Review

A Literature Review to Propose a Systematic Procedure to Develop “Nexus Thinking” Considering the Water–Energy–Food Nexus

Cássia Juliana Fernandes Torres ^{1,*} , Camilla Hellen Peixoto de Lima ² ,
Bárbara Suzart de Almeida Goodwin ¹, Terencio Rebello de Aguiar Junior ¹ ,
Andrea Sousa Fontes ¹, Daniel Veras Ribeiro ³ , Rodrigo Saldanha Xavier da Silva ¹ and
Yvonilde Dantas Pinto Medeiros ¹

¹ Department of Environmental Engineering, Polytechnic School, Federal University of Bahia (UFBA), Salvador 40210630, Brazil; barbiesuzart@hotmail.com (B.S.d.A.G.); terencio.junior@ufba.br (T.R.d.A.J.); asfontes@gmail.com (A.S.F.); rssaldanha91@gmail.com (R.S.X.d.S.); yvonilde.medeiros@gmail.com (Y.D.P.M.)

² Civil Engineering Program, Alberto Luiz Coimbra Institute for Postgraduate Studies and Research in Engineering (COPPE), Federal University of Rio de Janeiro (UFRJ), Rio de Janeiro 21941909, Brazil; camillahpl@gmail.com

³ Department of Materials Science and Technology, Polytechnic School, Federal University of Bahia (UFBA), Salvador 40210630, Brazil; verasribeiro@hotmail.com

* Correspondence: torres.cjf@gmail.com

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Abstract: There is a growing interest in the literature on the theme of the water–energy–food nexus, as there is growing recognition that sectors that share natural resources have interdependent and interconnected systems. Despite the widespread popularity of nexus thinking, it still lacks standardized procedures and methodologies to assist in its development. Therefore, this paper proposes, from a literature review, a systematic procedure to assist in the development of management models based on nexus thinking. To this end, 304 papers were analyzed using the following criteria: nexus concept, type of approach, geographic scale, elements in the nexus system, application context, and types of assessment methods and tools. The results of the review served as the basis for determining the procedure, which consisted of four steps: (a) understanding nexus thinking, (b) identification of composing variables, (c) evaluation (diagnosis and prognosis), and (d) decision-making. In addition to the standardization of these steps, the main information used to compose the procedure was organized and synthesized with a mind map.

Keywords: Water–energy–food nexus; mind map; nexus concept; methodological development

1. Introduction

Generalized crises in the water, energy, and food sectors have compromised several regions of the world, aggravating the relationships between the availability and demand for those resources. Water scarcity and decline, unstable food supplies, energy uncertainties, and degradation of ecosystems are common problems that many countries have been facing. Projections up to 2050 indicate a global population growth that may reach approximately 9.8 billion [1]. The same projections point to losses in agricultural production ranging from 9% to 21% resulting from climatic interference [2]. Furthermore, water demand is estimated to increase by 55% [3]. In addition to the problems mentioned in these projections, crises and conflicts among different correlated sectors are intensifying in various locations, especially in Asia, Africa, and Latin America [4].

Existing interdependences among the variety of sectors that sustain the global economy involve five relevant aspects: (a) the fundamental elements of water, energy, and food are interlinked; (b) economic sectors have a relation to at least one of the three aforementioned elements; (c) alterations in any of those elements cause chain reactions in segments associated with them; (d) negative impacts generated by the consumption of those elements are passed on to society; and (e) the interdependences among those elements are increasingly apparent in this scenario of crisis and scarcity of resources [5–9].

Because of these aspects, the need to re-evaluate management models specifically, the availability of resources, and their implications in meeting the growing demands are imperative. Even though the interconnectedness of water, energy, and food systems is widely acknowledged, the sectors that represent them continue to formulate fragmented policies and projects. Fragmentation occurs especially for cultural reasons. The definition of plans, programs, and actions followed that conception, neglecting the necessary integration between the government and public policies.

For example, governments often design agricultural policies and subsidy programs, such as fertilizer regulations and their applied projects/initiatives, without considering the complexity of the links to energy and water in the production chain [10]. Similarly, in many countries, energy subsidies are provided to agriculture without considering their implications for surface water, groundwater depletion, and degradation [10]. Only in recent years has a growing concern developed for both the water and energy footprint of food products and the inefficiencies in agricultural production chains [11].

The adoption of unilateral plans and actions has been directed to solve the problems of a single sector. Throughout history, the lack of integration among the economic segments, associated with the adopted political models, pointed to several failures in reducing crises in the global system [12]. Governments take action, and companies or communities that affect a resource generally transfer the consequences to other resources, with the possibility of impacting the place where the process started, or to other correlated areas [4,5].

The recognition and increased visibility associated with the interrelationships among multiple sectors sharing natural resources was originally evidenced in the World Economic Forum (WEF) in 2008 [13,14]. Its concept has been defined as interdependencies and interconnections among water, energy, and food, in particular, involving widespread crisis scenarios and climate uncertainties [15]. Despite the relevance given to this theme at the forum, only in 2011 at the “The Water, Energy, and Food Security Nexus—Solutions for the Green Economy” conference was the nexus line of thought consolidated [16–18].

The main reasons behind the consolidation and growing visibility of the nexus concept can be associated with insecurities in water, energy, and food supply. Other contributing factors are the effects of climate change (such as droughts and heat waves worldwide), increasing demands for natural resources [5,19], and failures in management and governance strategies [5].

Insecurity scenarios can trigger social, economic, and environmental crises while also presenting opportunities to create solutions. Those answers can be discussions based on the search for solid and effective pragmatic ideas/proposals that meet the interests of multiple interconnected sectors aiming to reduce future environmental impacts. As part of the answer, the nexus theme has gained increasing space in the academic literature [20–22] as a solution to global challenges. The nexus field can also aid in achieving the United Nations Sustainable Development Goals (SDGs) [23] and the goals proposed in the Paris Agreement under the United Nations Framework Convention on Climate Change [17,24].

Since the consolidation of the nexus theme, several authors have highlighted complexities involved in their approach. First, one can recognize the lack of consensus in defining the concept of the term nexus [25,26]. Some define this term as a process for integrating and managing different sectors through joint coordination to promote sustainable development [26–28]. Other researchers consider it as a “new thinking” [8] or a “new integrated management paradigm” [5,29] to address global change and challenges; it is just an adaptation of principles and concepts that were already addressed in the

scientific field [30] or an approach to the treatment of externalities in various sectors, focusing on system efficiency rather than the productivity of isolated sectors [7], among other concepts.

In addition to the conceptual aspect, there are major challenges in its application and operationalization, such as (a) the need for innovative methodologies and decision support tools to deal with complex interrelationships, minimize investment risks, and maximize economic returns [10,31]; (b) nexus modeling [25,27,32]; (c) institutional, legal, and governance issues [33–35]; (d) spatiotemporal application scales [34]; (e) availability, access, and integration of all information [25,27]; and (f) monitoring advantages achieved by the practical implementation of the nexus concepts compared to the non-nexus context [30].

The intensity of these challenges varies from place to place. For example, regions that still have poor social–environmental perceptions and poor governance by companies, managers, and governments tend to complicate implementation of the nexus approach. In contrast, sites that have a consistent governance system and strong environmental awareness tend to facilitate their deployment. Therefore, the levels of complexity, time, and financial investments that involve a management model based on the nexus concept are dependent on the reality of each location and governmental priorities.

