

A method for classifying interrelation between sectoral regulatory laws and the 'water-energy-agriculture nexus concept' in Brazil

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ABSTRACT

We propose a method to classify the level of interrelation between the water, energy and agriculture sectoral regulatory laws and selected main characteristics of the nexus concept. This method was created to be applied with sectoral regulatory laws so a study case was conducted in Brazil. The results show that all analysed legislations have low to medium interrelation with the criteria intrinsic to the nexus concept; the policies that stood out the most, regarding the number of criteria present in their scopes, were the national irrigation policy and the desertification policy; and in order to operationalize the nexus concept in management models in the Brazilian context, adjustments and a restructuring of regulatory laws are necessary. The proposed method was able to investigate the interrelation between regulatory legislations with the characteristics of the nexus concept as well as their strengths and weaknesses.

Key words | methodological proposal, policy analysis, water-energy-agriculture nexus

HIGHLIGHTS

- The method allows the classification of the level of interrelation between sectoral regulatory laws and the main characteristics present in the nexus concept in an innovative approach.
- A simplified structure was applied based on criteria and scales that can be implemented for other spatial scales and countries.

INTRODUCTION

Historically, institutional arrangements and sectorial regulations have been commonly organized independently, pushing each sector to develop its strategies, policies, plans, and actions (Eftelioglu *et al.* 2016; Embid & Martín 2018; Huckleberry & Potts 2019).

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Developing and implementing sectoral policies independently and without taking into account the trade-offs and impacts between the multiple sectors involved can lead to risk and inconsistent approaches (De Strasser *et al.* 2016). Risks are inherent in systems where different sub-sectors share the same resources (Gallagher *et al.* 2016). Consequently, they may also face similar uncertainties associated with them. Inconsistencies often refer to the fact that policies are still being formulated individually,

even recognizing the interrelations and interdependencies between related sectors and sub-sectors (Bhaduri *et al.* 2015).

Over time, global environmental changes, including climate change, have required greater understanding and consideration of the links and interdependencies between sectors such as water, energy, and food production (Leck *et al.* 2015). The idea of individuality came to be confronted with the need for integrated studies to answer increasingly complex and multidisciplinary problems (Hoff 2011; WEF 2011; Eftelioglu *et al.* 2016).

The recognition attributed to interrelation between the water, energy and agriculture sectors was initially discussed at the World Economic Forum in 2008 (Smajgl *et al.* 2016; Embid & Martín 2017), gaining international prominence through the Conference 'The Water-Energy and Food Security Nexus – Solutions for the Green Economy' in 2011 (Hoff 2011; WEF 2011; Liu *et al.* 2017). Interrelation in this case can be defined as the reciprocal relationship between sectors on a bilateral basis. Since the conference, the term 'water-energy-food nexus' (systems organized in networks) has been used in a variety of contexts to advance the understanding of their interrelations.

For Huckleberry & Potts (2019), the nexus concept has emerged as a powerful approach to address the social and environmental challenges created by land-use and climate change. Hoff (2011) sees the nexus concept as an analytical approach to derive strategic resource management solutions with an emphasis on integrated system efficiency rather than isolated sector productivity. There is no consensus on the nexus concept, it is interpreted as processes that integrates ideas and actions from different stakeholders present in different sectors in pursuit of a common goal to achieve sustainable development (Endo *et al.* 2017).

Because the nexus concept is perceived as integrated management, this terminology is often associated with integrated water resources management (Abdullaev & Rakhmatullaev 2016; Roidt & Avellán 2019), integrated environmental policy management (Venghaus & Hake 2018), and more recently integrated solid waste management (García *et al.* 2019; Roidt & Avellán 2019). Due to the aforementioned concepts' previous existence, some authors question the nexus concept's innovation in conceptual terms and its lack of coherence in more practical terms (Biggs

et al. 2015; Cairns & Krzywoszyńska 2016; Wichelns 2017; Venghaus & Hake 2018).

Despite these criticisms, there is one feature that strongly defines the nexus concept and makes it an innovative approach, which is the shift from a single sector-centric perspective or a single resource to a multi-centred and multi-level perspective (Bazilian *et al.* 2011; Bréthaut *et al.* 2019). Dealing with water-energy-food nexus interrelations in a sustainable way has become one of humanity's great global challenges (Endo *et al.* 2015). Besides that, existing integrating concept applications have shown that the transformation required to implement these concepts requires a framework that explicitly explains interdependencies not only between resources but also between their policies (Venghaus & Hake 2018). The analysis of the coherence of sectoral policies and institutional arrangements through the nexus concept represents the essential aspects of achieving their operationalization.

This paper was based on knowledge gaps and challenges presented by Bazilian *et al.* (2011), Bhaduri *et al.* (2015), Liu *et al.* (2017), Larcom & Gevelt (2017), and Embid & Martín (2018) regarding the investigation of institutional and legal aspects involving the nexus concept. The gaps and challenges were: (I) institutional organizations are not yet sufficiently structured to support the nexus dialogue (Bazilian *et al.* 2011); (II) the lack of innovative methodologies and decision support tools to deal with complex interrelations between water, energy, and agriculture, minimizing investment risks and maximizing economic returns (Bhaduri *et al.* 2015; Liu *et al.* 2017; Mercure *et al.* 2019); (III) the need to evaluate whether existing sectoral regulations are appropriate to the nexus concept requirements (Larcom & Gevelt 2017; Embid & Martín 2018); and (IV) in some cases does not require a radical overhaul of the regulatory frameworks and governance system, as some regulations may be structured to address the implications of nexus analysis, requiring merely revisions and better articulation (Larcom & Gevelt 2017).

