



Evaluation of the influence of public policies on the water, food and energy Nexus in the Guandu hydrographic region – Rio de Janeiro – Brazil

Avaliação da influência de políticas públicas no Nexo água, alimento e energia na região hidrográfica Guandu – Rio de Janeiro – Brasil

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ABSTRACT: The Nexus approach focuses on the integrated assessment of development and management options aimed at water, energy and food (WEF) security. This article presents a methodological strategy for assessing the influence of public policies (PP) on WEF security, which was implemented in the Guandu hydrographic region (RH-II), emphasizing the municipality of Rio Claro, RJ. The methodological strategy has four stages: PP survey and systematization at different levels in a database, identification of criteria and classification of PP, selection of structuring and integrating PP, and assessment of PP. In the case of RH-II, about 43% of PP meet more than one security area. Five PP were selected as structuring and integrative and evaluated in relation to their potential impact on the WEF security in the study area. The study area was very promising for applying the Nexus approach to assess the potential impact of PP on WEF security, as it has a high percentage of forest remnants and a high demand for water and energy. These factors make WEF security a target for PP forest, soil and water restoration and conservation, and compensation mechanisms. This methodological strategy can be used in other regions or river basins of the country, to support the integrated management of WEF security.

Keywords: criteria; classification; integration; sustainability; selection.

RESUMO: A abordagem Nexus foca na avaliação integrada das opções de desenvolvimento e gestão visando às seguranças hídrica, alimentar e energética (SHAE). Este artigo visa apresentar uma estratégia metodológica para avaliação da influência de políticas públicas (PP) nas SHAE, sendo aplicada na região hidrográfica Guandu (RH-II), com ênfase no município de Rio Claro, RJ. A estratégia metodológica é composta de

quatro etapas: levantamento e sistematização de PP nos diferentes níveis em base de dados, identificação de critérios e classificação das PP, seleção das PP estruturantes e integradoras e a avaliação das mesmas. Para o caso da RH-II, cerca de 43% das PP atendem a mais de uma segurança. Cinco PP foram selecionadas como estruturantes e integradoras e avaliadas em relação ao potencial impacto nas SHAE da área de estudo. A área de estudo foi bastante promissora para a aplicação da abordagem Nexus para avaliação do potencial impacto das PP nas SHAE, pois possui um elevado percentual de remanescentes florestais e elevada demanda por água e energia. Esses fatores a tornam alvo de PP de restauração e conservação florestal, do solo e da água e de mecanismos de compensação. A presente estratégia metodológica pode ser aplicada em outras regiões ou bacias hidrográficas do país, visando subsidiar a gestão integrada das SHAE nas mesmas.

Palavras-chave: critérios; classificação; integração; sustentabilidade; seleção.

1. Introduction

Changes in land use and cover, and population growth impact ecosystems' capacity to provide goods and services to humankind, and influence the production and stability of water, food and energy supply in a specific territory. According to The Organization for Economic Cooperation and Development and the Food and Agriculture Organization (OECD/FAO, 2012), global demand for water, energy and food will grow by 50%, 80% and 60%, respectively, between 2000 and 2050. The scientific-instrumental approach of the Nexus (water- energy-food) was launched at the World Economic Forum (WEF, 2011), aiming at the integrated assessment of different development and management options for the promotion of water, energy and food (WEF) security.

Cook & Bakker (2012) identified in the literature five dimensions that support water security definition and are its own purpose: quantity and availability, risks related to vulnerability and water, meeting human needs, sustainability, and water in military and environmental security. Food security is defined as “a scenario in which all people have physical, social, and economic access to enough, safe, and nutritious food that meets their dietary

needs and food choices for an active and healthy life at all times” (Peng & Berry, 2019). Literature does not meet a consensus on the concept of energy security, but the definitions are based on some common principles: accessibility, efficiency, environmental sustainability, social acceptability (Sovacool & Brown, 2010, Narula & Reddy, 2016, Mara *et al.*, 2022).

Gevelt (2020) states that while there is improved technical understanding of the dynamics of the water-energy-food nexus, this knowledge has not been successfully applied to develop effective and actionable policies. To effectively implement this approach as a tool for territorial management and development, it is essential to take into account the existing political instruments at various levels – national, regional, and local. Such instruments can encourage and ensure changes in an integrated manner with positive impacts on water, energy, and food (WEF) security.

Several studies from various countries have utilized this approach and have demonstrated potential and desirable strategies for integrating policies and actions aimed at managing water-energy-food resources (Bizikova *et al.*, 2013; Rasul, 2014; Mariani *et al.*, 2016; Metzger *et al.*, 2016; Al-Saidi & Elagib, 2017; Ferraco & Moraes, 2018; Shannak *et*

al., 2018; Ferreira, 2020; Durand-Lasserve *et al.*, 2020; Naranjo & Willaarts, 2020). Understanding the interaction of WEF security and addressing them in an integrated way is still a major challenge.

According to Lenzi (2018), public policy (PP) consists of measures and programs implemented by the State in order to ensure and implement the rights set out in the Federal Constitution and in other legal documents. The security PP has been implemented to ensure the autonomy, development and protection of a nation. Accordingly, it is necessary to contemplate WEF security in this context. Brazil is presented with major challenges related to the integration of PP focused on social and environmental issues.

