 5.2.3 Chapter 4 Conclusions: Local perspectives on the Rio Negro Basin in Uruguay through a sustainability appraisal of the water-energy-food nexus

Like other agriculture-exporting regions, Uruguay faces sustainability challenges driven by growing global food and commodities demand and climate variability, generating increased pressure on local water, energy, and food (WEF) resources. The RNB case is of particular interest for sustainable outcomes because it compromises 40% of the Uruguayan territory and recently became home to the country's largest foreign investment in history (El País, 2023). The RNB is considered a WEF nexus hotspot where numerous interactions occur between the agricultural, water, and energy systems, and sustainability is a local concern due to a water quality problem (Mohtar & Daher, 2016). By embracing sustainability principles as an overarching guidance for the sustainable development of WEF systems, this study contributed to closing a governance gap remaining in the WEF nexus literature regarding the elaboration of shared principles to facilitate outcomes negotiation and reduce power imbalances across WEF nexus

institutions and actors (Weitz et al., 2017a). To achieve this, I conducted a sustainability appraisal of WEF sectoral interactions taking place in the RNB against sustainability criteria for the river basin, aiming that these are not overlooked in planning and management (George, 2001; Shah & Gibson, 2013). The sustainability criteria were operationalized through a set of qualitative appraisal questions and semi-structured interviews conducted with local actors. Data from the RNB Commission were also examined.

Overall, any of the sustainability principles show a strong enhancement toward sustainability. The results show that more activities are diminishing than enhancing overall sustainability, and the pursuit of economic sustainability dominates as the main criterion to assess trade-offs (Coffman & Umemoto, 2010; Berke & Conroy, 2000). To illustrate, sustainability principles such as political and commitment accountability and inter-system coordination and integrity show enhancement, while socio-ecological resiliency and integrity, and democratic decision-making and social learning are criteria still lagging and in need of attention. Based on the empirical evidence appraised, several sustainability criteria need to be negotiated for the overall sustainable outcomes, for instance, how basin-level decisions and regulations enforcement is consistent with national sustainable development goals. In addition, the findings on the democratic decision-making and social learning criteria show power imbalances across WEF nexus actors (Weitz et al., 2017b). For instance, according to interviewees, the RNB's cross-sectoral collaboration emerged to smooth the entrance of a Finnish forestry pulp mill as a new user of the river basin resources, and local users have been refused transparent

participation to negotiate interests and formulate the desired outcomes. Also, local fishers have been marginalized and excluded from participation in the RNB commission.

After testing the use of sustainability principles as shared criteria needed to support WEF cross-sectoral governance and decision-making (Weitz et al., 2017a), this study's findings shed light on the significant challenges in managing trade-offs stated in the Uruguay Sustainable Development Report (IDB, 2021). The empirical evidence found from the sustainability appraisal was merged with the sustainability criteria for river basin planning and management to suggest procedural changes for the RNB governance. To illustrate, supporting sustainability processes in the inter-system coordination and integrity will require: (1) revisiting the old policies (e.g., The Forestry Act of 1987) and aligning them with the present commitment to sustainable development, (2) increasing coordination for cross-sectoral collaboration, not only through co-participation in projects but at the institutional planning and implementation level, (3) ensure the basin commission meeting are open to a rich discussion about how the WEF sectors interact and honest trade-off analysis, (4) communicating how the inter-system coordination is planned and implemented to the diverse actors, and (5) considering the aspiration and expectations of all actors about participating in decision-making. In conclusion, this chapter provided a new perspective on examining WEF nexus sustainable development by employing well-established sustainability principles for river basin planning and management (Gibson, 2006; Shah & Gibson, 2013).

## 5.3 SYNTHESIS AND TAKEAWAYS

Pursuing the 2030 Sustainable Development Agenda and the WEF SGDs is one of our society's biggest aspirations. In this dissertation, I conducted three interrelated WEF nexus studies using a sustainability lens to develop new approaches and identify actionable measures to support the SDGs implementation. The overarching goal across the three chapters was to provide a new perspective on studying WEF systems aiming to generate knowledge to guide complex systems toward sustainable pathways and translate visions into action (Kates, 2011; Miller et al., 2014). In Chapter 1, I appraised the extent to which the WEF nexus research has generated actionable knowledge supporting the SDGs implementation. Taken together, these results provide strong evidence of the role of research and the contribution the WEF nexus literature can enable to the understanding of the conditions on which the SDGs could be implemented in different contexts. The findings also show that the WEF nexus literature explicitly considering the SDGs mainly focuses on governance and environmental protection themes, with fewer studies focused on themes such as target populations and affordability. However, these results further support the argument that less emphasis is put on distributional justice (Leese & Meisch, 2015), livelihood (Wichelns, 2017), and gender concerns (FAO, 2018). The overall results suggest that more research should be directed to contribute to all elements of the target statements and the SDGs cross-cutting themes with less research, such as finance, adequacy, target population, affordability, and international cooperation. Applying the proposed codebook could lead to a fundamental change in how research is conceived to

be easily transferred and become actionable for those who need the knowledge for better decision-making.