Given the specifics of each location and the challenges highlighted, previous research has addressed these relationships through case studies and literature reviews. Case studies involve sociopolitical realities at different scales (country, state, city, and organizations) [36–43] and the development of new methodologies and models [19,44–46]. There are also case studies that quantify the interrelationships between nexus elements. However, literature reviews focus on the concepts and methodologies applied to the nexus concept [27]. There are reviews of methods incorporating sustainable systems indicators (SSIs) used to assess water use in industries [43] and modeling approaches used for dynamic decision-making, the latter focusing on mathematical optimization, agent-based modeling, and game concepts [38]. Additional studies have addressed nexus thinking in the urban context [21] and different methods for comparing the level of tool complexity used in the nexus approach [37]. Finally, methods and tools for evaluating interlinks among nexus elements [25,27,28,47–50] to develop a framework of conceptual knowledge for scientific analysis and policy formulation associated with the urban nexus [22] have been proposed.

Despite the advances of the mentioned studies, there are still gaps to be overcome that motivated this research. The central point of investigation of this paper refers to the lack of standardized procedures and methodologies to assist in the development of “nexus thinking” [10,31]. To our knowledge, no review has focused on this aspect considering all the phases comprising a nexus approach, the synthesis of information for its application, and the interdisciplinary involvement of multiple contexts and variables.

Noteworthy are two methodological development studies for the assessment and implementation of the nexus concept at a river basin scale [11,12]. The first study comprises participatory principles directed to transboundary basins, based on qualitative (workshops, questionnaires, interviews, and follow-up meetings) and quantitative (indicators) instruments [12]. The second study presents a three-step approach applied at Rio Duero in Spain to identify interactions among sectors and discuss existing conflict mitigation strategies in the basin [11]. Both studies have different proposals compared to the procedure proposed by this research.

The elaboration of a nexus procedure intends to highlight the method for its implementation. That is, it presents a procedure that represents application steps clearly and synthetically. The steps tend to promote standardization in the use of this type of approach, which leads to uncertainty reduction in conceptual, methodological, and applied aspects. Therefore, to overcome this knowledge gap, this paper proposes, from a literature review, a systematic procedure to assist in the development of management models based on nexus thinking.

The research has two parts. The first part focuses on reviewing the existing literature. This review represents a meta-analysis of the scientific articles selected for the study based on six research criteria. All analyzed criteria correspond to a set of information and variables that must compose a nexus

approach. The results achieved in these analyses direct the second part of the study, which proposes a systematic procedure targeting standardization of nexus concept developmental steps.

2. Materials and Methods

The methodology consisted of (Figure 1) a systematic review of scientific articles and the proposition of a systematic procedure of the nexus concept. The first part of the methodology used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol [51]. The PRISMA protocol assists in the identification and selection of articles on search platforms. The second part was built based on the results achieved in the systematic review. In this case, it involved three analysis points: (a) composition variables of the nexus concept; (b) types of studies developed involving this approach; and (c) trend of these studies.

Figure 1. Flowchart of the methodological development.

2.1. Identification and Selection of Scientific Papers (Steps 1, 2, and 3)

All steps in this methodology were developed based on the PRISMA protocol [51]. Step 1 presented the research platforms used in this study: Web of Science, SCOPUS, and Google Scholar. For step 2, selection of the papers was conducted based on two aspects: (a) the keywords “water, energy, food, nexus” presence in the title, keywords, and summary of the files; and (b) papers published in the period 2011–2019 (2011 represents the reference year in which this theme gained visibility at the “The Water, Energy, and Food Security Nexus—Solutions for the Green Economy” conference).

Step 2 resulted in 4172 records from the three databases: 300 documents in Web of Science, 322 in SCOPUS, and 3550 in Google Scholar. All documents identified in Web of Science and SCOPUS also appeared in Google Scholar. Thus, after removing duplicates, the total number of papers selected for screening was 3550.

Step 3 consisted of sorting and selecting articles. For this, five filters were used: (a) research articles, review articles, and short communications (institutional documents including dissertations, theses, or technical papers were excluded); (b) internationally indexed papers with an impact factor greater than 1; (c) papers published in journals that addressed one of the four disciplines of approach to the nexus concept (i.e., the environment, energy, water and food, or agriculture); (d) articles published in journals exclusively from social and behavioral sciences (economics, chemistry, or geography) were excluded; and (e) articles explicitly employing the nexus concept in terms of natural resource sustainability [25].

After applying the proposed filters, 304 papers were eligible for this case study. The selected papers were analyzed based on the classification criteria described in the next section.

2.2. Analysis of Papers—Classification Criteria (Step 4)

The criteria represent the challenges listed in the literature regarding (see Table 1) nexus concept, type of approach, geographic scale, nexus elements, the context of the application, and method type and assessment tools. The definition of the criteria took into consideration the reviewed papers related to the theme [22,25,27,47]. It is worth mentioning that the analysis of each article used as a base the set of all defined criteria. The main purpose of this step was to understand the nexus theme coverage scenarios.

Table 1. Paper classification criteria.

Criterion	Description
Nexus Concept	Analyzes the dimension of the use of the term nexus in the literature and identifies the concepts worked by different authors related to this approach.
Type of approach	Categorized into conceptual and application papers. Conceptual papers represent “theoretical” work. The application papers refer to case studies.
Geographic scale	Global (world, sets of countries, continent); national (countries); regional/local (states, cities, communities, companies, etc.); basin (watersheds, sub-basins, cross-border basins, and rivers); and undefined (for works that did not define a scale because it was not an application/case study).
Nexus elements	We considered all the arrangements among the nexus elements found in the literature, encompassing multiple combinations.
Context of application	Divided into large and small areas. The large area corresponds to the disciplines defined according to the scope of the journal used in the article selection stage, namely, environmental, energy, water, and food/agriculture. The small area represents contexts inserted into each large area. For example, social and economic context as small area inserted in environment context as large area.
Method type and assessment tools	This criterion includes the following categories: qualitative—including the application of social science methods and instruments; quantitative—including the application of quantitative methods and instruments; and qualitative/quantitative—including papers that worked with qualitative and quantitative methods. The classification category of papers that did not use tools or methods is “did not apply tools or methods”.

The nexus concept refers to two qualities: (a) understanding of the growing interest in the nexus theme from 2011 to 2019; and (b) definition of its concept and the concepts associated with its approach, based on the systematization of the results of the reviewed papers. The identification of the aspects defined took into consideration the abstract, introduction, and results of the papers.

In the type of approach criterion, two main features will be highlighted: (a) “conceptual papers”, which focus on understanding the structure of interlinks among the nexus elements and analyze its principles, with a descriptive and discursive character; and (b) “application—case study papers”, which in most cases refer to a spatial area application associated with a methodological character. Both features were identified during the screening of the title, abstract, introduction, and methodology of the reviewed papers.

For the geographic scale, we considered the relationship of large (global), medium (national), and small (regional/local and watershed) scales in the application of the nexus concept. Their identification was taken from the title, abstract, introduction, and methodology of the papers. This criterion is strongly associated with the “type of approach criterion” since every application paper has a geographical scale.

In the criterion “nexus elements” the following compositions were considered: (a) two elements (Water–Energy); (b) three elements (Water–Food–Energy); (c) four elements (Energy–Food–Water–Land); and (d) five elements (Water–Energy–Food–Land–Ecosystem).