Some public policy studies in Brazil focus on WEF security, but only a few adopt the Nexus approach (Vieira & Dalgaard, 2013; Mariani *et al.*, 2016; Ferração & Moraes, 2018; Mercure *et al.*, 2019). Analyzing the Nexus approach for the integrated management of water resources, Ferração & Moraes (2018) concluded that, legally, the main challenges lie in the State's ability to carry out management that integrates both federal and state competencies, in accordance with the water resources management policy. Dialogue between federal and state agents is not always consistent or obvious, but it should be acknowledged by these agents as essential. Mariani *et al.* (2016) conducted an analysis of opportunities and challenges related to the water-energy nexus. They emphasized the importance of finding solutions that go beyond conventional and sustainable approaches. They highlighted the need for the involvement of society as a whole, as well as public authorities, to ensure the availability of water, energy, and food for future generations.

The framework of political and legal instruments related to WEF security is extensive, thus necessitating the adoption of criteria to identify the ones that will have the most significant impact on the area under investigation. The purpose of this evaluation is to advise decision makers on whether to maintain, alter or terminate the program (Ramos & Schabbach, 2012). Costa & Castanhar (2003) explain that the assessment of public policies involves a methodical and objective evaluation of an already carried out or an ongoing program or project, focusing on its performance, execution, and results, in order to assess its effectiveness, efficiency, impact, sustainability, and appropriateness of its objectives. According to Grisa & Schneider (2015), public policies created for rural areas in Brazil have been ineffective because they lack an integrated approach to rural development. When assessing the sustainability of public policies in rural areas, a WEF security interconnection and interdependence approach may be a step ahead of the sectoral approach.

The Nexus project, undertaken in the state of Rio de Janeiro, was designed to evaluate the effect of rural conservation on WEF security near Ribeirão das Lajes reservoir in the Guandu Hydrographic Region (RH-II). This project aims to expand our knowledge of methods to measure the potential influence of PP on WEF security through the Nexus approach. Hence, a methodological strategy is proposed for classifying and selecting public policies (PP) which could have an effect on WEF security, which is then verified through a case study in RH-II, focusing particularly on the municipality of Rio Claro, RJ, an area directly impacted by the Ribeirão das Lajes reservoir.

2. Methodological strategy

2.1 Case study area

The chosen study area was the Guandu Hydrographic Region (RH-II), which is composed of the rivers Guandu, Guarda and Guandu-Mirim and is situated in the west of the Guanabara Bay basin in Rio de Janeiro state. It includes 15 municipalities: Seropédica, Itaguaí, Paracambi, Japeri, Queimados, Miguel Pereira, Vassouras, Piraí, Rio Claro, Engenheiro Paulo de Frontin, Nova Iguaçu, Rio de Janeiro, Mendes, Mangaratiba and Barra do Piraí. Its physiography is composed of two distinctive divisions: the Serrano Domain, which is made up of mountains and the Serra do Mar oceanic slope cliffs, ranging from 200 m to 800 m in height, and the Baixada Domain, consisting of a vast fluvial-marine plain, the Baixada de Sepetiba. Primary vegetation of the area is composed of dense rainforest and mangroves, remnants of the Atlantic Forest biome. The climate of the region is hot and humid, with average annual temperatures ranging from 20°C to 27°C, and annual precipitation from 1,000 mm to 2,300 mm, with variations depending on differences due to the altitude (AGEVAP, 2018).

The Lajes hydroelectric complex, a complex consisting of seven components - three power plants, two pumping plants, and six water reservoirs - is a major feature of this region's hydraulic infrastructure. The Santa Cecília and Vigário pumping plants transfer around 155 m³.s⁻¹ of water from the Paraíba do Sul and Piraí rivers toward the Guandu river basin (1,400 km²). RH-II comprises an area of 3,815.6 km² of the Southeast Atlantic Hydrographic

Region in the Atlantic Forest biome, which is approximately 1.7% of the Brazilian territory (AGEVAP, 2018). Figure 1 illustrates the hydraulic context and location of RH-II municipalities.

The area upstream of the Lajes reservoir is considered one of direct influence, with the municipality of Rio Claro being predominant, and whose effluent and sediment discharges affect the reservoir's water availability. The other municipalities exert indirect influence, due to demands for water or energy (Figure 1).

In the Rio Claro (RJ) area, the fragmented forest is situated on the opposite side of the Serra do Mar cliffs, near the headwaters of the Piraí River's contributing basins and in the area of hills and slopes surrounding the Ribeirão das Lajes dam (INEA, 2014). The region's forest cover is highly fragmented, mainly in the lower and flatter areas, and places of undisturbed, better-protected forests are situated on the inclines and peaks (TNC, 2013).

According to land cover mapping (Mapbiomas, 2019) the municipality's area was composed of 51% natural forests and 36% pasture areas in 2018. Data from the agricultural census (IBGE, 2017) show that the 662 rural establishments covered around 54,000 ha in 2016, of which the majority consisted of natural and cultivated pastures (52%) and native forests (44%).

The main environmental problems in RH-II can be attributed to agricultural practices, particularly to the use of fire in agricultural or pasture management, as well as to soil loss and rivers silting (INEA, 2015). The sanitation concern is a major environmental problem in Rio Claro (RJ), according to Xavier *et al.* (2023).

