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**BIBLIOMETRIC ANALYSIS OF THE SCIENTIFIC PRODUCTION OF THE
WATER-ENERGY-FOOD NEXUS
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***Abstract.** This paper analyzes, through a bibliometric review, more than five years of research of the water-energy-food nexus proposal. The study aims to provide a comprehensive review of intellectual production on the topics presented by researchers between the years 2012 and 2020. The technique for conducting a thorough analysis of the work, with a total final sample of 605 articles, originates from the bibliographic database of Scopus with the aid of the SciMAT software. Based on the data sample, it was possible to make associations and analogies with the groups formed by their similarities, their authors, their periods and their keywords, in addition to detailing the processes for a rigorous study in the software. The article contributes to the identification of future studies in the area, as it shows the contents that are not yet mastered but must contain a higher level of available information to innovative themes.*

***Keywords:** water-energy-food nexus, bibliometrics, food security, sustainable development.*

1. INTRODUCTION

Global demand for water, energy, and food is driven by rapid population growth, urbanization, and climate change and it is estimated that the increase is expected to reach more than 50% by 2050, compared to the 2015 level (Ferroukhi et al., 2015). This increase could put enormous pressure on the existing water, energy and food systems, which are already limited due to competing resource needs in different parts of the world. Most importantly, water, energy and food are interconnected. For example, extreme droughts caused by climate change can lead to significant food and energy security problems due to intensified stress on the water supply.

Under such circumstances, the concept of nexus water-energy-food was designed to study and manage global resource systems (for example, water, energy and food) comprehensively (Smajgl et al., 2015; Yilread, 2016). Sustainable management and the efficient use of water, energy and food can help achieve the Sustainable Development Goals (SDGs) established by the United Nations (UN). On the other hand, the population growth rate and the economic development driven by the industry cause wear and tear on the natural resources available to meet the growing demand for water, energy, and food (Sarkodie et al., 2019). Water availability is critical to the effectiveness and efficiency of energy technologies, while energy in effect is essential to supply water for the production of agricultural activities, industrial, and domestic supply in areas with water scarcity (Edenhofer et al., 2011).

Although the concept of nexus be promising, yet, counterfactual changes determine its effectiveness in achieving sustainable development or same deny sustainability. According to Sarkodie & Owusu (2019), a conceptual structure of the external factors affecting the nexus water-energy-food are identified in two ways, namely physical and social changes, which can have chronic or acute consequences in the structure of the nexus. Environmental pressures, such as climate change - in the form of intermittency and fluctuations in weather patterns, such as changes in temperature, radiation, precipitation and wind, hamper energy, food, and water productivity. Poor management of infrastructure, land

use, waste generation and depletion of natural resources are also examples of environmental pressures that affect the structure of the nexus. The pollution events and natural hazards, such as earthquakes, cyclones, floods, extreme temperatures and droughts, disturb the ecological system, thus affecting the functionality of food and water energy. Pressures from livelihoods such as urbanization, population growth, economic development, lifestyle consumption patterns, among others, exist as driving factors for anthropogenic greenhouse gas emissions – the resulting effect that disrupts food, water and energy security. The effect of socio-political pressures such as technology, science, innovation, research and development, regulations and policies seems to cushion the nexus water-energy-food and stimulate its functionality. The conceptual structure of external factors reveals that the nexus water-energy-food is not an independent concept, but it depends on several physical and social factors to serve its purpose.

Thus, the evaluation strategies of the nexus water-energy-food employed in this study analyzes the existing literature using the bibliometric technique – where bibliographic information about the published work, data quality and quantitative techniques were applied to empirically investigate academic documents between the years 2012 to 2020.

2. METHODOLOGY

In this research, the bibliometric indicators of the nexus food-water-energy theme are highlighted, based on the database of the Scopus platform. The generation of the analysis mapping was performed using the SciMAT software.