Furthermore, to our knowledge, no study addressing the nexus concept has developed a method for classifying the level of integration of sectoral policies concerning the main features surrounding the concept. Research directed at these aspects tends to help identify the limitations and challenges surrounding the implementation of the nexus

concept in management models. By recognizing this knowledge gap and challenges, this article's key questions are:

- (I) What is the level of interrelation between sectoral regulatory laws and the main characteristics present in the nexus concept? and
- (II) What are the main strengths and weaknesses of sectoral regulatory laws upon the nexus concept?

To investigate the key questions raised, this study aims to propose a method to classify the level of interrelation between the water, energy and agriculture sectoral regulatory laws and selected main characteristics of the nexus concept.

PROPOSED METHOD

This section presents the method proposal for the classification and evaluation of regulatory legislation in the water, energy and agriculture sectors in relation to the main characteristics involving the nexus concept. The method was based on an adaptation of the organizational structure of multicriteria analysis. Multicriteria analysis structures a decision problem in terms of several possible

alternatives and assesses each of them under various criteria at the same time (Hajkowicz & Collins 2007).

Although multicriteria analysis is widely applied into the context of decision-making, which does not match the proposal of the present study, previous experience from the main authors (Srdjevi et al. 2004; Medeiros et al. 2014; Torres et al. 2016) of this paper with this method inspired them to create an adaptation that fit this methodological proposal. The main aspect used from multicriteria analysis was the classification phase of alternatives according to multiple criteria.

Therefore, the method was structured in three stages as shown in Figure 1: (I) Step I: Definition of the criteria (Main characteristics of the composition of the nexus concept); (II) Step II: Definition of alternatives (Regulatory Legislation); (III) Step III: Evaluation and Classification of the interrelation between criteria and alternatives.

In order to test the proposed method minimum requirements were designed for each step of the application and a study case was conducted. The country selected for this application was Brazil. The country characterization and the minimum requirements are going to be described in more detail in the following sections.

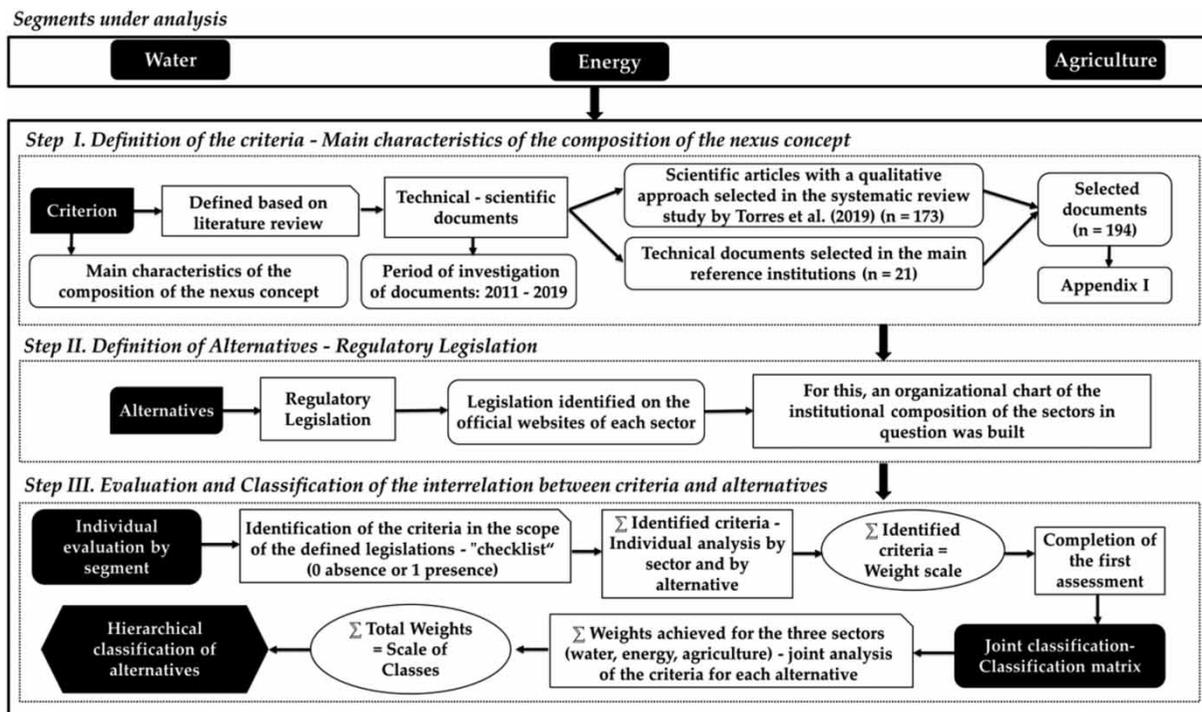


Figure 1 | Method steps.