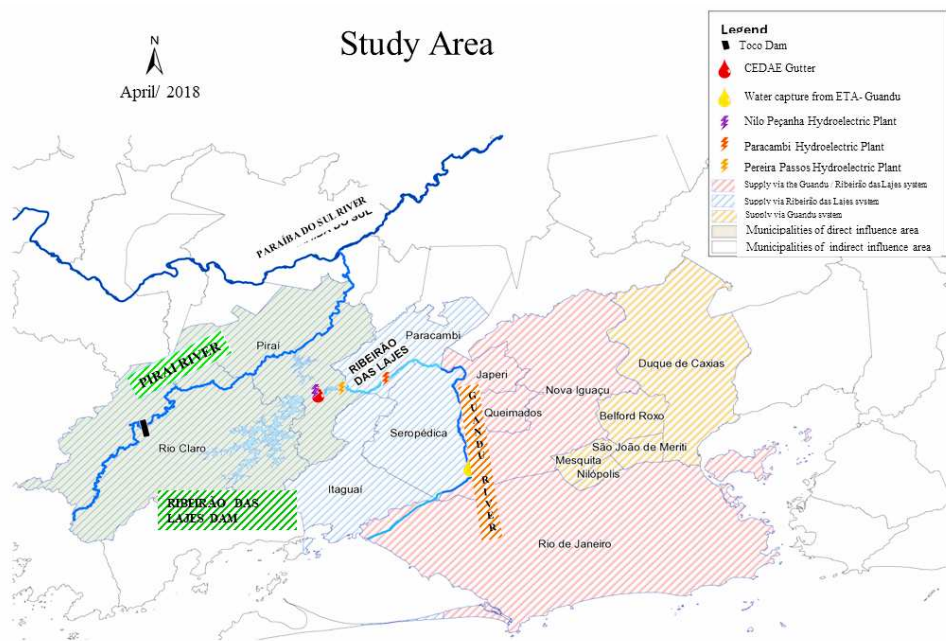


FIGURE 1 – Illustration of the study area.
 SOURCE: map prepared by the Nexus Project, 2018.

2.2 Development and use of the methodology in RH-II for evaluating public policies (PP) considering the Nexus approach

The first step of the study was to formulate a method, utilizing the available literature, which could facilitate the assessment of the potential impact of PP on WEF security. This method could use the Nexus approach, since the number of PP related to WEF security that exert influence in a territory in Brazil is substantial, when looking at the federal, state and municipal levels. The method developed is illustrated in Figure 2, and will be described in more depth below, with the database from the area of Guandu Hydrographic Region in Rio de Janeiro (RH-II).

2.2.1. Survey and systematization of public policies (PP) related to WEF security in RH-II

A comprehensive survey was carried out on national, state (Rio de Janeiro) and municipal public policy instruments (focusing on the municipality of Rio Claro, RJ, where the Lajes reservoir is located).

The following were considered as PP instruments: laws, bills, decrees, programs, resolutions, ordinances and other legal instruments with the potential to impact the WEF security.

The searches were carried out on platforms and websites of the federal and state governments, the municipality of Rio Claro, RJ and the basin under study (RH-II). Websites of non-governmental institutions (NGOs) and research centers working in RH-II were also consulted.

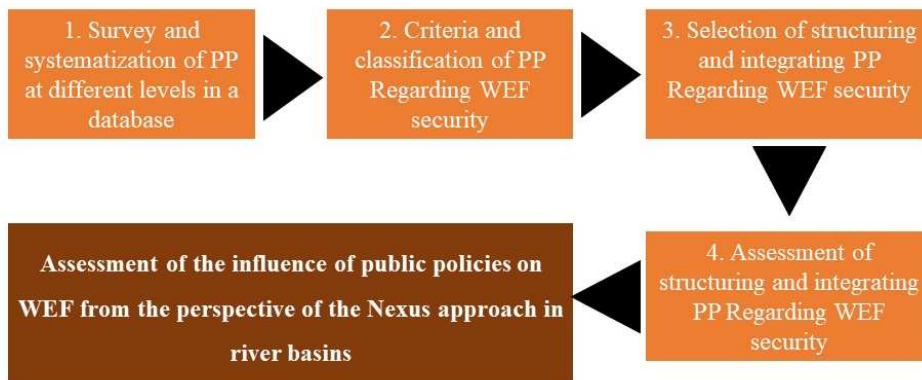


FIGURE 2 – Steps of the methodological strategy for evaluating the potential impact of Public Policies (PP) on water, energy and food (WEF) security, using the Nexus approach.

SOURCE: the author (2022).

For searches carried out on Google, the following terms were used: water security, food security, energy security, energy, food, hunger, water, preservation, sustainability, natural capital, ecosystem or environmental services, water resources, springs, rivers, seas, lakes, nutrition, malnutrition, agriculture, livestock, farming, bioenergy, biofuel, electricity, biome, Atlantic Forest, RJ, Rio de Janeiro and the names of the municipalities that make up the study area.

The research extended across 2018 and 2019. All PP locations were individually assessed with respect to their importance for the WEF security of the study region. In addition to policies concerning water security, which involve forest protection or conservation, and directly affect the amount and quality of water in river basins were also examined. Policies that relate to granting or tax collection for water use, payments for ecosystem services (PES), climate change were also considered as to WEF security. Next, the information was compiled into an Excel spreadsheet database.

2.2.2. Criteria for classifying PP related to WEF security in RH-II

At this stage, certain criteria were determined for classifying the PP linked to WEF security, with each criterion having a score allotted to it (Table 1).

The chosen criteria take into account aspects that promote increased participation and social benefit from policies, as well as factors concerning sustainability. Table 1 displays the key characteristics of the Nexus approach (WEF, 2011).