2.1 Database (Scopus)

Initially, the Scopus platform was used to select the database. The platform, which has more than 69 million records, offers access to the database of citations in several areas of study (Moral-Muñoz et al., 2020). The selection of keywords related to the theme of this research allowed a detailed choice of documents for the bibliometric analysis.

The words were selected according to the titles most used by researchers in the field. However, as the words were tested in the “Advanced Search” command on the website, it was observed that their writing order directly influenced the results of the documents. As a result, more than five attempts were made to explore the way the website progressed in the results as the sequence of terms varied. Table 1 shows the final search in Scopus and the number of articles associated with it. After choosing the keywords, the types of documents were delimited. Only articles from journals, conference proceedings and reviews were considered, as these were analyzed more relevant for the purpose of the work to assess the progress of the most abundant content related to the water-energy-food nexus theme.

Table 1. Final research to build a database on the Scopus platform.

Scopus Search	Number of Articles
(TITLE-ABS-KEY ("few nexus" OR "fwe nexus" OR "wef nexus" OR "wfe nexus" OR "efw nexus" OR "ewf nexus")) OR ((TITLE-ABS-KEY ("water, energy, food nexus") OR TITLE-ABS-KEY ("water, food, energy nexus") OR TITLE-ABS-KEY ("food, water, energy nexus") OR TITLE-ABS-KEY ("food, energy, water nexus") OR TITLE-ABS-KEY ("energy, food, water nexus") OR TITLE-ABS-KEY ("energy, water, food nexus"))) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "cp")) AND (LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR,2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012))	605

2.2 SciMAT Software

After selecting the database, a systematic analysis was carried out with the purpose of investigating the research field and its thematic evolution. The SciMAT software (website:<http://sci2s.ugr.es/scimat>) was the main tool for this investigation as it provides most of the utilities available in scientific mapping softwares (Cobo et al., 2011).

The databases from Scopus were exported with the RIS format, then added to SciMAT and finally the remaining steps were divided as shown in Figure 1.

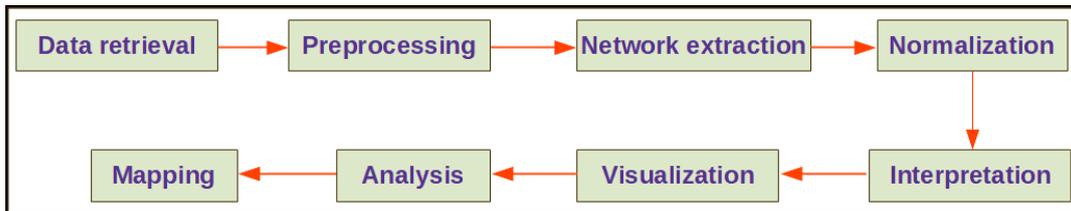


Figure 1. Workflow of scientific mapping.

3. RESULTS

3.1 Analysis by authors and documents

Initially, the main results of the SciMAT and Scopus software were selected. The first six authors with the greatest influence in the study area were analyzed, based on the number of published documents: Mohtar, RH with 10 documents, Taniguchi, M. with 8 documents, Liang, S., Ringler, C. Rulli, MC and Venghaus all with 7 documents (Figure 2).

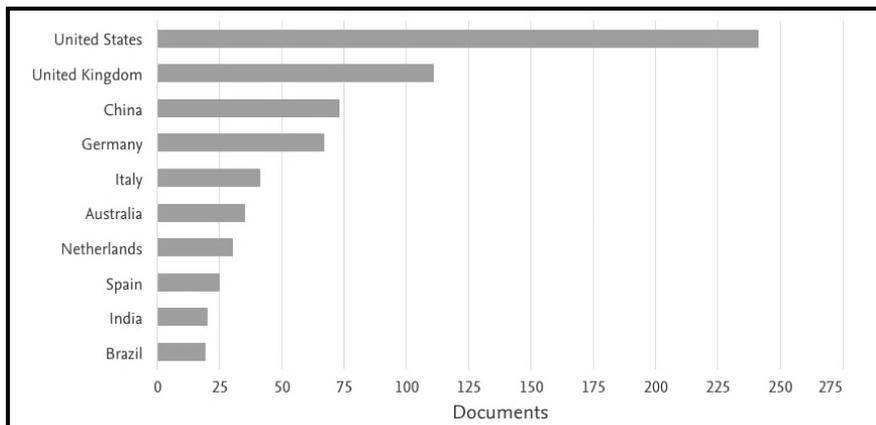


Figure 2. Authors with the largest number of documents in the Scopus search base using the keywords in Table 1.