Characterization of the case study: Brazil

Brazil is a country with continental dimensions (8,510,295.914 km²), located in South America. The country stands out in the agricultural sector, being one of the main suppliers of raw materials to the world economy. In terms of energy, the country also excels in hydraulic generation and bioenergy production, it has a diversified matrix with a high share of renewables.

Despite the advances mentioned, in recent years, Brazil has been going through great uncertainties due to the water crises that have advanced in several regions, in addition to the consecutive political and economic conflicts at the national level with repercussions in the whole society.

Water crises and, its conflicts were a motivation to the first nexus concept studies in the country back in 2015. These studies were developed in order to propose solutions to the water crisis between two Brazilian largest metropolises, Rio de Janeiro and São Paulo (Giatti *et al.* 2016). Although the nexus concept studies advanced in the country over the years (e.g. FAPESP 2015; Vilanova & Balestieri 2015; Giatti *et al.* 2016; INPE 2016; CNPq 2017; Arroyo 2018; Semertzidis *et al.* 2018; Castillo *et al.* 2019; Deveza, 2019; Mercure *et al.* 2019), none of the studies surveyed, so far, contemplates an investigation of the interrelation between regulatory legislation with the characteristics of the nexus concept.

In view of this, the development of the proposed procedure in Brazil is considered pertinent in order to identify the strengths and weaknesses of sectoral regulatory legislation aiming at greater integration between them.

Administrative political organization in Brazil

The Federal Constitution of 1988 organizes political and administrative Brazil in entities of the Federation formed by the Union, States (26), Federal District and municipalities (5,570), all endowed with autonomy in legislative, governmental, tax, and administrative powers (Brazil 1988). In other words, according to the Constitution, all the entities of the Federation can legislate, organize and manage their territory, and the Union must intervene only in situations of disorder that interfere with National integrity. Besides, it is important to mention that despite the autonomy of the Federated

Entities, their legislative competences follow a hierarchy of power: Federation – State/Federal District – Municipality.

In the water sector, the Federal Constitution defines as the domain of the Union 'lakes, rivers and any body of water in lands that belong to its domain, or that bathe more than one State, serve as limits with other countries, or extend to foreign territory or from it, as well as marginal lands and river beaches' (Brazil 1988).

The energy sector is segmented between public and private companies in the attributions of generation, commercialization, transmission, and operation of energy. The Federal Constitution defines potential hydroelectric energy and mineral resources as federal assets, so the exploitation or use of these resources can only be carried out with authorization or concession from the federal government (Brazil 1988).

The agricultural sector, the Federal Constitution, played a fundamental role in its development by promoting the country's agricultural policy. This sector has undergone several cycles of transformation, from its rudimentary beginning and of little expression in the country to large mechanized agricultural complexes (agribusiness) of significant relevance in Brazil's trade balance.

Definition of criteria – main composition characteristics of the nexus concept (step I)

To identify the main characteristics that involve the nexus concept, a total of 194 technical – scientific documents were selected in the period from 2011 to 2019, as shown in Appendix I. These documents were surveys from two main sources: Torres *et al.* (2019) papers database; and technical documents from reference institutions such as, the United Nations Food and Agriculture Organization (FAO), the International Institute for Sustainable Development, the Economic Commission for Latin America and the Caribbean (ECLAC), the Institute of Stockholm Environment (SEI) and International Energy Agency (IEA).

Torres *et al.* (2019) conducted a literature review on the nexus concept, its database contains 304 papers, among those 173 qualitative scope and 131 quantitative scope. To develop the presented criteria for this study only articles of a qualitative scope were used from this database (173 papers), disregarding the articles classified as quantitative due to their greater discussion directed towards the application of the

nexus concept and not merely their theoretical approach. Besides, the database additional 21 technical documents that were surveyed from the aforementioned institutions.

194 technical – scientific documents (173 papers and 21 technical documents) were used to propose 18 criteria for each sector that represent the main characteristics of the nexus concept for this study. In total there were 18 criteria (6 for water, 6 for energy and 6 for agriculture sectors).

Definition of alternatives – regulatory legislation (step II)

The alternatives are represented by the federal regulatory laws for the water, energy, and agriculture sectors. This step requires the exclusive usage of legislation of a regulatory nature. To identify these laws in Brazil, an online survey was carried out on the official websites of the ministries: for water resources, Agência Nacional de Águas (National Water Agency) <<https://www.ana.gov.br/>>, for energy, Ministério de Minas e Energia (Ministry of Mines and Energy) <<http://www.mme.gov.br/>>, and agriculture, Ministério da Agricultura, Pecuária e Abastecimento (Ministry of Agriculture, Livestock and Supply) <<https://www.gov.br/agricultura/pt-br>>. Additionally, government technical documents present in the Federal Government's official online diary were analyzed. Official acts of the executive, legislative and judicial public administration are published in the Diário Oficial da União (Official Gazette).