The definition of the “context of application” was performed by analyzing the abstract and the introduction of the papers. For this criterion two classifications were considered: (a) for the large area (environment, energy, water, and food/agriculture) from the scope of the journal; and (b) regarding the small area, which represents the central theme discussed in the papers in one of the four major areas defined. There were some cases where the scope of the journal fell into a specific area, such as the environment; however, the papers prioritized another segment, such as water or agriculture, more broadly. In this case, the classification followed the area prioritized by the article in its context.

The criterion “type of method and assessment tool” was identified based on the abstract, methodology, and results of the papers. The basis of identification used by this criterion considered: (a) the frequency of occurrence of models citations within the papers; or (b) those that did not were not cited within the papers but had characteristics present in their structure that allowed its use. This aspect is important because it allows the insertion of new tools not yet covered in articles involving the nexus theme. However, these are tools that have a structure to enable their evaluations. In addition to identifying the main assessment tools and methods, this paper presents a discussion of limitations in nexus modeling, to promote greater contributions to the scientific and applied literature. Examples of composing this criterion are in questionnaire applications, workshops, interviews, agent-based modeling, applications of the Delphi technique, mathematical modeling platforms, energy and mass flow modeling, indicators, multicriteria analysis methods, life cycle assessment (LCA), and input–output analysis.

The results found with the analysis of the criteria served as the basis for the elaboration of a systematic procedure to represent the nexus approach.

2.3. Elaboration of the Systematic Procedure of “Nexus Thinking” (Step 5)

The systematic procedure of nexus thinking represents the steps necessary to develop this theme in resource management systems, which requires understanding their characteristics, objectives, operation, composition variables, and trends. This information is part of the papers published related to the topic in question.

Therefore, to define the procedure, two points were considered: (a) bibliographic review highlighted in item 2.1, and (b) proposition of nexus concept development steps. These steps were defined to guide the development of future nexus research involving the development of conceptual models, methodologies, and decision support systems. The proposed steps followed a hierarchical order in which it was first necessary to understand what the nexus concept was about; then, its method of development must be defined; and finally, the ways to operationalize this approach must be known.

The results of the criteria analysis indicated in Table 1 were used to list the procedure composition variables. All variables must be part of the nexus procedure, although they may not all be used in its application. The definition of variables for an application will depend on the need for the study. Importantly, different compositions among variables lead to different results. For example, a study that considers watershed scale, groupings of three nexus elements (water, energy, and food), and the use of modeling platforms may have different results if one of these variables changes. Thus, the composition variables of a nexus procedure are dynamic, and their development steps are permanent for each application.

Mind mapping methodologies served as the basis for organizing the information and variables identified in the article review. This methodology, originally discussed by Tony Buzan, consists of creating links among ideas in a creative, unrestricted, and free way, represented in a hierarchical (radial) way [52]. The construction of mind maps can be employed in interdisciplinary areas, starting from a central idea. For this study, the central idea corresponded to the nexus concept. From it, the variables and concepts identified in the literature review were synthesized and associated.

3. Results and Discussion

This session will present the results found in the review of the papers (step 4) and the description of the systematic procedure of nexus thinking (step 5).

3.1. Results Found During the Analysis of the Papers

3.1.1. Nexus Concept

From the literature review, it was possible to notice a growing increase in the use of the term nexus in scientific papers (see Figure 2), especially from 2016 (79% for a total of 304 papers). Different authors have also highlighted the increasing attention paid to the nexus theme [22,25,27,30,53,54].

Figure 2. Results found regarding the year of publication of the papers.

This increase mainly was due to two aspects: the increased use of the nexus approach in global discourse and debates about the natural resources [54,55]; and the lack of clarity and consensus related to the presentation of its concept and application [30,55], which generates doubts and uncertainties that can promote research.

Therefore, it is possible to synthesize the nexus concept as a “multisectoral management tool” directed to qualitative and quantitative evaluations of interrelated and interdependent systems. Its objectives involve shared management, strategic and adaptive planning, formulation of correlated public policies, cooperation among multiple sectors, and application of sustainable methods in any context. Key features of this theme include networked, generalist, open, dynamic, multicentered, and multifaceted networked systems because the nexus concept is based on interconnections and is open to the existence of multiple interaction possibilities among different sectors, contexts, and scales. It has dynamism because it involves temporospatially modified elements, depending on the physical, economic, and political conditions, and the natural condition itself. It is multifaceted because it has varied characteristics defined depending on the situation employed. It is multicentered because all elements to be considered must occupy a central position where they all have the same level of relevance.

Because of these characteristics, it is possible to see that the nexus concept involves many variables interconnected through a networked system. For this approach to be better developed, a systematic procedure is required to coordinate its application, which involves understanding its theoretical

underpinning. In this sense, after a systematic review, thirty themes were identified associated with the nexus concept (see Section 3.2). This paper considered the following main themes that supported its formation: (a) sustainable development; (b) water, energy, and food security; (c) water and energy efficiency; (d) resilience; (e) multisectoral and multilevel governance, and (f) the green economy.

Sustainable development is the basic premise of the nexus concept as both have the same ideology of “using present resources without compromising service to future generations” [56]. Resource security is part of the objectives of sustainable development and corresponds to the main goals of the nexus concept: water security, ensuring the availability of adequate and reliable water resources [57]; energy security, “uninterrupted availability of affordable energy sources” [57]; and food security, “food availability, access, stability, and consumption” [57].

To achieve the security needed to obtain natural resources, the nexus proposal works based on the water and energy efficiency in different economic activities that depend on these resources. Water efficiency is associated with the use of clean technologies that minimize water consumption [9]. Energy efficiency refers to reducing energy consumption to achieve savings and reductions in greenhouse gas emissions [58]. Thus, greater energy efficiency results in higher shares of renewable energy [59]. Water and energy efficiency should be a strategic priority for all sectors [60], especially in times of climate instability.

The nexus concept points to resilience as a principle for managing the ability of its elements to cope with different environmental adversities, including the ability to adapt to climate change [61]. To address the adversities and complex interactions among disparate systems, multisector and multilevel governance is crafted as a tool to ensure the successful implementation this concept in management processes.

Governance represents a series of institutional rules, practices, and policies by which decisions are made and implemented [62]. These decisions represent the interests of different levels of society in a negotiated and equitable manner [62]. Multisectoral and multilevel governance implies a system that coordinates all sectors and scales in an integrated manner [7]. In the nexus concept, good governance represents the foundation of the success of its implementation in the management process.

Finally, the green economy is the basis for economic development with the least possible environmental impact. The green economy results in improved human wellbeing and significantly reduced environmental risks [63,64]. The themes identified in this section serve as an aid to the elaboration of future conceptual models.

3.1.2. Type of Approach

The first papers that appeared on the theme of the nexus represented purely theoretical and empirical studies (especially in the period from 2011 to 2013). These papers primarily considered characterization of the interconnections among water, energy, and agriculture systems. The characterization of these interconnections can be conceptual (without defining an area of application) [7] or applied in case studies [33,65,66].

Over time, new studies emerged that began considering the quantitative aspects of interconnections among nexus elements. Among the topics covered by these studies, it is possible to find discussions of (a) tools and methods capable of representing and quantifying interconnections, (b) the need to develop new methodologies and tools for more complex evaluations, and (c) the need to change composition and administrative planning involving institutional and regulatory aspects. The topics presented have been increasingly used by authors, especially applied to case studies.