When investigating the affiliations of each of the featured authors, a greater notoriety was noticed in countries such as the United States, United Kingdom, China, Germany and Italy. As shown in Fig. 3, three of the aforementioned countries have the highest number of publications on the topic in the past twenty years.

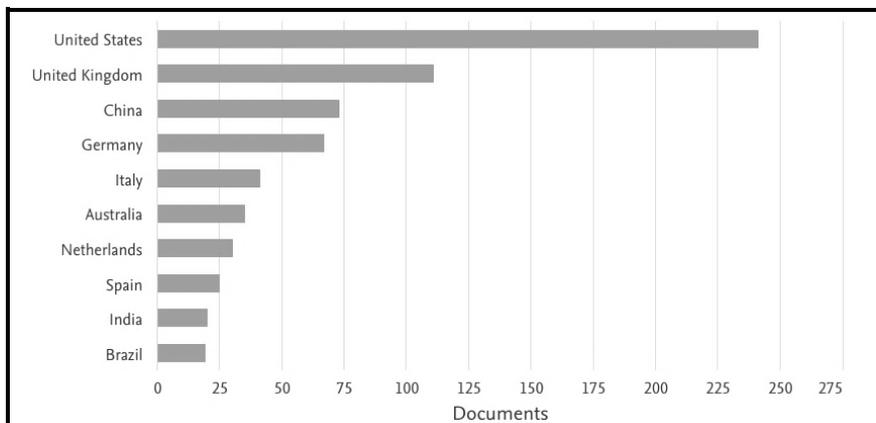


Figure 3. Countries with the largest number of documents in the Scopus search base using the keywords in Table 1.

Querying the database on Scopus resulted in a total of 605 documents between 2012 and 2020. Figure 4 below illustrates the number of documents per selected period. The first period (2012 – 2014) corresponds to only 3.64% of the documents attached for analysis. Even though there is an evident difference in the number of articles from the selected periods, for a more detailed analysis, the division every three years between 2012 and 2020 was necessary, because in the first years the quantity was insufficient to be divided in just one year. In addition to the purpose of uniform annual division of periods, every three years, many social, political and environmental changes have taken place in the world, making the published content innovative and diverse.

The second period (2015 – 2017) has a total of 200 documents, while the last period (2018 – 2020) has 92% more when compared to this value, with 384 documents. Evidently, since 2011, the approach to this theme has grown every year. This growth may have been driven by the perception arising from the importance of the theme for sustainable development throughout the world.

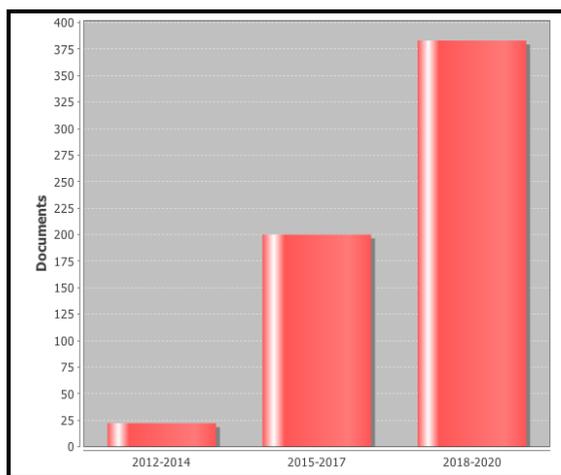


Figure 4. Number of documents per selected period.