Chapters three and fourth integrated the literature of the WEF nexus approach and sustainability sciences. Research in sustainability sciences and WEF nexus recommend reframing governance challenges to investigate cross-sector, cross-scale interactions and manage trade-offs by integrating different knowledge systems (Matson et al., 2016; Pahl-Wostl, 2019). Sustainable development has an inherent regional character, where many sustainability synergies and trade-offs are operationalized (Kates, 2001; Wu, 2013). As expressed by Lele et al., 2013, "governance challenges are at the heart of the nexus in each region" (p.44). Therefore, the synergistic local social, economic, and environmental implications must be considered in context. Two interrelated FEW nexus studies were conducted in the Rio Negro Basin in Uruguay, where numerous interactions occur between the agricultural, water, and energy systems, and sustainability is a local concern due to a water quality problem. These studies illustrate the challenges of coordinating the national development agenda with local livelihood.

In chapter three, the reframing of the water quality problem with nexus thinking and a systemic and agent-focused approach demonstrates that the WEF nexus interactions generated other negative and dispersed effects with the WEF sectors and other sectors depending on water resources, such as tourism, fishing, and swimming. These findings further support the importance of adequate framing to improve governance responses and support sustainable development (Ness, 2020; Wiek, 2015; Ness et al., 2010). This study also contributes to the recent scholarly aiming to enable effective governance and

decision-making by understanding root causes and causal relationships and identifying intervention points (Arnbjerg-Nielsen et al., 2022; Kellner, 2023). Alternative intervention points were suggested to support problem-solving capacity and sustainable development. Seven alternative intervention points were identified regarding benefits, immediate causes, and root causes. The implications of intervening in these points and the potential changes toward sustainability were discussed. One suggested alternative intervention point is opening the public discussion to the benefits of the same activities creating adverse effects, enabling a trade-off identification and analysis. The FEW nexus literature constantly states trade-off analysis as a central concern. Prior research has focused on describing the biophysical nature of the trade-offs in different contexts (McCornick et al., 2008; Newell et al., 2019; Pahl-Wostl et al., 2021). Nevertheless, performing such a trade-off analysis may not be possible without a clear association of the sectoral benefits and dispersed adverse effects.

In the fourth chapter, I applied sustainability criteria for river basin planning and management as shared criteria needed to support WEF cross-sectoral governance and decision-making. Weitz et al. (2017b) stated the need for overarching guiding principles to facilitate outcomes negotiation and reduce power imbalances across WEF nexus institutions and actors. Based on the empirical evidence appraised, several sustainability criteria need to be negotiated for overall sustainable outcomes. For instance, how basin-level decisions and regulations enforcement is consistent with national sustainable development goals. Furthermore, the findings on the democratic decision-making and social learning criteria show power imbalances across WEF nexus actors as they may

have unequal participation in the decision-making (Weitz et al., 2017b). The functioning of the RNB commission illustrates the institutional capacities and the conditions for WEF cross-sectoral coordination and collaboration (Lele et al., 2013; Opejin et al., 2020; Weitz et al., 2017a). For instance, related to how administrative resources are allocated and responsibilities assigned to foster multi-sectoral collaboration. How the cross-sectoral collaboration emerged in the case of the Rio Negro, and the scattered local perspectives about potential honesty to formulate and negotiate interests show the lack of trust and common ground hindering democratic decision-making—which has been found critical for collaborative governance by WEF actors in another context (Jones & White, 2022).

## 5.4 RESEARCH LIMITATIONS

This dissertation reader should bear in mind that the studies presented here are subject to particular research limitations. In the second chapter, the systematic findings of the systematic literature reviews must be considered based on specific research limitations. Like many research databases, SCOPUS does not perform a full-text search through the database search engine. This study's literature explicitly mentioning the sustainable development goals within the WEF nexus is limited to those using the term “sustainable development goal” in the title, abstract, or keywords fields. There may be additional literature addressing the sustainable development goal within the WEF nexus, but these publications, as they do not include the term in the title, abstract, or keywords, were excluded. The potential existence of additional research focused on sustainable development goals is the main limitation to generalizing the results. Within the literature sample of 128 documents included for screening, only 98 documents included the term

“sustainable development goal” in the abstract, and 33 documents included the term in the keywords. These findings underline the need for best practices when selecting keywords and drafting an abstract to make the work more relevant and accessible through research databases’ search engines (Pahlevan Sharif et al., 2019).