The application of the method in regulatory legislation of national scale was chosen because the Federal laws have precedence, that is, priority over State and Municipal laws according to the Federal Constitution of 1988 (Section 2.1.1). Therefore, the first changes that must be made in legislative terms must be at the Federal level, so as to guide the changes at lower levels.

Figure 2 contains an organizational chart of the institutional composition of each sector under analysis in Brazil. It can be observed that each sector is inserted in a governmental Ministry, and aligned to each Ministry are the specific secretariats, departments, councils, and bodies.

Evaluation and classification of the interrelation between criteria and alternatives (step III)

The evaluation step consisted of identifying whether the criteria are included in the scope of the alternatives

(legislation). To identify the criteria in the scope of the legislation, a matrix must be filled out as a minimum requirement to move forward. The matrix contains two numerical codes, 1 to indicate presence of the criterion and 0 its absence, the outcome of this first matrix is a checklist.

After this process, the sum of all the criteria present in the alternatives analysed by the type of segment (water, energy, and agriculture) is performed. For example, in Legislation 1, x criteria of the water segment, x criteria of the energy segment and x criteria of the agriculture segment were found. The results of the sums for each segment corresponding to a weight scale as shown in Table 1.

The weight scale was built considering a total of six criteria per segment, totalling 18 criteria. There is no requirement for the number of criteria that one can use on its studies when applying this method, but if the criteria number changes a new scale may have to be adapted.

With the filling of the matrix by the weights shown in Table 1 (classification by segment) the joint classification is performed. This classification is performed considering the comparison between the sum of the weights of all the criteria fulfilled in the matrix with the classes determined in Table 2. The classes were defined symmetrically, both with the same amplitude, totaling six classes due to the maximum limit of the class being 18 (corresponding to the total number of criteria).

RESULTS AND DISCUSSION

Main composition characteristics of the nexus concept

Based on the 194 technical – scientific documents, eighteen (18) criteria were established as the main characteristics of the nexus concept for this study, with six representing the water, energy and agriculture segment (Table 3). Overall the criteria were based on two aspects: the occurrence of the terms in the analyzed technical – scientific documents and their level of relevance (essential aspects of the nexus concept). For this study, all the selected criteria have the same relevance in the evaluations of regulatory legislation, therefore no weight system was used to differentiate their relevance. All criteria are used to evaluate and classify all alternatives individually.