3.2 Analysis by word

Figure 5 shows the map of overlapping terms, that is, the variation of words over the three analyzed periods. The words that remained in use are represented by the arrows to the right, those that are no longer used are represented by the up arrows, and the words that have been added are represented by the down arrows.

The increasing number of words over the three periods is directly proportional to the number of documents. Analyzing the word distribution, the first period contains 271 terms, of which only 166 continued to be cited in the following interval. In the second interval there is an increase of 1532 new words, representing 90% of the total for that period. For the last period, only 46% of the total words were included, leaving 918 terms and entering 2485. Thus, the variation of words from one period to another is significant, which indicates that the most talked about topics within the nexus content can present innovative characters for this area of research.

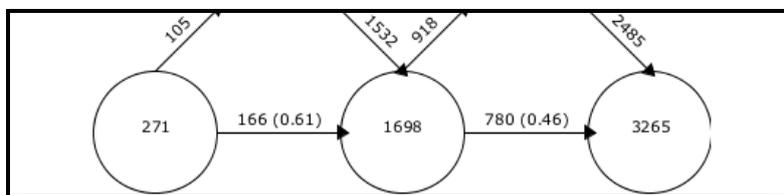


Figure 5. Longitudinal view - Map of overlapping terms.

In Figure 6, the conceptual evolution of the water-energy-food nexus can be seen. This longitudinal view allows to identify part of the main keywords, even the transitory and new items of each period, and those that remain for two consecutive periods (Cobo et al., 2011). Each column represents an annual grouping: 2012 – 2014, 2015 – 2017 and 2018 – 2020 respectively. It can also be added that the first spheres of each column are the most relevant words of the theme, according to the selected years.

When observing the evolution map and the development of the themes of the nexus water-energy-food research, most thematic areas present connections of different intensities between the selected periods, in other words, they are grouped directly or indirectly into similar or equal topics. This occurs because certain broader themes are inserted in more specific titles that tend to deepen the content over the years.

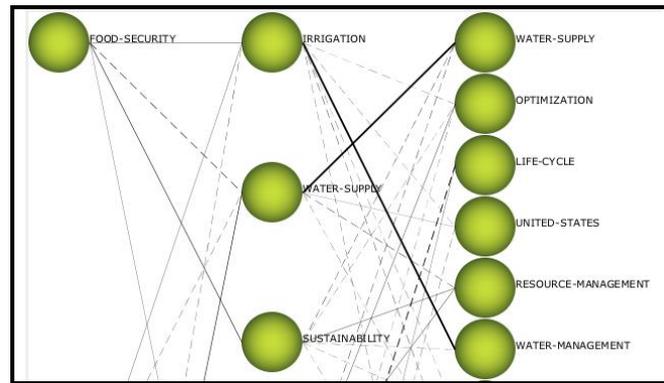


Figure 6. Longitudinal view - Evolution map.

3.3 Analysis by period

The distribution of words from the first period (2012 – 2014) is shown in the strategic diagram in Fig. 7a (Callon diagram), in which the study was highlighted in three main topics: food security, watersheds and climate change. The motor theme of this period is food security with a high index of centrality and density; therefore, it is considered a developed theme and of great importance for this field of research. As shown in Tab., the performance of this main theme is more than double compared to the other words, which proves its essentiality. In addition, this network has greater connections with the topics of sustainable development, water management, food supply and water resources (Figure 7b).

The theme of climate change, located in the quadrant of basic and transversal themes, even with few citations and low development, is considered a relevant topic for research. In the fourth quadrant, there is the hydrographic basin network, which, although it is a developed theme and with a high number of citations, is still far from the other research areas of that period.