At the Nexus Project workshop (April 16 to 19, 2019) at Embrapa Solos in Rio de Janeiro, the authors presented the criteria to the participants, who then validated them with experts. The workshop participants were subsequently asked to assess the legitimacy of each of the criteria previously selected (Table 1). The purpose of this step was to validate the experts' assessment of whether the criteria used to categorize public policies (Table 1) were effective in measuring the WEF security of the Guandu hydrographic region – Rio de Janeiro. Experts approved the criteria by consensus. In addition to the three authors of this article, 27 workshop

TABLE 1 – Criteria and scores assigned to classify public policies related to WEF security.

Criteria	Code	Score
Is in force	C1	1
Considers income aggregation/economic compensation	C2	1
Contains terms related to sustainability	C3	1
Includes participatory processes	C4	1
Contributes to the provision of ecosystem services	C5	1
Actions to raise awareness and train the population	C6	1
*Considers one security	C7	1
*Considers two securities	C8	2
*Considers three securities (WEF security)	C9	3

SOURCE: the authors.

* These scores are not cumulative.

participants were also present. Seventeen were specialists with greater expertise in food and water security (16 researchers from Embrapa Soils and 1 researcher from EPAMIG - Minas Gerais Agricultural Research Company), 3 participants from The Nature Conservancy (TNC), the NGO responsible for the Payment for Ecosystem Services project in the study area, and 9 from the academia (5 from the Rural University of Rio de Janeiro (UFRRJ), specialists in energy security, with academic projects in the study area; 3 from Fluminense Federal University (UFF), with expertise in water security; and 1 from São Paulo University (USP-São Carlos), specialist in Public Policies).

PP classification at all levels (national, state and municipal) was done based on the total score achieved for the various criteria, grouped into 5 classes, namely: PP not in force regardless of the score obtained; PP in force, structuring with total scores equal to or <5 ; PP in force, structuring with total scores >5 ; PP in force, complementary with a sum of scores equal to or <5 and PP in force, complementary with a sum of scores >5 .

Structuring PP were the most influential in determining the WEF security for the study area. Structuring PP sets forth guidelines at the strategic level, disregarding programs, plans, or projects since they are linked to intermediate or operational guidelines (Secchi, 2013; Raeder, 2014). Complementary PP were precisely those containing intermediate or operational guidelines.

Following this, this classification method was utilized on the RH-II PP, allowing the PP to be classified according to their potential effect on WEF security in the study area.

2.2.3. Selection of PP in relation to their relevance to WEF security

Structuring PP with a total score >5 were selected for a more comprehensive assessment. These PP were considered the most integrative regarding WEF security for RH-II. In this selection, when there were PP at both the national and state/municipal level with the same approach, the more local

PP (state or municipal) was chosen, since it seems to have a greater influence on the WEF security of the study area. The Payment for Ecosystem Services (PES) project – Water and Forestry Producer (WFP), established by Municipal Law n° 514/2010, though not being structuring, received a score >5 and had a direct influence in the WEF security of the study area. It was included in the class of structuring PP with a total of scores >5.

2.2.4. Assessment of structuring and integrating public policies with greater relevance for WEF security in RH-II

According to Carvalho (2003) and Costa & Castanhar (2003), public policy evaluation may be conducted in three ways: assessing goals, assessing processes and assessing impacts. This study focused on assessing the potential impact of PP identified and classified in the WEF security for the study area. Initially, the criteria that led to their highest score in relation to the WEF security were assessed in the selected PP and, subsequently, the analysts of the PP influence (potential impacts) on the WEF security in the study area.

3. Results and discussion

3.1. Survey and systematization of public policies (PP) related to WEF security in RH-II

The total number of PP identified at different levels (federal, state and municipal) related to WEF

security, with potential impacts on RH-II was 87. PP regarding WEF security were effective from 1934 to 2017, though some of them are no longer applicable.

The level of policies most commonly encountered was the national one (71 PP – 82%), then the state level (14 PP – 16%), and the municipal level (2 PP – 2%) had the lowest percentage. This result shows the amount of PP related to WEF security concentrated at the national level. Affonso (2000) has identified challenges related to decentralizing PP to states and municipalities, namely: inadequate instruction to take on new responsibilities; excess or insufficient control and monitoring of decentralized social policies; inconsistency between the increase in the command power of subnational governments over public spending.

Regarding the type of security that the identified PP can influence, it was found that the majority of them meet water security (20 - 23%) and energy security (20 - 23%), followed by food security (9 - 10%), with the remainder being considered as meeting more than one of the WEF securities analyzed. Of the total PP identified at all levels, 15 (17%) cover water and energy security, 4 (6%) cover water and food security and 18 (21%) cover the three types of security (Figure 3).

Consequently, 43% of policies comply with more than one pillar of the Nexus approach, although they do not totally integrate WEF security, mostly in a sector-specific way (Figure 3). The necessity for greater integration between energy and water security policies in the study area has been a driving factor, particularly as hydroelectric energy production is dependent on managing the water reservoirs in the region.