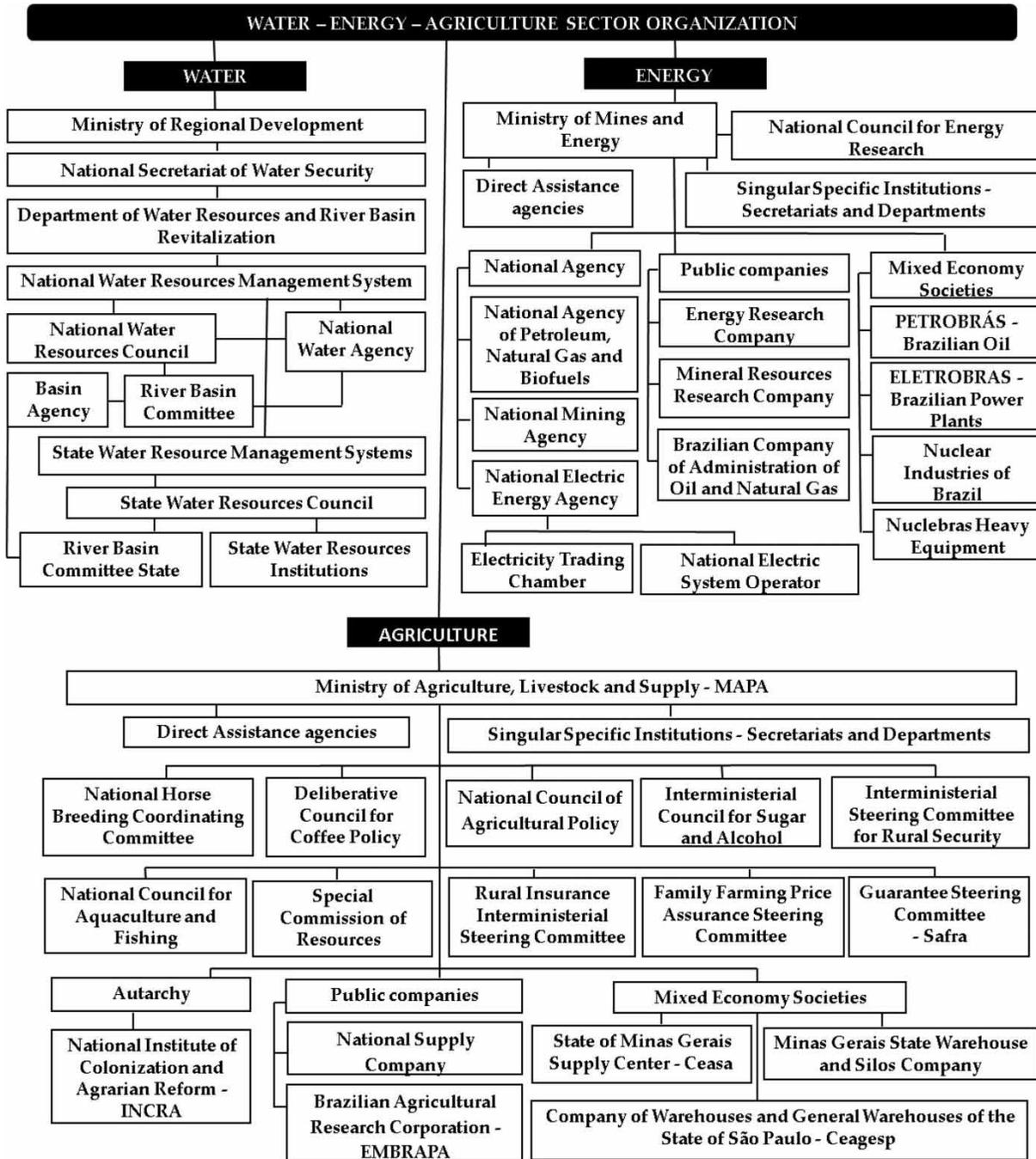


Figure 2 | Institutional organization of the Water-Energy-Agriculture sectors in Brazil.

Identification and characterization of the main regulatory laws in Brazil

In Brazil, ten federal regulatory laws were identified, as shown in Table 4. It can be seen that the laws were formulated in

different time periods. Some of these laws have been updated over time, while other laws remain with the same scope.

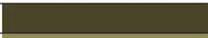
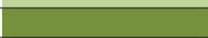
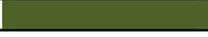
The water sector in Brazil is governed by the National Water Resources Policy (Law n°. 9433/1997), which brings water management as decentralized, participatory

Table 1 | Weight scale for individual assessment by segment

Category	Numerical Scale *	Description	Colour Scale
Very high	6	Six criteria were met	
High	5	Five criteria were met	
Intermediate	4	Four criteria were met	
Average	3	Three criteria were met	
Low	2	Two criteria were met	
Very low	1	Only one criterion was met	
It has no interrelation	0	No criteria met	

*Each segment has a maximum of six criteria as shown in Table 1.

Table 2 | Rating scale – joint classification

Description	Classes	Colour Scale
Excellent interrelation	16 -18	
High interrelation	13 -15	
Intermediate interrelation	10 - 12	
Average Interrelation	7 -9	
Low interrelation	4 - 6	
Very low interrelation	1 - 3	

and integrated (Brazil 1997). The sector has recently undergone changes in view of the update of the National Basic Sanitation Policy (Law n° 11,445/2007 updated by Law

n°. 14,026/2020). In its updated version, the National Water Agency (ANA) is responsible for establishing the reference standards for the regulation of public basic sanitation services (Article 1/Law n°. 14,026/2020). This tends to approximate the relationship between water resources services and sanitation services in the country. In addition to this change, the new legal framework opens up the participation of private companies in public tenders for sanitation services, promoting greater competition between public and private companies, ending the preference of state-owned companies (Brazil 2020). For this sector, three legislations were selected for analysis.

Table 3 | Analysis criteria considering water, energy and agriculture segments

Water	Energy	Agriculture
Water security (C1)	Energy security (C7)	Food security (C13)
Conservation and rational use (efficient) of water (C2)	Conservation and rational use of energy (C8)	Encourage the use of unconventional water sources, promoting reuse (C14)
Integrated relationship between surface water and groundwater (C3)	Mitigation of greenhouse gas emissions (C9)	The incentive to increase alternative energy sources (bioenergy, wind and solar) in agricultural systems (C15)
Water resources without dissociation between quantity and quality (C4)	The incentive to increase renewable energy sources in the energy matrix (C10)	The incentive for more sustainable production by reducing greenhouse gas emissions (C16)
Encourage the generation and transfer of technologies related to the efficient use of water (technological efficiency associated with water efficiency) (C5)	Foster the generation and transfer of technologies related to energy efficiency (technology efficiency associated with energy efficiency) (C11)	Foster the generation and transfer of technologies related to resource efficiency (technological efficiency associated with agricultural efficiency) (C17)
Integration with the National Water Resources Policy and the National environmental policy ^a (C6)	Integration with the National Energy Policy and the National Environmental Policy ^a (C12)	Integration with the Agricultural Policy and the National Environmental Policy ^a (C18)

^aThe National Water Resources, Energy and Agricultural Policies should always be compared along with the National Environmental Policy against other laws, the only exception is when they are compared with themselves.