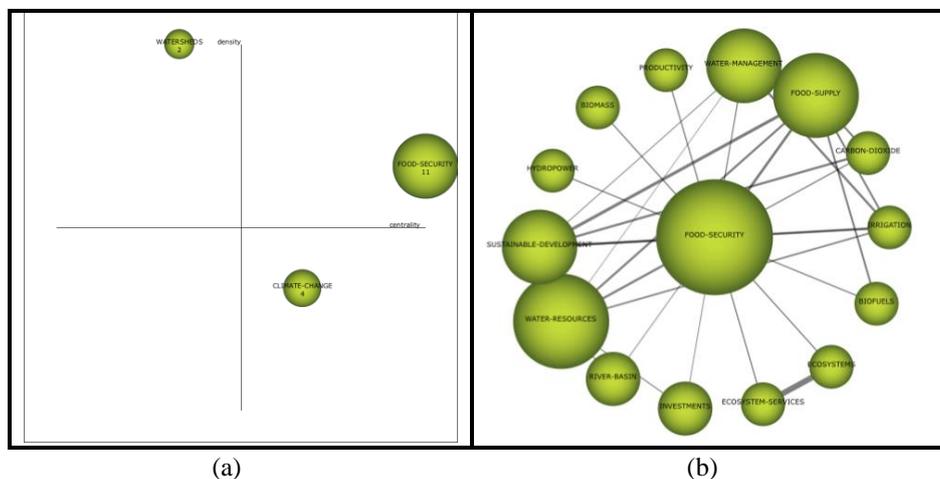


Figure 7. Strategic diagram for the 2012 – 2014 period.

Table 2. Performance of keywords for the period 2012 – 2014.

Name	Number of documents	Number of citations	h-index
FOOD - SECURITY	11	483	10
WATERSHED	2	284	2
CLIMATE-CHANGE	4	25	2

In the second period (2015 – 2017), with a total of 200 published documents, there was an increase in the number of keywords. Figure 8a presents the motor themes – water supply and irrigation – with different impacts. Water supply

according to Tab. 3 has more citations and a higher h-index. However, both themes are important for the base of the research according to the high levels of density and centrality.

Agriculture and water management are the keywords with the greatest connection to the motor theme irrigation (Figure 8b), while for water supply the main connections are with sustainable development, water resources and climate change (Figure 8c). In addition, the basic and transversal themes - water-energy-food nexus and sustainability - received many citations and have a high h-index, showing influence for research even though they are not yet well developed.