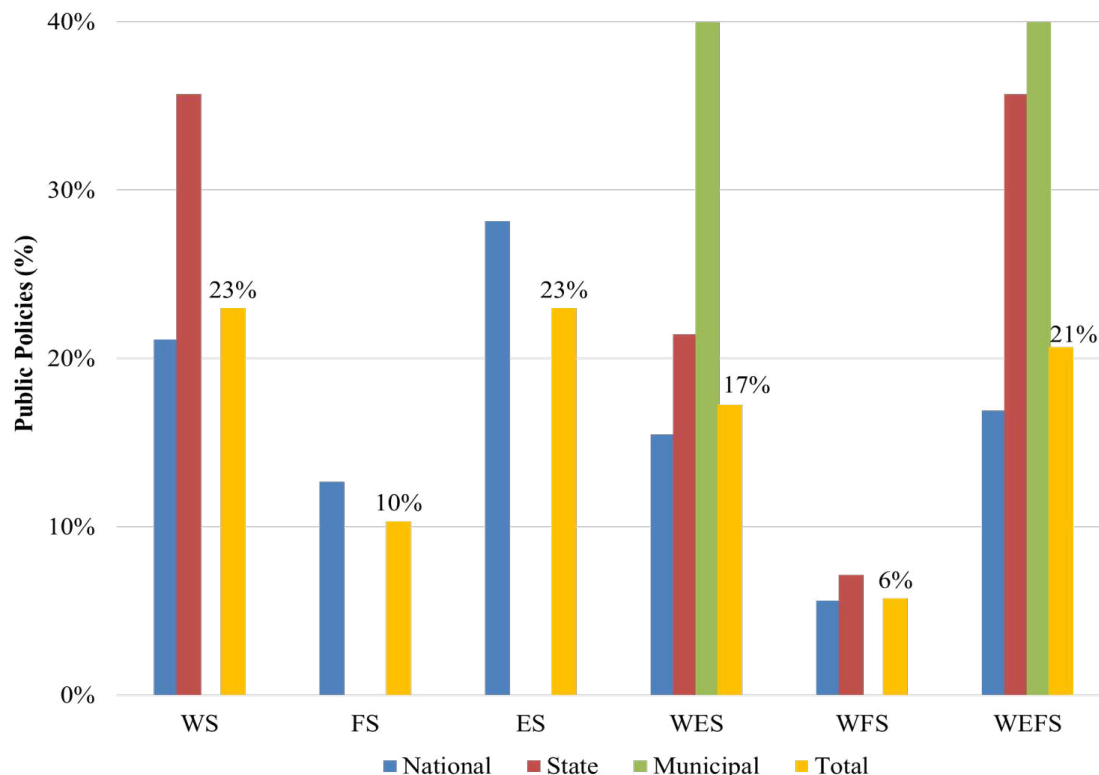


FIGURE 3 – WEF security type (WS – water security; FS – food security; ES - energy security; WES – water and energy security; WFS – water and food security, and WEF – water, energy and food security) the policies account for by level of action.

SOURCE: the authors (2022).

Wichelns (2017) argues that considering the failure to implement Integrated Natural Resource Management (INRM), another effort towards integration must be questioned as the Nexus approach. There are successful experiences in some parts of the world applying the Nexus approach (Machell *et al.*, 2015), whose solutions can be adapted and used in the present area of study.

It's worth noting that of the 20 PP related to water security, 36% are at a state level (Figure 3). This result is relevant because the study area is strategic for the public water supply in the metropolitan region of Rio de Janeiro. RH-II has the Committee for the Hydrographic Basins of the Guandu, Guarda

and Guandu-Mirim rivers (Guandu-RJ Committee) and the Association for Water Management of the Paraíba do Sul River Basin (AGEVAP) that are very structured and are among the most active in the state of Rio de Janeiro. Several instruments of the National Water Resources Policy – Law nº 9,433/1997 (Brasil, 1997) were implemented in this region.

Ferreira (2020) underlines that water security and its association with the supply of water resources are fundamental to the Nexus approach and shape the majority of relationships between the three sectors (water-food-energy), even though the paradigm of the Nexus approach imposes efforts

to ensure that assessments have a balanced and intersectoral perspective.

All PP related exclusively to energy security are at national level (Figure 3). On the whole, gathering knowledge about these PP was quite challenging, particularly at the state and local level. Energy security is of utmost importance in this area because of the presence of the Lajes hydroelectric complex. Light, which operates this system, currently has the largest land property in the state of Rio de Janeiro, and supplies 72% of the energy consumed by the state.

Policies related to food security are few 9 (10%). These policies are at national level or associated with water and energy security at state and municipal level (Figure 3). RH-II is highly urbanized, with 97.6% of its population living in urban areas, and agricultural activity is not very

significant, with livestock farming being more relevant (INEA, 2014).

3.2. Public policies classified in relation to WEF security in RH-II

Scores were calculated for the public policy proposals based on the applied criteria (Table 1). The highest-scoring PP were those that met the greatest number of established criteria. Consequently, they are more tightly connected to WEF security and are seen as structuring and integrative in this study. Out of the 87 PP raised, 9 are not in force; 25 are in force, structuring PP with a total of score = or <5; 5 are in force, structuring PP with a score >5; 41 are in force, complementary PP and with a score = or <5, and 7 are in force, complementary PP and with scores >5 (Figure 4).