Case studies have been used most frequently in nexus discussions, comprising 74% of all studies (225 out of 304 papers). The papers that included case studies especially contemplated two types of analyses: (a) nexus diagnosis, which involves recognizing the interrelationships among its elements for a given locality, and (b) analysis of future planning scenarios (prognosis). Both diagnosis and prognosis are relevant to for nexus concept application. Diagnosis is important because it shows

the local reality of the degree of interconnections among nexus elements. Prognosis is relevant for presenting projections of future scenarios of nexus approach development.

The conceptual category included only approximately 26% of papers (79 out of 304). Despite the predominance of case studies, 57% of the reviewed papers had a qualitative character and did not work with the quantitative aspect. The tendency for qualitative work reflected three issues: (a) the inherent complexity of nexus modeling; (b) the structure of the existing methods and models having inherent limitations; and (c) legal, institutional, and governance issues in the passage from theory to practice.

3.1.3. Geographic Scale

The management unit of the elements addressed by the nexus approach is organized at a variety of spatial scales. Using this wide range of scales makes it very challenging to characterize and manage interactions beyond their spheres of control and influences on their size [27,31]. The definition of the appropriate limit represents a very relevant factor, considering that the results vary according to the determined limit [27]. In this scenario, one should always consider three aspects: (a) small spatial scale (regional/local and watershed), although incorporating a smaller number of variables tends to result in a partial evaluation of the system because it does not consider all existing interconnections; (b) medium spatial scales (national), which generally present an ideal format for the application of the nexus concept because they cover variables and processes from all over the country, although the number of variables will depend on the size of the country under analysis; and (c) large spatial scales (global), which tend to have a larger number of variables and processes. Consequently, greater data requests increase the complexity of the evaluations.

The definition of geographic scale is essential to achieve an application of the nexus approach. In this case, every procedure for applying the nexus concept must use this criterion. Results show that 74% (225 out of 304 papers) used a geographic scale and 26% (79 out of 304 papers) did not use a geographic scale. Among the papers that used scale, 24% corresponded to the regional category, 19.1% to the basin category, 18.4% to the national category, and 12.5% to the global category (see Figure 3). From 2018 to 2019, the usage of a global scale studies decreased, and the regional scale and basin scale increased.

Figure 3. Results: (a) number of articles sorted by geographic scale; (b) geographic scale used in articles distributed by year of publication. *Papers that did not use the geographical scale.

The watershed scale is used more often in the context of water resources management/hydrology, water security, and ecosystem services. The global scale is mainly used in contexts of climate change and sustainable development. The regional/local scale is closely associated with urbanization contexts. At the national scale, we highlight the contexts of energy security, food security, and agriculture, among others.

There are some contexts that, although feasible on small scales, are influenced by larger scales. In an economic context, an example of this characteristic is the relationship between fuel price and food price [33]. Rising food price studies are usually conducted on a small scale (watershed, regional, local) and have a strong influence on fuel prices conducted on a large scale (global). Some analysis of interlinks among nexus elements demonstrate that a definition of only one type of spatial scale may not represent the full understanding.

3.1.4. Nexus Elements

The number of elements in the nexus structure has grown considerably, making room for other relationships with the earth, nutrients, and the climate, among others [47]. Although this progress is improving the resolution and analytical capacity of interactions among these resources, the demand for information has increased. The lack of information and the complexity associated with nexus interrelationships tend to hamper the usage of evaluation tools [47]. In practical terms, conducting joint evaluations among a large number of emerging nexus elements tends to achieve what some authors call “integrative imaginary” [54]. Table 2 illustrates the main arrangements among nexus elements identified in the review papers.

Table 2. Nexus elements identified in papers.

Subtitle	Initials	%	Source
Water–energy	WE	13.8	[67–70]
Water–food	WF	1	[71]
Ecosystem–water	EW	0.3	[72]
Energy–food–water	EFW	66.6	[73–77]
Water–energy–climate	WEC	1.3	[78]
Water–energy–ecosystem	WEE	1.6	[79,80]
Water–energy–carbon	WEC	1.0	[81]
Water–land–food	WLF	0.3	[82]
Water–energy–economic	WEE	0.3	[83]
Water–energy–environmental	WEE	2.6	[20,84]
Water–energy–land	WEL	0.3	[85,86]
Energy–water–agriculture	EWA	0.3	[87]
Water–energy–food–health	WEFH	0.3	[88]
Food–energy–water–waste	FEWW	0.3	[89]
Water–energy–food–environment	WEFE	0.3	[90]
Water–energy–food–land–climate	WEFLC	0.3	[91]
Water–energy–food–ecosystem	WEFE	3.6	[12]
Water–energy–food–land	WEFL	2.6	[4,8]
Water–food–nutrition–health	WFNH	0.3	[92]
Water–energy–food–climate	WEFC	1.6	[16]
Water–energy–climate–land	WECL	0.7	[93]
Water–energy–food–land–ecosystem	WEFLE	0.3	[94]
Food–water–energy–land–economic	FWELE	0.3	[95]

Elements are interpreted and defined differently in targeted study settings within nexus terminology. “Water” is the element found in all links, whether present in the association of two or more elements or not. Key definitions for the water element found in the articles include (a) conventional (surface water, rain, and groundwater) and unconventional resources (desalination water and wastewater) [96]; and (b) “green water” (rainwater), “blue water” (water in lakes, reservoirs, rivers, and aquifers), and “gray water” (wastewater) [97,98]. Among these definitions, gray, blue, and green water are approached in the context of agriculture, most frequently associated with water consumption in agricultural production systems (water footprint). One definition that has been gaining ground within the nexus approach is virtual water. This term has stood out in the relationship of virtual water consumption in power generation [79] and intrinsic virtual water in food consumption [74].

The “energy” element represents the second most used element in the links. Its definition has been used within energy services (generation, transmission, distribution) to develop transportation, heating, cooling, and lighting activities. Mechanical energy (work) and potential, kinetic, or chemical energy (i.e., that in chemical bonds) were not the focus of the reviewed papers. Among the energy typologies, bioenergy gained prominence. Some authors brought a strong competitive relationship between the production of agriculture and bioenergy [99].

Food represents the third most used element in the links. It has been addressed in the context of agricultural activities and is closely associated with food security. The concepts of water and energy footprints are widely applied methods in this category.

The other elements emerged from integrating these relationships, although less frequently. Some authors have imposed the ecosystem as a central element of the nexus because it is responsible for water, energy, and food production and is explicitly associated with ecosystem services [100,101]. The climate is most commonly addressed in association with climate change [78,102]. Land is, in most cases, used in the agricultural context and linked to bioenergy production, land use, or food production [91,102]. Nutrients are mostly linked to agricultural inputs [103].

Of the compositions among the different elements identified in Table 2, the original format (energy–food–water) of the nexus concept stood out with 66.6% of the analyzed work (see Figure 4). The second most used composition by the studies was water–energy with 13.8% (42 out of 304 papers). All other compositions among the nexus elements achieved lower frequencies of participation in the reviewed papers.

Figure 4. Results found: (a) number of articles classified by nexus elements; (b) nexus elements used in papers distributed by year of publication.

The composition of two elements was increasingly present in all the years of publication of the reviewed papers. The large participation occurred because of the greater simplicity in quantifying and representing the interactions between two elements. In contrast, papers that used five elements mostly occurred in qualitative studies, especially publications from 2019. Over time, the complexity of integrating multiple elements in a single evaluation system tended to reduce due to advances in nexus theme studies.

The criterion “nexus elements” represents the primary variable of the nexus procedure composition. Different associations among the nexus variables tend to get different outcomes. In some cases, one element may be more valued than another for a specific context. Users should avoid prioritizing one element over the others, as the nexus concept works in a multicenter manner, where all the segments involved should have the same level of relevance. These observations should be considered in the nexus procedure as well as the different views of each sector when implementing this concept.