Table 4 | Main federal legislation present in the water, energy and agriculture sectors in Brazil

Sectors	Federal regulatory legislation	Initials
Water	Law n° 9,433/1997 – National Water Resources Policy	L1
	Law n° 11,445/2007 – National Policy to Sanitation. Amended by Law n°. 14,026/2020	L2
	Law n° 13,153/2015 – National Policy to Combat Desertification and Mitigate the Effects of Drought	L3
Energy	Law n° 9,478/1997 – National Energy Policy. Amended by Law n° 12,490/201	L4
	Law n° 10,295/2001 – National Policy for Conservation and Rational Use of Energy	L5
	Law n° 13,576/2017 – National Biofuels Policy	L6
	Law n° 11,097/2005 – Introduction of biodiesel in the energy matrix. Amended by Law n° 13,033 of 24/2014.	L7
Agricultural	Law n° 8,171/1991 – National Agricultural Policy	L8
	Law n° 12,787/2013 – National Irrigation Policy: Amended by Law n° 13,702/ 2018	L9
	Law n° 12,188/2010 – Institutes the National Policy of Technical Assistance and Rural Extension for Family Agriculture and Agrarian Reform	L10

As for the energy sector, a major breakthrough was achieved with the National Biofuels Policy (Law n° 13,576/2017) proposed to contribute to meet the country's commitments to the Paris Agreement under the United Nations Framework Convention on Climate Change (Brazil 2017). The sector in the country is governed by Law n°. 9,478/1997, which defines energy policy as 'a set of programs, plans, projects and legislation to develop the energy sector' (Brazil 1997). For this sector, four legislations were selected for analysis.

In the case of the agricultural sector, three legislations were selected for investigation. In Brazil, the sector is governed by Law n° 8,171/1991. Similar to the energy sector, agricultural policy is defined as a set of programs, plans, projects and legislation to develop and coordinate the agricultural sector (Brazil 1991).

Case study application

Based on the defined criteria and the selected legislation for each sector, the application of the proposed method was conducted. Table 5 contains the filling matrix with the results of the checklist carried out in the documents of the sectoral regulatory legislation. In this case, the weight scale presented in Table 1 was applied, which corresponds to the individual assessment of alternatives through the criteria for each segment.

Overall, the results show low interrelation between the analyzed laws against the criteria defined to represent the main characteristics present in the nexus concept. Some of

the facts that may have influenced this result could be related to:

- i. Hierarchical structure of Brazilian laws: The fact that in Brazil, the water, energy and agriculture sectors were structured in a segmented manner, as presented by the Federal Constitution of 1988 (Brazil 1988). This fact was also discussed by Benites-Lazaro *et al.* (2020), which affirms that land, energy and water are managed in isolation by separate and disconnected institutional entities. Within the scope of the analyzed legislation, it was possible to notice the lack of integration between them. Each legislation tends to focus only on its sector and does not cover direct communication with other laws.

The lack of integration between the laws and the low number of criteria shows that, in order to operationalize the proposed nexus concept, regulatory laws must be restructured, and along with them their institutional arrangements. This restructuring can be carried out through changes in current laws, it may not always require the creation of new laws. For example, the national sanitation legal framework was recently updated instead of being replaced by a new law. Its update included changes in its scope and the restructuring of its related institutions. Through these proposed changes, there is a chance that actions of the water resources sector will become closer to the actions of the sanitation sector, which are both interconnected by the same regulatory agency.

- ii. Climate variability decreasing environmental resources (e.g. water security problems): for example, another

Table 5 | Result of individual evaluation by segment

Sector	Criteria	Water			Energy				Agriculture		
		L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
Water	C1	0	0	1	0	0	0	0	0	0	0
	C2	1	1	1	0	0	0	0	1	1	1
	C3	0	0	0	0	0	0	0	0	0	0
	C4	1	0	0	0	0	0	0	0	1	0
	C5	0	1	1	0	0	0	0	0	0	0
	C6	1	1	1	0	0	0	0	0	1	0
Σ Water criteria		3	3	4	0	0	0	0	1	3	1
Weight scale for individual assessment by Segment *		Average	Average	Intermediate	It has no interrelation	Very low	Average	Very low			
Energy	C7	0	0	1	0	1	0	0	0	0	0
	C8	0	1	0	1	1	0	1	0	0	0
	C9	0	0	0	1	0	1	0	0	0	0
	C10	0	0	0	1	0	1	1	0	1	0
	C11	0	0	0	1	0	1	0	0	0	0
	C12	0	0	0	0	1	0	1	0	1	0
Σ Energy criteria		0	1	1	4	3	3	3	0	2	0
Weight scale for individual assessment by Segment *		It has no interrelation	Very low	Very low	Intermediate	Average	Average	Average	It has no interrelation	Low	It has no interrelation
Agriculture	C13	0	0	1	0	0	0	0	0	0	1
	C14	0	0	1	0	0	0	0	0	0	0
	C15	0	0	0	0	0	1	0	0	1	0
	C16	0	0	1	0	0	0	0	0	1	1
	C17	0	0	0	0	0	0	0	1	1	1
	C18	0	0	0	0	0	0	0	0	1	0
Σ Agriculture criteria		0	0	3	0	0	1	0	1	4	3
Weight scale for individual assessment by Segment *		It has no interrelation	It has no interrelation	Average	It has no interrelation	It has no interrelation	Very low	It has no interrelation	Very low	Intermediate	Average

^aWeight scale defined in Table 1. L1: National Water Resources Policy; L2: National Basic Sanitation Policy; L3: National Policy to Combat Desertification and Mitigate the Effects of Drought; L4: National Energy Policy; L5: National Policy for Conservation and Rational Use of Energy; L6: National Biofuels Policy; L7: Introduction of biodiesel in the energy matrix; L8: Agricultural Policy; L9: National Irrigation Policy; L10: National Policy for Technical Assistance and Rural Extension for Family Farming and Agrarian Reform.