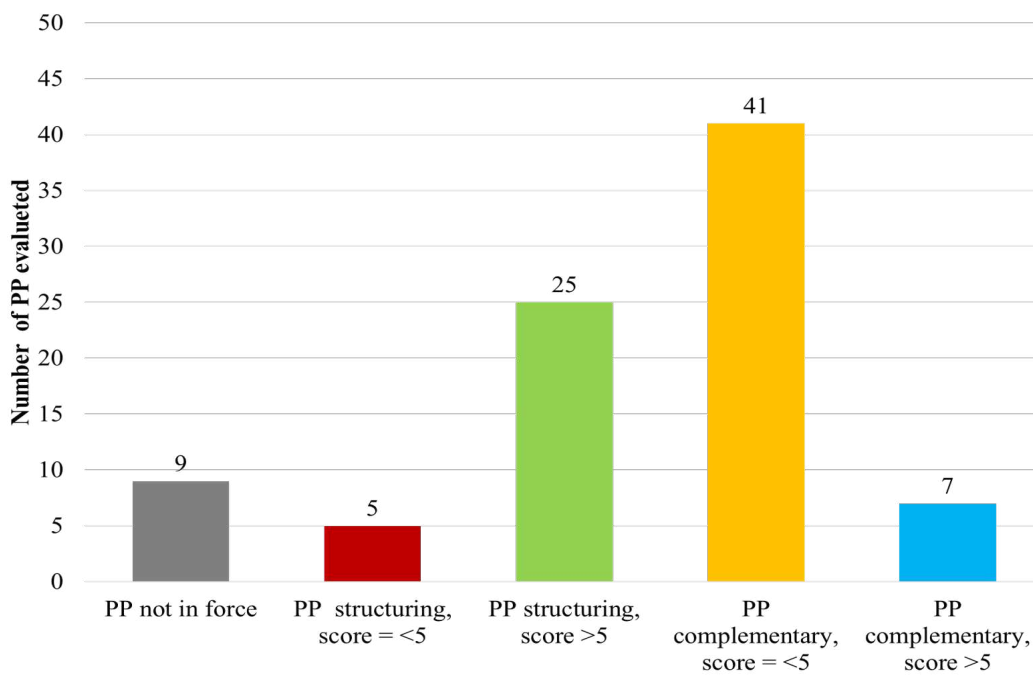


FIGURE 4 – Number of public policies (PP) by class

SOURCE: the authors (2022).

Among the PP in force (78 PP), 41% received scores greater than 5, and 59% received scores lower than or equal to 5. Approximately 50% of policies in force were classified as complementary (Figure 4).

3.3. Public policies selected and evaluated for RH-II

Considering the structuring and integrating PP, those that received the highest scores (score >5) were selected for assessment, according to the criteria adopted in the PP classification stage (Table 1), which are expected to have the greatest impact in WEF security in the study area. The five selected PPs were fully evaluated, identifying the aspects that met the criteria adopted in their classification, in relation to their relevance or potential impact on WEF security. Criterion C1 was not considered because all PP selected for evaluation were in force. Criteria C7, C8 and C9 (Table 1) were all disregarded since the selected PP fulfilled WEF security. Table 2 shows the aspects of the five structuring and integrative PP, in terms of compliance with the WEF security related classification criteria adopted.

Income aggregation and financial compensation (C1) are aspects that help recognize the value of environmental benefits, often disregarded in the conventional market (positive externalities) and which, in turn, benefit WEF security and are present in the selected PP. As to sustainability (C2), the mechanisms and instruments that value conservation, adaptation to climate change and the permanence of environmental goods and services inherent to WEF security stand out in the PP content. Durand-Lasserve *et al.* (2020) emphasize the importance of the Nexus approach so that energy,

water and food production is more sustainable and resilient.

The aspects related to participation and institutional articulation (C3) are related to the structuring of governance mechanisms for the implementation of PP. Examples such as the creation of councils involve government, civil, business and academic actors, and representatives of the national, state, and municipal levels, such as the State Water Resources Council (CERHI).

Ecosystem services (C4), understood as the benefits that ecosystems provide to humans (MEA, 2005), were considered an important issue in this study for the promotion of WEF security. Bekchanov *et al.* (2015) mention that ecosystem services should gain greater importance in debates on the water-energy –food nexus, due to their social benefits, such as supporting economic activities and providing better means of subsistence in rural areas.

The awareness raising and training of the population (C5) provided for in the PP refer to the involvement of beneficiaries, and promote awareness raising and the adoption of soil and water conservation practices that are fundamental for the advancement of WEF safety. Awareness can occur directly, through awareness-raising programs as provided for in the State Policy on Global Climate Change and Sustainable Development and Water and Forest Producers. In addition, awareness can occur indirectly, by encouraging the creation of social infrastructure, as provided for in the Forest Code, or by preparing a register of Payment for Ecosystem Services experiences, as provided for in PROHIDRO/PRO-PSA (Table 2). Durand-Lasserve *et al.* (2020) report that many policies resulted in low acceptance and, therefore, it is imperative that local governments and communities get involved for the Nexus approach to be successful.

TABLE 2 – Aspects of the five structuring and integrating PP in relation to the classification criteria for potential impacts on WEF security in RH-II.