3.1.5. Context of Application

The context directs the central point of investigation of a nexus study and must be defined in the development procedure. When context change occurs, other variables also tend to be changed, such as geographic scale, nexus elements, type of approach, or other variables. Despite the strong influence of this criteria, the studies should consider the central objective of the procedure that intend to represent the nexus concept, including identifying and evaluating the interrelationships among its elements to propose integrated planning scenarios targeting their implementation in multisectoral and multicenter management systems.

This objective directs the elaboration of development stages of nexus thinking without considering direct interference of the application context. Currently, it is possible to notice that the category that obtained the highest publication frequency was the environment (50%) followed by water resources (21%). It is possible to see an increase in the number of publications of papers related to energy (20.2%) and agriculture (10.1%), see Figure 5. Similar results are also present in other nexus studies [25], describing an assiduity of papers published in environmental journals. From 2017 to 2019, there was an increase in the number of publications in all considered contexts, especially in the energy segment.

Figure 5. Results: (a) number of papers classified by context; (b) context applied to papers distributed by year of publication.

Each area defined as large has a wide variety of contexts associated with them (small areas). In the area of “water resources”, most articles covered topics such as (a) reservoir operation [46,67,104], (b) water allocation [83,105], (c) integrated management [106], (d) integrated management directed to transboundary basins [12,67,107–109], and (e) dam construction and associated risks [61].

In agriculture, issues such as (a) irrigated agriculture [44,110], (b) wastewater treatment and reuse in urban agriculture [111], (c) food waste [112], (d) agricultural water management [71,113], and (e) the role of phosphorus (P) in nexus relations [103] were covered. In the energy sector, issues such as (a) bioenergy [86,114,115], (b) water consumption during energy production [116], and (c) impact on aquatic species through the release of thermoelectric effluents [68] were considered.

In terms of the environment, we found the widest range of contexts were studied within this approach, including themes involving (a) the circular economy [20,73,117,118], (b) ecosystem services [94,100,101], (c) the green economy [63], (d) sustainable development goals [17,119], (d) governance of nexus [75], (f) the nexus in urban systems [3,76,120,121], and (g) interdependencies between water and energy in environmental certifications [45].

Considering the topics covered in each area, one must consider that, although the present study did not include articles from journals exclusively from the social, economic, and geographical fields, the papers used during the review contained discussions involving the nexus concept and the fields above.

The main topics found in the reviewed papers included “politics” [75,122–125], “economics” [118], “climate change” [125–130], “water, energy and food security” [5,131], “crises and risks” [55,61,132], “sustainable development” [20,133], and “governance” [16,38,41,57,134].

3.1.6. Method Type and Assessment Tools

The criterion “method type and assessment tools” is one of the most discussed by authors in the literature [22,25,27,38,43,47] and has extreme relevance for assisting in the development of nexus procedure steps. Analysis of the papers revealed that any tool that can evaluate two or more systems (water, energy, food, land, and other elements) in an integrated manner could be employed as a nexus assessment tool as long as it used its approach. In this case, it is possible to align four study types involving this criterion: (a) studies that have tested tools from different areas adapting their use to address the nexus approach [78,114,135,136], (b) authors who have used combinations between different qualitative and quantitative tools and methods [26,84], (c) specifically reviewed studies for discussion of evaluation methods and models [22,25,27,38,43,47], and (d) research that has focused on developing new tools and methods [44,46,137].

Regardless of the type of study developed, it was recognized that a nexus tool must be flexible, dynamic, and interactive, and it needs to represent and evaluate the relationships among the systems considered. Additionally, it should consider the management and regulation of these resources, assist decision-makers in defining planning strategies and integrated public policies, make allowances for the development of socio-economic scenarios, subsidize trade-off assessments and synergies across multiple sectors, and allow analyses that consider the variability of spatial and temporal scales present in the systems considered. The literature analysis did not identify a model that responded to all highlighted aspects. What can be understood currently are tools that address one or more aspects mentioned.

The assessment methods and tools included are qualitative, quantitative, or qualitative–quantitative. The quantitative category represented 46% of the reviewed papers. Within this category, 39% were indicators and indices (such as water footprint, energy pinch, and LCA), 32% mathematical modeling platforms (WEF Nexus Tool 2.0; WEAP–LEAP: Water Evaluation and Planning system—Long-range Energy Alternatives Planning System; CLEWS: Climate, land, energy and water Strategies), 7% mass and energy flow models, and 22% comprised other methods and tools.

Papers that did not use assessment methods or tools accounted for a total of 29% (88 out of 304 papers). The qualitative and quantitative category occupied the third position, with 13% (39 of the 304 papers), followed by the qualitative category with 12% (37 of the 304 papers). Table 3 lists the main evaluation methods and tools identified in the articles analyzed. The third column of this table contains the calculation of the percentage for the usage of each method and tools per category (qualitative, quantitative, and qualitative–quantitative). The quantitative category considered 140 papers overall, while the qualitative category had 37 papers, and the qualitative–quantitative category had 39 papers (see Figure 6).

Figure 6. Results: (a) number of papers ranked for the criterion of method type and assessment tools; (b) key quantitative tools identified in papers.

Table 3. Main methods and tools identified in the literature.

Category	Method Type and Assessment Tools	%	Source
Quantitative	WEAP–LEAP—Water Evaluation and Planning system–Long-range Energy Alternatives Planning System	4.3	[78]
	WEAP AND Indicators	2.9	[42,128,138]
	CLEWS—Climate, land, energy, and water Strategies	1.4	[93,102]
	MuSIASEM—Multiscale Integrated Analysis of Societal and Ecosystem Metabolism	0.7	[139] *
	WEF Nexus Tool 2.0 AND Input–output analysis	0.7	[140]
	Nexus Assessment 1.0	0.7	[141] *
	PRIMA—Platform for Regional Integrated Modeling and Analysis	1.4	[142]
	SWAT—Soil and Water Assessment Tool AND Indicators	1.4	[101]
	SEWEM—System-Wide Economic–Water–Energy Model	0.7	[83]
	MODFLOW—Modular finite-difference groundwater flow	0.7	[29]
	LCA: Life Cycle Assessment	10.7	[74,77,143,144]
	Water Footprint	6.4	[71,145,146]
	Indicators and indices	20.0	[108,119,136, 147–149]
	Water Footprint AND LCA	1.4	[114]
	Input–output analysis	16.4	[18,150–152]
Qualitative	MCDA—Multicriteria Decision Analysis	5.7	[153,154]
	Sankey Diagram	7.1	[155]
	<i>Others</i>	17.4	[53,67,79,107, 127,129,130,135, 156,157]
	Application of questionnaires AND interviews	29.7	[89,158–160]
	Institutional Analyses	16.3	[161]
Qualitative and quantitative	Workshops AND focus groups	18.9	[23,162]
	Discourse analysis	10.8	[150]
	<i>Others</i>	24.3	[163,164]
	Modeling platform/Indicators and qualitative method	25.6	[84]
	Indicator and qualitative method	41	[12]
Qualitative and quantitative	Water and energy footprint AND GIS	2.6	[110]
	<i>Others</i>	30.8	[14,165,166]

* They are not scientific papers.