factor that has been occurring in Brazil that has a direct impact on sectoral interrelations refers to water scarcity. The country experienced a severe water scarcity crisis; among those, one hit its two biggest cities (Rio de Janeiro and São Paulo) in the period from 2014 to 2016 (Giatti *et al.* 2016; Soriano *et al.* 2016; Mercure *et al.* 2019). This crisis highlighted for the government and population the dependence of the energy and agriculture on the water sector. This crisis challenged stakeholders regarding the real causes of these problems and its solutions. Besides all these problems, in this period and region, there was also a conflict between the energy and water sectors because the electricity policy encouraged the use of water for generation of energy, affecting the drinking water availability (Mercure *et al.* 2019).

Another example was mentioned by Benites-Lazaro *et al.* (2020). The authors highlight that Brazilian stakeholders reacted to certain events (e.g. expansion of sugarcane and water scarcity), yet changes in public policies have failed to consider the interdependence among various sectors. The authors believe that the nexus concept can aid policy-making because it identifies the interdependencies among such linked systems and mitigates the emerging risks to resource security. The bioethanol sector (Law n° 13,576/2017) is used as an example of a possible pilot for

the implementation of a nexus concept with a high chance of success in Brazil.

It should be noted that water is a link that connects all other sectors that make up a nation's economy and survival. Therefore, the lack of this resource brings the need for reflection on the current management model. In this scenario, legislation starts to be validated, discussed and reformulated, new regulations and government programs are structured, and a closer relationship between sectors that have joint demands and share risks tends to occur to contain conflicts.

Complementing the assessment of legislation by segment, Table 6 shows the results found from the final classification of regulatory legislation. As can be seen, the policies evaluated presented similar classifications, from low to very low interrelations with the criteria for characterizing the concept of nexus, except for the Irrigation Policy (L9), which obtained the highest score, being classified as average interrelationship. No analysed legislation scored above nine criteria. In other words, no policy was rated as high or excellent interrelation.

In a hierarchical manner, the laws of greatest interrelation with the characteristics of the nexus concept for the least interrelation are:

- (I) Irrigation Policy (L9);
- (II) National Policy to Combat Desertification and Mitigate the Effects of Drought (L3);

Table 6 | Result of the final classification of regulatory legislation

Sector	Water			Energy				Agriculture		
	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
∑ Criteria - Water	3	3	4	0	0	0	0	1	3	1
∑ Criteria - Energy	0	1	1	4	3	3	3	0	2	0
∑ Criteria - Agriculture	0	0	3	0	0	1	0	1	4	3
∑ Total	3	4	8	4	3	4	3	2	9	4
Rating scale - Joint classification*	Very low interrelation	Low interrelation	Average Interrelation	Low interrelation	Very low interrelation	Low interrelation	Very low interrelation	Very low interrelation	Average Interrelation	Low interrelation

*Class scale defined in Table 2.

- (III) National Policy to Sanitation (L2), National Energy Policy (L4), National Biofuels Policy (L6) and National Policy of Technical Assistance and Rural Extension for Family Agriculture and Agrarian Reform (L10), all with the same score;
- (IV) National Water Resources Policy (L1), National Policy for Conservation and Rational Use of Energy (L5) and Introduction of biodiesel in the energy matrix (L7), all with the same score;
- (V) Agricultural Policy (L8), with the lowest score.

The agricultural policy (L8) stood out for having the lowest score: only two criteria were present in their scope, followed by the Water Policy (P1), National policy for the conservation and rational use of energy (L5) and the policy Introduction of biodiesel in the energy matrix (L7), with three criteria met, all of them belonging to their segment.

As for the integration between regulatory laws, it was possible to notice that the irrigation law, referring to the agricultural sector, was the only one that presented integration with more than two regulatory legislations, energy, water resources, sanitation, and environmental law.

For L1 (National Water Resources Policy), no associations were identified with energy policy and agricultural policy. It is important to note that agricultural activity and energy generation, in the water resources policy, are considered as users of water, as well as mining activities, industry, among others. Therefore, any mention of these activities is described in the context of 'users', as can be seen in its article 3, item IV: 'General guidelines for action for the implementation of the National Water Resources Policy are the articulation of water resources planning with that of user sectors and with regional, state and national planning' (Brazil 1997).

By making a comparative analysis of water resources policies and other sectoral regulatory policies, it was possible to notice that for the water sector, the desertification policy (L3) obtained a greater correlation with the proposed criteria than the water policy itself (L1) and sanitation (L2). As in the agricultural sector, the irrigation law (L9) has greater integration between the criteria under analysis than the agricultural policy itself (L8). In the case of the energy sector, the energy policy (L4) and the biofuel policy (L6)

obtained the same number of criteria met in their documents.

It is important to highlight that the results presented in this section are associated exclusively with the validation of the proposed method. Its application consists of investigating sectoral regulatory laws regarding their level of interrelation with criteria that represent the main characteristics of the nexus concept. The proposed method cannot be classified as a nexus concept application itself. What it can do is aid in the identification of strengths and weaknesses present in the scope of regulatory laws against the principle within the nexus concept.