PP selected	Compliance with classification criteria				
	C1 – Income aggregation/ economic compensation	C2 – Sustainability	C3 – Participation	C4 – Ecosystem services	C5 – Awareness and empowerment
Native Vegetation Protection Law (Forest Code) (Brasil, 2012)	Provides for the creation and mobilization of economic incentives to encourage preservation and restoration of native vegetation	Provides mechanisms and instruments for the protection and sustainable use of native vegetation in priority areas	Provides collaboration with civil society to create policies for the preservation and restoration of native vegetation	Mentions carbon sequestration, scenic beauty, biodiversity conservation, conservation of water services. Aims to ensure the provision of ecosystem functions, including the maintenance of biodiversity	Provides for the implementation of public infrastructure for sports, leisure and educational and cultural activities
State policy on global climate change and sustainable development (Governo do Estado do Rio de Janeiro, 2010)	Aims to finance reforestation, restoration and preservation projects in natural areas of the Atlantic Forest biome.	Envisages preserving, conserving and recovering environmental resources, considering the protection of biodiversity	Encourages the participation of municipal governments, as well as of the organized civil society	Provides practices and initiatives that may receive incentives	Provides for the development of awareness-raising, and mobilization programs, and disseminating information and training
State Program for Conservation and Revitalization of Water Resources - PROHIDRO and PROPSA (Governo do Estado do Rio de Janeiro, 2011)	Provides for Payment for Ecosystem Services (PRO-PSA)	Aims to promote the integrity and environmental conservation of river basins	Provides or the regulation of PRO-PSA are under the responsibility of State Water Council	Provides practices and initiatives that may receive incentives	Provides for the preparation of the state registry of Payment for Ecosystem Services
Tax on Circulation of Goods and Services – (ICMS-E) (Governo do Estado do Rio de Janeiro, 2007)	Provides for transfers of ICMS resources to municipalities	Provides that the percentage to be distributed to municipalities is based on the environmental conservation criteria	Provides that each municipality must organize its own Environmental System	Aims to distribute resources for environmental conservation	Provides that the State, through the State Secretariat for the Environment, will establish a support program for municipalities.
Water and forest producer project – PAF (Rio Claro, RJ, 2010)	Provides for Payment for Ecosystem Services	Aims to encourage the adoption of conservation practices, to increase vegetation cover and to implement sanitation on rural properties	Provides for making agreements with government entities and civil society for technical and financial support	Aims to improve the quality and quantity of water and the conservation of biodiversity	Provides that payment for ecosystem services promotes environmental awareness among rural landowners

SOURCE: the authors.

3.3.1. *Forest Code (National) – Law nº 12,651/2012*

Despite being a law of national scale, the Forest Code (Brasil, 2012) primarily serves a local purpose, as it establishes the rules of how native vegetation and agricultural and forestry activities can harmoniously interact on rural properties. This law has an immediate effect on the management of rural land use, which is closely connected to the WEF security of a given territory. The Forest Code provides for the creation and mobilization of economic incentives and compensation, such as Payment for Ecosystem Services (PES), to promote the preservation and recovery of native vegetation on rural properties.

Mendes *et al.* (2019) state that the main benefits of Legal Reserve areas (LR), besides the economic and human health benefits, are for water, energy, food and climate security. Their principal aim is to keep biodiversity in agricultural areas, like crop pollination or natural pest control.

According to Salamene *et al.* (2011), native vegetation in the permanent preservation areas (APP) of the Guandu River represents around 13% of the total 934.4 ha of APP areas. The authors stress that these fragments are imperative for sustaining the water quality of the Guandu basin, since the forest fragments are limited in terms of their surface area.

There are still many gaps in the implementation of the Brazilian Forest Code, however, its importance for WEF security must be recognized. Melo *et al.* (2021) emphasize in their study that the restoration of forests and landscapes is a promising strategy to improve WEF security. They argue that “forest security” should be a fourth basic dimension

of a new nexus structure of water, energy, food and forest security. The key principles of this new framework support an integrated role of forests in sustainable development and in the involvement of local communities in nature-related solutions. In the municipality of Rio Claro, around 35% of the total area of rural establishments is occupied by APP and/or LR (IBGE, 2017), thus the application of the Forest Code has a major role in environmental adaptation at the municipal level, with potential impact on WEF security.

3.3.2. *State policy on global climate change and sustainable development (state) – Law nº 5,690/2010*

The state policy for global climate change and sustainable development (Governo do Estado do Rio de Janeiro, 2010) seeks to bring Rio Janeiro's development model in line with a low-carbon economy and sustainable development, and to suggest the implementation of measures dealing with mitigation, adaptation and resilience to combat the effects of climate events. Vieira & Dalgaard (2013) consider the importance of applying the Nexus approach (WEF security) in the climate change context. Turetta *et al.* (2022) proposed a methodological framework to assess the impact of conservation practices on WEF security. Forest conservation and restoration, in addition to the potential for carbon sequestration and storage in biomass and in the soil contribute to reducing floods (FAO, 2005), and have a great potential for mitigating and adapting to climate change (Monteiro *et al.*, 2017, Monteiro *et al.*, 2019).

In 2018, in the municipality of Rio Claro, approximately 51% of the territory was occupied by significantly altered and discontinued (TNC, 2013) remnants of the Atlantic Forest (MapBiomass, 2019), and 36% by pastures with different levels of degradation. It indicates the potential for applying the technologies foreseen in the ABC Plan in this territory, mainly related to the recovery of degraded pastures and the implementation of crop-livestock integration systems. Large areas occupied by pastures, especially if poorly managed, cause intensive soil exposure to erosion processes. The ABC Plan technologies offer environmental and economic gains, and have direct and indirect influences on WEF security in the examined area.

3.3.3. State Program for Conservation and Revitalization of Water Resources - PROHIDRO and PROPSA (state) – State Decree n° 42,029/2011

State Decree n° 42,029/2011 (Governo do Estado do Rio de Janeiro, 2011) regulates the state program for the conservation and revitalization of water resources (PROHIDRO) and its subprogram, called PRO-PSA – State Program for Payment for Environmental Services. The aim of PROHIDRO is to provide the revitalization, when necessary, and the conservation, where possible, of water resources as a whole through the management of elements of the physical and biotic environments, considering the river basin as a planning and work unit. PRO-PSA prioritizes investments in rural areas and public water sources, observing the criteria to be approved by the State Water Resources Council (CERHI-RJ), which represents progress in the protection of water

resources, forests and biodiversity. Owners of rural land in the state of Rio de Janeiro who favor the conservation, maintenance, expansion or restoration of ecological benefits are entitled to receive Payment for Ecosystem Services (PES).