The wide variety of tools is often justified by the need to represent different associations among nexus elements. For example, analyses of the level of integration of public policies, stakeholders, and institutions can be improved and supported by social methods. Assessments of interrelationships between natural resources and economic activities could benefit from mass–energy flow models and indicators. Scenario analysis studies tend to use mathematical modeling platforms, while the decision support tool and multicriteria analysis methods are more frequently found in decision-making processes. To apply a nexus procedure in its entirety, one should consider using all of these tools.

Among the models presented, WEAP–LEAP [167] represents one of the most promising tools in the nexus approach analysis because it can integrate different systems (water, energy, food, and climate) and requires little input data. Furthermore, it has a user-friendly interface and allows monitoring the planning parameters that allow evaluation of climate change interferences to protect the population, among other aspects intervening in the sectors.

The CLEWS and platform for regional integrated modeling and analysis (PRIMA) platforms are open source-based models that integrate various models through their interfaces [33,47,102,142]. Multiscale integrated analysis of societal and ecosystem metabolism (MuSIASEM) is a web-based platform that, although it represents a viable framework for use in the nexus approach, has some

restrictions. Its interface is complex, there is difficulty in configuring relations between the biophysical and economic system flows, and it uses a large amount of information [47].

The WEF Nexus TOOL 2.0 and Nexus Assessment 1.0 are also websites, and they require less information. The WEF Nexus Tool 2.0 was initially designed for use in Qatar. Therefore, the model has some restrictions for application involving different contexts and scales [47]. Currently, this model has expanded to serve other regions [168].

The LCA was one of the nexus theme tools most addressed by researchers because of its three resource functions [49,74,77,94,169]. This tool allows the identification and evaluation of all inputs that make up a life cycle of a process or product to assist in the evaluation of transfers between them, and it allows quantification of the environmental impacts correlated to the system under analysis.

The water footprint represents one of the most simplified methods in the nexus approach in terms of data solicitation and evaluation. It is ideal for studying interrelationships among elements of the nexus as long as one of these elements is water (water–energy, water–food).

Multicriteria decision analysis (MCDA) in the context of the nexus can assist stakeholders in selecting and defining the best strategies and actions in the sectors as well as selecting the variables to be used in the structure. It also assists in the definition of the nexus planning spatial boundary and selection of key stakeholders in each sector of interest for decision-making.

In addition to the instruments used in the literature associated with this theme, the present study included two other instruments: the AQUATOOL model and conceptual/mental models, considering their promise. AQUATOOL was developed by the Political University of Valencia (UPV) and consists of a set of software directed to developing and analyzing decision support systems around the planning and management of watersheds. It is a relevant tool for integrated testing, creating a link among multiple types of software [170].

Conceptual models (MCs), created by Novak [171], are graphical tools for organizing and reproducing knowledge through concepts and propositions. Mind maps (MMs), proposed by Tony Buzan [52,172,173], are methods that link ideas and themes via links. Because of their characteristics, both methods are very important for structuring a nexus model because they represent interconnections among concepts, principles, and variables.

Statistical methods and geoprocessing tools were not considered in Table 3 because they are part of most papers that deal with data manipulation.

3.1.7. Limitations Involving Nexus Modeling

All models reviewed in this study had limitations and restrictions that were associated with the specificities inherent in each tool or method. In addition to the specifications of each model, limitations also occurred because of the low amount of information available in the line of interest. The literature showed that the main limitations associated with nexus modeling involved five aspects: (a) existing complexity when considering the three features and their dynamic interactions simultaneously in a single model [25,27,174]; (b) models capable of translating various categories of metrics involving water, energy, and food systems and correlated variables [27]; (c) sufficient databases to support integrated assessments [25,27,35]; (d) spatial boundaries of the system to be modeled [27]; and (e) the need for interdisciplinary modeling that combines qualitative and quantitative assessments [25].

This research adds some reflections targeting contributions to the area in question:

- (a) It is not pertinent to model a system that does not yet have a defined conceptual model, which generates many uncertainties about its representativeness.
- (b) For nexus modeling, it is recommended to restrict the central elements to be represented in its structure and to make the correlated secondary elements explicit, as they can perform quantifications considering all elements (e.g., water, energy, food, ecosystems, nutrients). This has emerged in the literature primarily (central) in a single model; currently, it is not tangible. Therefore, in this case, an assessment using a chain-integrated toolkit can be considered. Here, the result of one model is input to another [25,27,39].

- (c) A globally representative nexus model tends to be difficult to achieve today because of the lack of information linearity, significant differences in management models, and strong political and economic divergences.
- (d) The real need for new software to represent the interconnections of the nexus elements must be verified by the reality to be reproduced; a well-defined system can be quantified using a suitable set of tools.
- (e) To aid nexus modeling, it is opportune to envision developing a shared database, which will also be accessible, reliable, and leveled according to the kind and quality of information, as indicated in the literature. The lack of information, or lack of leveling among various data, is, without question, one of the biggest obstacles for modeling systematization. It is important to highlight that, in practice, there are information inconsistencies that should have been presented equally; however, they are made available by different institutions of the same sector in a divergent way. The leveling tends to withdraw the ambiguity of this information, when applicable.
- (f) This research believes it is essential to use GIS (Geographic Information System) tools in the nexus concept. The use of spatial databases is promising in small-scale discretization studies that lack information, such as small river basins studies.
- (g) Lastly, it is important to understand that some limitations in the nexus modeling studies can only be identified when the modeling is being performed. In addition, even if these limitations are solved throughout the years, it is not known what the advantages intrinsic to the implementation of nexus thinking are in more practical terms, once new challenges emerge with higher significance.

3.2. Systematic Procedure of “Nexus Thinking”

An overview of the data obtained from reviewing the articles highlighted several possibilities for using the nexus concept. Despite the great diversity found, it was possible to define a procedure that represents the studies involving this approach and allows the development of future research to be directed.

The definition of the procedure considered the nexus concept as a multisectoral, integrated management tool. Therefore, like any instrument, it needs a procedure to assist its operationalization. Furthermore, results found referring to the criterion “type of approach” showed that the nexus studies had a standard development that repeated each application, changing only its variables such as geographic scale, context, elements, methods, and evaluation tools, among others. This standardization helped in the definition of the nexus procedure composition steps (see Figure 7): (a) understanding of the nexus concept; (b) identification of intervening variables and factors (composition); (c) evaluation, which involves diagnosis and prognosis; and (d) decision-making. Table 4 displays the discretization of the procedure composition steps and also contains the reference of the papers that facilitated the elaboration of the procedure steps. It is important to note the following:

- (a) The concepts associated with the nexus approach presented in the first step (understanding the nexus approach) were present in most articles analyzed, especially articles classified as conceptual (theoretical).
- (b) The composition step was the result of papers that presented discussions mainly focused on territorial planning, interactions between nexus elements, and their intervening factors.
- (c) In the diagnostic step, papers discussing nexus assessment methods and tools were used as a reference for defining the “definition of assessment methods and tools” subcategory.
- (d) Most papers inserted in the prognostic step (scenario analysis) were also included in the diagnostic step.
- (e) The papers used as a base for the last step of the procedure, “decision making”, were case studies that focused on supporting decision-making processes.

Figure 7. Mind map of the nexus concept.

Table 4. Standardization of the systematic procedure composition steps to use the nexus concept.