In the third chapter, the interpretation of the results must be examined, considering that the causality this study aimed for is not based on conditional probability but using qualitative linguistic connectors. Using qualitative linguistic connectors, this study intended to reframe the problem grounded on empirical data that communicate what is causing the water quality problem as described in the local context. A limitation of this study is the absence of previous studies using the methodological approach employed here. To my knowledge, no study has used linguistic connectors to approach document analysis aiming to find causal-effect relationships. This study cannot provide an exhaustive explanation of how autocoded linguistic connectors facilitate the analysis, especially in Spanish, as this research does not engage with quantitative analysis of the coded segments. This study could be a foundation for future research to validate linguistic connectors' use to facilitate causal qualitative analysis. Furthermore, the potential alternative intervention points suggested should be considered in the limitation that this study did not evaluate or estimate the human and economic resources required for implementation.

In the fourth chapter, the empirical results of this study should be considered in light of several limitations. First, even when this study reached the data sample for case studies through six semi-structured interviews (Hernández Sampieri et al., 2014), a higher

number of interviews could include the perspective of other actors involved in the ongoing dialogues about the Rio Negro Basin; however, a complete representation of all actors' perspectives lies beyond the scope of this study. Second, there is a methodological and time constraint limitation since an intercoder reliability assessment, or inter-appraisal, was not conducted through the data analysis. Although this does not limit the contribution the first author made serving as an external appraiser to basin development against sustainability criteria, involving other appraisers could enhance the results, especially if these are local actors with diverse backgrounds and specializations (Thérivel & Minas, 2002; George, 2001).

Finally, this research does not engage in an exhaustive cross-scale analysis of public documents, except for the national documents referenced in this study. All reports or plans at the national level focused on sustainable development that may impact the river basin were not examined.

## 5.5 FUTURE RESEARCH

There are several future research opportunities that emerge from this dissertation research. In the second chapter, the results of the systematic literature reviews show the need for WEF nexus studies in support of all elements of the SDGs target statements. For instance, even though most of the empirical studies comply with the criteria for the target population theme based on the geographical locations, the empirical studies focused on the target population besides being in a developing country were scant. In general, the lack of studies focused on vulnerable populations, children, women, the elderly, small-scale farmers, and indigenous people is concerning. Further data collection could be

extended to non-English publications to examine the contributions of the WEF nexus literature on other languages. In addition, further studies investigating the finance and affordability cross-cutting theme could experiment with using ProQuest's ABI/INFORM Collection, a business and trade database with English-language publications worldwide. As mentioned, some studies were found to interface within more than a cross-cutting theme. This finding is promising since the comprehensiveness of the intended SDG targets is considered. Now that the potential of using this operational codebook to assess the contribution towards the SDGs has been tested, this codebook could be repeated with other SDGs to assess future research trends and help address concerning gaps, such as the lack of research attention given to vulnerable groups and distributional justice.

In the third chapter, an alternative intervention point for change towards sustainability is that the Energy Utility communicates the hydropower dam operating rules, protecting biodiversity and local livelihood for other users, such as fishers and bathers. The dam operation conflicts with other local uses. A possible explanation for the lack of co-management could be related to sectoral power asymmetry. Further studies could be undertaken to examine any power imbalances across sectors making actors perceive the possibility of WEF nexus collaboration differently (Jones & White, 2022). In addition, integrating sectoral plans and actions may also be essential for a potential change toward sustainable development. The path for such integration is not clear or easy. Scale and sector mismatches have been identified as the main barriers to collaborative FEW nexus governance (Jones & White, 2022; Pahl-Wostl et al., 2021). Further studies could follow the suggestion of different scholars of using an ecosystem

health and services perspective (Heal et al., 2021; Arnbjerg-Nielsen et al., 2022). Finally, conducting a visioning exercise was suggested to increase engagement with the integrated planning process and long-term commitment. Further research could be conducted using the same TPS framework to create a sustainability solution vision. (Wiek, 2015).

In the fourth chapter, the case of the RNB has a nuance showing that further studies could be carried out with a social and environmental justice lens due to power imbalances across WEF stakeholders and unequal participation in decision-making. Furthermore, future research could be conducted to examine the extent to which Corporate Social Responsibility has been instrumentalized to avoid and contain conflicts in the context of a developing country (Estudios Rurales Tacuarembó, 2020).

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