Climate regulation, protection against natural disasters, water resources preservation and conservation of biodiversity all require the provision and support of environmental services in order to guarantee WEF security (Bekchanov *et al.*, 2015). There is great potential for the provision of environmental services to be an option to obtain direct and indirect social, environmental and economic benefits for WEF security in the study area. This is attributed to 51% of the municipality of Rio Claro being formed by remnants of the Atlantic Forest, and to the PRO-PSA modalities that compensate rural owners who comply with the Atlantic Forest Law (Brasil, 2006), thus diminishing the pressure on the remaining native forests in the area. One of the PES projects supported by PRO-PSA is the Water and Forest Producer project (PAF), in the municipality of Rio Claro, which will be described in a specific item.

3.3.4. Tax on Circulation of Goods and Services – ICMS-E (state) – Law n° 5,100/2007

State Law n° 5,100/2007 (Governo do Estado do Rio de Janeiro, 2007) included the environmental conservation criterion in the transference of the Tax on Circulation of Goods and Services (ICMS) to municipalities in the state of Rio de Janeiro. The Ecological ICMS (ICMS-E) is intended to positively affect the environmental quality of muni-

icipalities through a tax mechanism that guarantees an investment in environmental conservation to municipalities.

The ICMS-E has multiple elements of support for WEF security, such as the establishment of financial incentive mechanisms for conservation and environmental preservation, the incentive to create Conservation Units, the creation of a governance structure for resource management and incentives for increased sanitation and adequate collection and disposal of solid waste. Xavier *et al.* (2023) found in their study that deficiencies in the sewage treatment system have profound impacts on water availability, and the demand for water to dilute sewage is equivalent to twice that necessary for water for human supply in RH -II, including in the municipality of Rio Claro, RJ.

Furthermore, this PP is comprehensive, as it considers the regulations of several other policies within its scope, such as the Forest Code, the National System of Conservation Units (SNUC), the National Water Resources Policy, and the National Basic Sanitation Policy.

Several research projects have investigated the governance issue regarding the Nexus approach. Using case studies from Nepal, India and Thailand, Gyawali (2015) pointed out challenges and governance options that can accept social and physical uncertainties and create synergies in the water, energy and food areas. Stein & Jaspersen (2019) presented a methodological framework to investigate Nexus governance in the Nile River region in Africa and stressed that it is necessary to identify solutions for the integration of governance systems, so that the application of this approach can be successful.

3.3.5. *Water and forest producer project – PAF (municipal) – Law n° 514/2010*

Municipal Law n° 514/2010 (Rio Claro, RJ, 2010) implements the Water and Forest Producer project (PAF) in the municipality of Rio Claro and authorizes financial payments to owners that join the project. The main objective of the PAF is to increase forest coverage in permanent preservation areas and other priority areas, thus improving the quality and quantity of water resources in springs (Castello Branco, 2015).

Among the main challenges for the administration and forest management of RH-II is the loss of forest cover, which accelerates the degradation of soil and consequently that of water resources, mainly due to fires and the replacement of forest by pastures (INEA, 2014). Evidence suggested that forest coverage in the municipality of Rio Claro was boosted due to the success of the project, as the properties enrolled in the PAF experienced a larger increase than those in the non-project areas (Fiorini, 2018). The project also brought important results to the Rural Environmental Registry (CAR), provided for in the Forest Code, due to technical assistance to implement the CAR for all properties contracted by the PAF (Teixeira *et al.*, 2019). The expansion of the project to other RH-II sub-basins, related to PRO-PSA (Governo do Estado do Rio de Janeiro, 2011) for the Guandu region, began in 2018.

4. *Conclusions*

Public policy instruments of various kinds are connected to WEF security. Therefore, the methodological strategy employed in the current

study was pivotal to identify, categorize, choose and assess the most relevant PP for the study area. The methodological strategy can be applied to other sets of policies related to the Nexus approach, in similar socioeconomic and environmental contexts. Of the 87 public policies identified at different action levels, those at the national level are predominant (82%), and indicate a certain centralization of PP related to WEF security at the federal level. However, 43% of PP meet more than one pillar of the Nexus approach, thus demonstrating a trend towards integration of WEF security. The classification of PP as structuring and integrating allowed selecting 5 PP to analyze their contributions to WEF security in the study area.

As a result of the methodological strategy applied, we can state that the public policies considered structuring and integrative and with the greatest influence on WEF security in the study area are those that promote the management and conservation of soil, water and native vegetation. Organizations, infrastructures, technical assistance, income, and credit are all methods that can be used to reward those who actively participate in environmental preservation. Therefore, policies such as PROHIDRO/PRO-PSA, State Policy on Global Climate Change and Sustainable Development and Ecological ICMS have great potential to contribute to the implementation of the Nexus approach. The study area has a high percentage of vegetation natural cover (51%) which may be the target of policies that have conservation and compensation mechanisms (PES), such as the Forest Code and the Water and Forest Producers Project, with strong impacts on WEF security.

The Nexus approach is highly suitable to be implemented in this study area. On the other hand,

despite being under the influence of many policies aimed at the use and conservation of water resources – with the involvement of several government institutions, universities, civil society and the third sector – the study area, still faces serious sanitation problems. This has a significant and direct effect on the water security pillar, which is integral to the Nexus approach, and indirectly impacts the energy and food security pillars. To advance this issue, the private sector should be more involved in the integration of water, energy and food production management policies and instruments, to reach sustainability in RH-II. It is extremely necessary for the provision of diverse services and benefits to society, not only for its inhabitants, but also beyond its borders, as it provides water, energy and food for the greater metropolitan region of Rio de Janeiro.

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