Research Questions	1—Understanding the Nexus Approach	Description	Method Type and Assessment Tools	Source
What are the concepts associated with the nexus concept? How can the conceptual model be elaborated?	Literature review	State of the art	Conceptual models (MCs) and mind maps (MMs)	[5,8,14,16,17,20,22,30,32,36,54,55,63,96,112,131,133,146,169]
	Identification of associated concepts	Identification of the main themes associated with nexus concept and definition of its concepts		
	Relationships among concepts	Identification of links among concepts		
Expected outcome	Presentation of a conceptual model of nexus concept representation			
Research Questions	2—Composition	Description	Method Type and Assessment Tools	Source
At what scale? What are the composition elements? What are the main factors that interfere with the interrelationships among nexus elements? What are the links among elements?	Territorial planning	Definition of the geographical scale of application of the nexus concept	GIS tools, MCDA	[17,32–34,36,55,94,99,131]
	Definition of nexus elements	Definition of the social elements (actors, public policies, projects, and actions)		
		Definition of physical elements (natural resources, economic activities, and services)		
	Definition of Intervening Factors	Definition of factors that have interference in the interrelationships among nexus elements		
	Definition of links among elements	Identification of relationships among defined elements		
Expected outcome	Identification of the composition elements of the nexus concept and their interrelations			
Research Questions	3—Diagnosis	Description	Method Type and Assessment Tools	Source
What data are needed? How will the diagnosis be made? What methods and tools will be needed?	Identification and analysis of sectorial databases	Identification of available sectoral databases	Statistical methods, GIS tools, Mathematical modeling platforms; indicators and indices qualitative methods	[5,20,25,27,28,33,37,47,48,96,132,151,158]
		Primary data collection—in the field		
		Consistency and analysis of data collected in databases and the field		
	Definition of assessment methods and tools	Definition of methods and tools to assist in the diagnosis		
	Recognition	Assessment of interrelationships among social elements		
Evaluation of the interrelationships among physical elements				

Table 4. Cont.

Expected outcome		Current mapping of the interrelationships among nexus elements		
Research Questions	4—Prognosis (scenario analysis)	Description	Method Type and Assessment Tools	Source
What data are needed? What methods and tools will be needed? What are the proposed nexus planning scenarios?	Definition of planning scenarios	Projection of interrelationships among variables based on intervening factors (population growth, climate change, etc.)	Mathematical modeling platforms; indicators and indices; qualitative methods	[42,78,84,93,100,104,105,107,110,116,130,138]
		Projection of the sectoral structure (the organization and functioning of institutions and actors) and regulatory frameworks to meet the premises of the nexus concept		
	Definition of assessment methods and tools	Definition of methods and tools to assist in prognosis		
	Proposition of goals	Definition of strategies to implement the proposed short-, medium-, and long-term scenarios		
	Shared risk management analysis for all proposed scenarios			
Expected outcome	Prospecting nexus planning scenarios for a study area. Compare the results of the reference scenario (current diagnosis) with the projection scenarios (prognosis). Point out the advantages achieved for multiple sectors regarding the implementation of nexus development scenarios.			
Research Questions	5—Decision-making	Description	Method Type and Assessment Tools	Source
Who are the players/stakeholders? Were the management models pointed out in the nexus planning scenarios well accepted?	Definition of players/stakeholders	Definition of key actors in decision-making	Decision-Support Tool, MCDA, qualitative methods	[153,154,175]
	Decision-makers analysis	Profile analysis of the constituent actors of the decision process		
	Training workshops	Conduct training workshops to help decision-makers understand the nexus theme. The training must be continuous		
	Decision-making	Presentation of strategies for key actors and decision on whether or not to apply the nexus concept The decision on the implementation of the proposed nexus planning scenarios		
	Action plan	In case of approval, the definition of the actions to be implemented		
Expected outcome	The decision on the implementation or non-implementation of the nexus concept in management models			

The first part of the procedure dealt with the knowledge of the subject under study. For this, it is necessary to identify the concepts that are associated with its development and application. The main concepts identified in the literature review are in Section 3.1.1 (nexus concept) and Figure 7. The primary purpose of this phase assisted in the elaboration of conceptual models focused on the nexus approach. The user must have in mind that this phase can be done one time and reused in different ways or redone from scratch.

The second part of the procedure involved the survey of the procedure composition variables, which were divided into nexus elements and intervening factors. Nexus elements are natural resources, economic activities, services, and social elements (actors, institutions, policies, and others). Intervening factors are aspects that interfere in the interrelationships among nexus elements, such as climate change, population growth, geographic scale, and context, among others. The results found in the analysis of the geographic scale, application context, and nexus elements criteria were used as a basis for gathering nexus composition information.

At this stage, the geographical scale (global, national, regional, and watershed) and the interrelationships among the nexus elements were determined. The scale is crucial for the application of the procedure, as it delimits the coverage limit and the interactions among nexus elements that guide the development of all other procedural steps. Interactions can occur between resources and activities (e.g., water and energy consumption in agricultural production); resources and services (energy consumption in water supply systems); among resources, services, and activity (energy consumption in wastewater treatment from industrial, domestic, and agricultural activities); and among their own resources (water needed to maintain the integrity of aquatic ecosystems). The number of interactions among these elements works based on combinatorial analysis; that is, the greater the number of elements, the greater the number of interactions among them.

It can be seen that the variables were dynamic in the procedure, as not all will be considered in an application. The choice of composition variables and their intervention factors is variable for each study according to its context and objective. The definition of these components will influence all other parts of the procedure.

Once the variables of the composition are defined, the evaluation phase of the interrelationships among nexus elements followed; it was divided into diagnosis and prognosis. Diagnosis represents a current assessment of the reality of interconnections, while prognosis represents the analysis of future scenarios.

The diagnosis phase recognized the interrelationships levels among the elements as well as challenges and limitations that surround its implementation. The development of this phase directly depends on the availability of databases from all sectors involved. For the treatment and analysis of information present in databases, potential tools are statistical methods, GIS tools, or other methods or tools directed to this purpose. Low data adherence makes it impossible to diagnose the relationships proposed by the nexus concept duly. Initially, it is interesting to analyze the types of databases present in the study area to define strategies to make the diagnosis possible.

Subsequently, it is possible to construct a prognosis that refers to planning scenarios for application of the nexus concept (contemplating short-, medium-, and long-term forecasts). These scenarios try to represent, from simulations, the likely implementation of this concept in a local management reality. Thus, the greater the level of integration among the multiple sectors—and the greater the sustainability of actions, plans, and projects practiced by these sectors—the easier the proposed scenario implementation becomes.

For both the diagnostic and prognostic phases, it is advisable to use integrated qualitative and quantitative assessment methods and tools. Nexus evaluations involve analysis of the social elements (analysis of the level of integration between institutions and sectoral legislation) and quantitative interlinks among physical elements (relationships of demand, consumption, and impact on the interaction among water–energy–food elements). In both cases, analysis considers at least two to three distinct elements, which, when evaluated together, can cause the insertion of a large number of

variables into the system. In cases where assessment tools and methods are not sufficient or significant to represent the complex interactions among nexus variables, proposing new tools and methods that address these specificities could be a solution. The main tools and methods are presented in 3.1.6 (method type and assessment tools).

Following the prognosis, the last step of the procedure consisted of making a decision about the application use of the nexus concept in management systems, actions, and projects. During this phase, the profile of players/stakeholders is defined and analyzed to allow empowerment of the decision-makers. It is not possible to make a decision of what is not known. To facilitate decision-making, sectoral actors should be presented, and the technical and economic feasibility of implementing these scenarios understood. Presenting the technical and economic feasibility is necessary because no manager or policymaker will make the time and financial resources available to invest in an approach that does not present sufficient arguments for its implementation. The action plan defines, after approval by the decision-makers, the actions that will enable the implementation of the proposed scenarios.