In this sense, the method proposed in the present study brings an investigation of the level of interrelation of the regulatory laws that coordinate the water, energy and agriculture sectors in the country, as well as evaluating criteria of great relevance for the security of its resources and that are recommended in the nexus concept.

The application of the proposed method made it possible to identify the main weaknesses and strengths present in the scope of each law (Appendix II). Despite the results indicated, it is important to mention that the application of the method does not directly refer to the operationalization of the nexus concept, but rather a necessary and important step to achieve this goal.

The big issue in integrating regulatory legislation and inserting factors that involve systems efficiency, refers to the fact that, in practical terms, the activities carried out in the water/sanitation, agriculture and energy sectors also tend to be integrated because they are governed by these laws. Thus, it is hoped that the decision-making processes, investments and actions are developed together, whenever they have an intersection point between them. In this sense, programs and actions implemented in one sector automatically refer to gains for other correlated sectors as long as the trade-offs and risks inherent in the process are accounted for. This implies better targeting of investments with reduction of waste of public funds, maximization of synergies, strengthening of governance systems and internalization of social and environmental impacts (Rasul & Sharma 2016; Pardoe *et al.* 2017; Stephan *et al.* 2018; Albrecht *et al.* 2018). For this to happen, one of the first steps is to assess the current scope of legislation, which was proposed and made in the present study.

FUTURE TRENDS

Once the method is applied into the Federal Regulatory Laws, the next step should be to study a smaller scale; for example, state and municipal laws of water, energy and agriculture. Studying small scales could aid the investigation of the level of interrelationship between the legislations of other spatial scales and to identify their points of interconnectivity with the proposed criteria, pointing out their strengths and weaknesses. The results to be achieved with this investigation must be compared with the results identified in the present study to have a greater coverage of the country's legal situation regarding the aspects investigated. In Brazil, it is recommended to carry out the analysis by state and regions (Northeast, North, Southeast, South, Midwest), considering its territorial dimension.

Another extension that must be carried out is to compose an investigation of public policies in Brazil. The proposed method could be applied to analyze government programs and project documents in the country's water, energy and agriculture sectors. Appendix III contains a list of the main public policies for the development of these sectors that could aid in this next phase. This investigation could identify possible overlaps between the programs and their actions and their level of interrelation.

The proposed method can be easily modified and also could be applied in different countries and scales. Some of the suggestions for adaptation include: identification and changes if necessary of the criteria to define the nexus concept to another study or scales (if the criteria number change the scale of weights would have to be adapted too); and more sectors could be added to the analysis besides water, energy and agriculture (e.g. economy and the environment could be added).

CONCLUSION

The nexus concept still represents a paradigm for public management of natural resources. Traditional models of natural resource management no longer respond to today's complex social and economic problems, so new

strategies need to be considered. The nexus concept could be part of this new strategy. In this paper, a new method was proposed for the classification of sectoral regulatory laws based on the corresponding main characteristics of the nexus concept for this study. With the results achieved, it can be concluded:

- All analysed legislations have low to medium interrelation with the criteria that represent the main characteristics of the nexus concept for this study. The policies that stood out the most, regarding the number of criteria present in their scopes, were the national irrigation policy and the policy to combat desertification.
- The analyzed laws must contain points of interconnectivity (water reuse and unconventional water sources in agricultural and energy policy; use of renewable energy sources in agricultural and water policy, among others) and its guidelines must advocate efficient and safe resources.
- Older laws need to be reviewed and updated in order to achieve higher interrelation between themselves and be more efficient and synergistic.
- The strengths identified in the laws must be strengthened with interconnected public policies aiming at greater efficiency in actions and the weaknesses must be carefully investigated so that they are eradicated.
- Current regulatory laws in the agricultural sector in Brazil need to consider water, energy, and technological efficiency as a prerequisite for releasing investment in sector projects and programs.
- The Brazilian energy sector needs to be tightly integrated with water and agricultural legislations, especially when referring to the biofuels and biodiesel policies that have a strong association with the agricultural sector. Some examples that characterize advances in the more intense approximation between the sectors under study in Brazil arose from the need to solve problems present in situations of a scarcity of a certain natural resource in common between them. In other words, because they share the water, energy, and agricultural risks and insecurities, they have tended, due to circumstances, to a greater recognition of the existence of interrelations and interdependencies between

them, which has fostered some joint actions. This represents management in a crisis; however, the nexus proposal is to make this interconnected management continuous throughout the process.

In order to achieve an efficient and synergistic inter-sectoral and shared management, changes in the medium to long term must be initiated by its institutional and legislative base. The proposed method represents an important factor in the change process; however, its individual application alone is not sufficient to achieve more ambitious goals in terms of operationalizing the main characteristics of the nexus concept proposed for this study. It should be noted that investigations about the practical effectiveness of the regulatory laws analyzed as well as their interference in society were not considered in this study. For this, it is recommended to structure research with this objective through the application of questionnaires, interviews, development of a focus group, or other methods that help to gather information about the applicability of these laws.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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