The decision-making process presents the biggest challenge in the nexus procedure. The great complexity involves intrinsic subjectivity in the actors that make up a decision process. Any decision, whether or not to implement the nexus concept in a management model, is the responsibility of a group of actors, and these actors have different ideologies, thoughts, and a strong influence on the economic–political model practiced in their respective countries. Thus, the subjectivity becomes a facilitating or hindering item of the process.

3.3. Summary of Information Required for Nexus Procedure Development

There is significant demand for information to enable the development of the steps defined in the nexus framework. These can be obtained from sectoral databases (secondary data) or via field collection (primary data). Databases can be classified into three types: (a) characterization—data presented to describe some characteristics of a sector, without monitoring the information presented (for example, the descriptive profile of a power plant that does not present its production capability); (b) productivity—data presented in a format that allows its manipulation, with its data being monitored (for example, production history of a plant exposed in Excel spreadsheets); and (c) documentary—data presented in technical and scientific documents, published in journals, theses, and reports, among others.

For productivity databases, the information presented may vary depending on time scale—daily, weekly, monthly, yearly—or a different scale. It may also vary based on the data monitoring period, whether the period is historical (sequence of observations of data continuously collected over a period of time for regular intervals) or restricted (no data observation sequence, information is presented for irregular intervals). In addition, the spatial scale and types of data presentation quantities, such as volume, flow, and production, may impact the information presented, as may the information spatialization or georeferencing.

The forms of data presentation and their level of monitoring are relevant for the development of the diagnostic phases and definition of nexus planning scenarios that imply the use of models and evaluation methods. Key information regarding the use of these instruments includes:

Qualitative evaluation—social elements [41,84,88,91,122,150,158–161,164]

- (a) Historical context analysis: social, demographic, economic, political, and cultural relations present in the area of study;
- (b) Analysis of the composition and operation of the sectoral structure: number of institutions and actors, legislations, and governance;
- (c) Characterization of the level of integration of the sectoral composition.

This section also includes socioeconomic variables, including population dynamics, trade relationships, cost of inputs over the course of production, and changes in land use, income, and metabolic pattern of modern societies [83,139].

Quantitative evaluation among links—physical elements [42,44,53,67,79,83,91,104,107,135,139,168]

- (a) Water: water availability (surface, underground); unconventional water sources; quantification of water consumption for irrigation, energy technologies, industry, and human supply; reservoir physical and operative data (initial volume, maximum volume, dead volume, quota $\times$ volume and quota vs. area curve, evaporation, observed volumes, operating volumes); water quality; sediment transport; and georeferenced data.
- (b) Energy: definition of primary and secondary energy sources; hydroelectric power generation data (turbine maximum flow, energy demands of the reservoirs in operation); quantification of energy needs for human supply (pumping, treatment, and distribution); quantification of energy needs for agricultural (crop, harvest, fertilizer, machine, and transportation) and livestock production; and georeferenced data.
- (c) Food/Agriculture: crop surveys by river basin district; areas irrigated by crop; irrigation systems and management used; climate data collection for the region's climatological water balance (actual evapotranspiration, monthly precipitation, effective precipitation); land use, soil–water movement; surveys of the inputs used in crop production; water and energy consumption in agricultural production and livestock (pumping, agricultural machinery, among others); environmental impacts of a product, process or system; and georeferenced data.

This information can be worked on in systems that consider the following: relationships between availability and demand of natural resources (consumption relations); trade-offs present in nexus relations; synergies and conflicts among sectors; scenarios that consider the interference of climate change and population growth in the water, energy, agriculture and ecosystem segments; governance relationships; service and product life cycle analysis; sustainable production; environmental impacts on the relationships among nexus elements; loss and risk systems; urbanization; relationships with ecological variables (e.g., ecosystem services and ecological dynamics); among others.

After the diagnosis and prognostic phases, three questions must be answered: (a) What changes in sector regulatory frameworks need to be made to implement a nexus approach? (b) Is there interest on the part of the sectors to implement the nexus concept, or is there resistance to change? (c) Is the implementation of the nexus approach technically, economically, and operationally viable? The answers to those questions aid in increasing reliability during the decision-making process. Over time, these doubts will tend to be reduced due to the need to work with integrated networks in cross-sector management models to deal with the complex dynamics of environmental problems and the world economy itself.

4. Conclusions

The literature review shows that the nexus concept can be understood as a multisectoral management tool that works on interconnected and interdependent network systems among different elements, especially water, energy, and food. The nexus approach has advanced significantly over the years in recognizing the interrelationships among its elements and in ways to support its evaluation and application. However, it is still centered on theoretical and investigative discussions. More practical aspects of the application of this approach tend to occur in the long run. It is necessary to continue advancing the concept to achieve better strategies for the viability of its operationalization.

From the analyses of some articles, we found that the insertion of new elements (climate, land, ecosystem, carbon) in the nexus system, in most cases, results in qualitative studies. Quantitative studies involving nexus modeling generally focus on two or three elements, and certain elements are given more prominence depending on a specific context. For example, within the context of water resources, the emphasis is given to the problems and views of the water sector compared to other sectors. Consequently, the water element stands out in relation to the other elements. The same is true when the context is changed for the agriculture/food and energy segments. After 2018, the number

of articles using the watershed scale and analysis of nexus relations for urban contexts (cities) has been highlighted.

Based on the results of the existing literature review, it was possible to determine a systematic procedure for the development of “nexus thinking.” This procedure characterizes the approach variables and synthesizes them through a mind map. The composition steps of this procedure include thematic understanding, analysis of the nexus concept composition elements, evaluation of the inherent relations among these elements, and decision-making.

The main challenges in the application of this procedure are the evaluation and elaboration of decision-making processes. The evaluation requires a large amount of data and models capable of representing the complex interactions among its elements. To date, no nexus model capable of representing all of its interactions and variables has been identified in the literature. The decision-making process involves a large number of actors, policies, management systems, and governance.

In general, the level of complexity present in the operationalization of the proposed procedure varies from place to place because of the discrepancies present in the sectoral relations and among their elements. This includes differences in data monitoring, technological advances, political, economic, and cultural aspects.

As guidelines for future studies involving the nexus theme, it is possible to point out the following:

- (a) Elaboration of conceptual models based on the first step (understanding of the theme) of the proposed procedure. Little has been done to identify detailed associations among all concepts associated with the nexus concept targeting their real understanding, integration, and functionality within this approach. In addition, the construction of conceptual models that also contemplate the other stages presented is recommended. The mind map can assist in this process by synthesizing and organizing a large amount of information necessary for its development;
- (b) Construction of specific methodologies for a particular area of study based on phases two (composition), three (diagnosis and prognosis), and four (decision-making) of the procedure. Developing methodologies tend to facilitate the application of the nexus approach for a given geographic scale;
- (c) Improvements, adjustments, and validation of all proposed procedures, targeting greater precision, and more specific and directional researches for this aspect. Currently, studies that address the nexus approach do not consider all its application phases, making it difficult to understand the totality of its process, its real limitations, and associated challenges.
- (d) Based on the procedure, proposed decision support systems should be designed based on multisectoral integration. That is, any decision-making involving policies, plans, projects, and actions of a particular sector must include trade-off analyses and impact assessments of all related sectors before being approved and implemented. This system tends to minimize conflicts, increase synergies, and target investments more consistently.

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