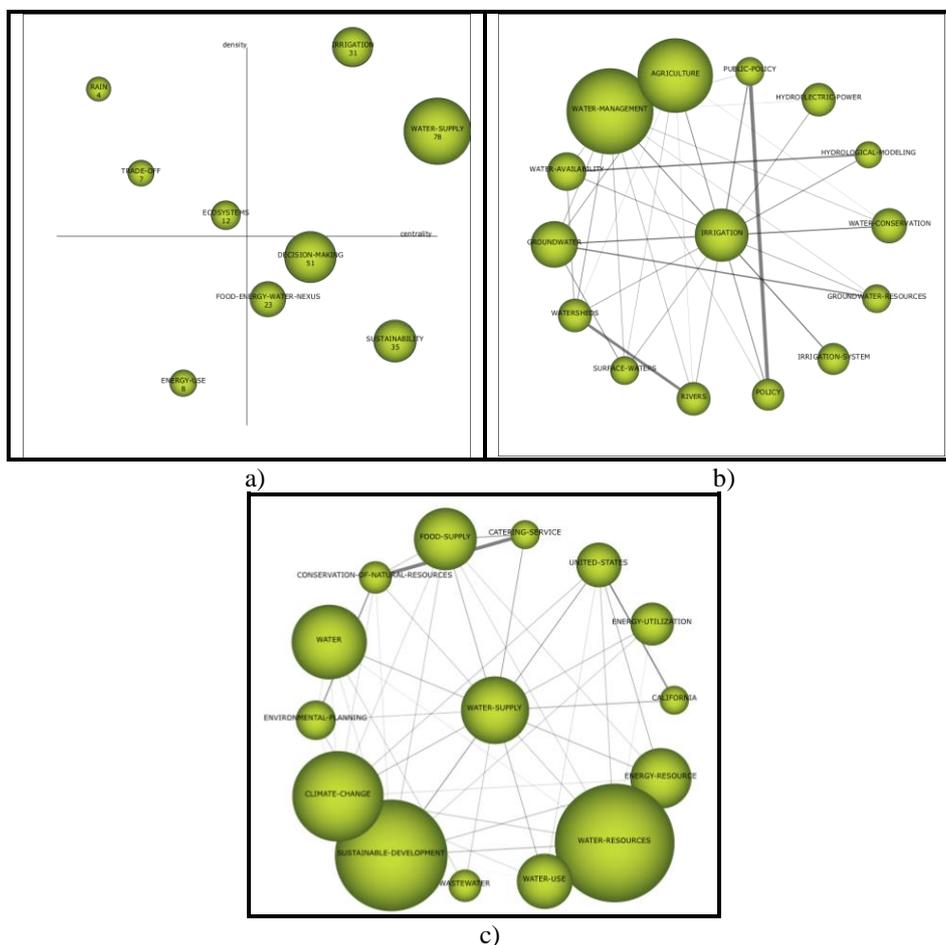


Figure 8. Strategic diagram for the 2015 – 2017 period.

Table 3. Performance of keywords for the 2015 – 2017 period.

Name	Number of documents	Number of citations	h-index
WATER-SUPPLY	78	2419	28
DECISION-MAKING	51	1804	24
SUSTAINABILITY	35	1043	18
IRRIGATION	31	590	15

Finally, the 2018-2020 period contains the largest number of published documents, therefore, the largest number of keywords for analysis of the strategic diagram. According to Fig. 9a and Tab. 4, it can be seen that the water supply motor theme has a very high density and centrality index, in addition to having a high impact in terms of document quantities and the h-index. This theme is in almost 85% of the documents from that period. Finally, it is important to note that water supply was also a driving theme in the previous period, which indicates great relevance in the studies of this research.

For the other motor themes of this period - optimization, water management, life cycle - the number of citations and the h-index are reduced to the point that they have less impact when compared to water supply. However, even though they are individual clusters, these keywords have important relationships with each other. This analysis can be seen in

the production of food with high consumption of water and energy, in which the optimization of these limited resources is significant especially in developing countries with an agricultural base.

Figure 9b shows a better distribution of the words connected to the water supply motor theme. The most closely linked keywords are: water resources, sustainable development, climate change and water. When comparing this map with Fig. 8c, it is possible to analyze that many words still remained in use.

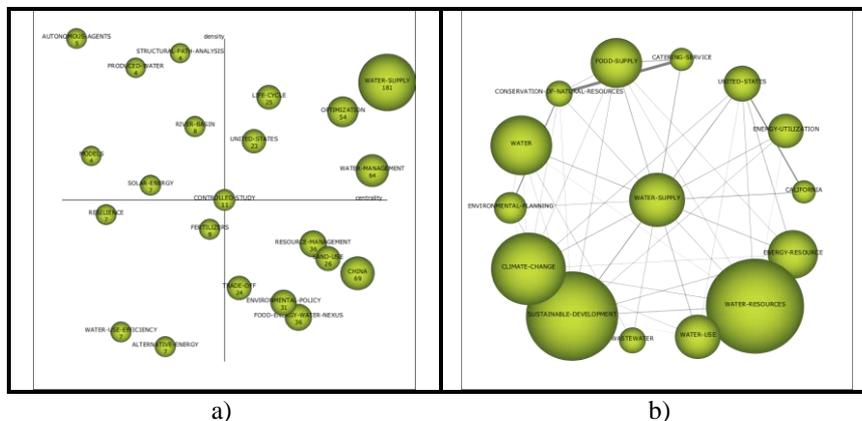


Figure 9. Strategic diagram for the 2018-2020 period.

Table 4. Performance of keywords for the period 2018-2020.

Name	Number of documents	Number of citations	h-index
WATER-SUPPLY	181	1.609	22
OPTIMIZATION	54	529	12
LIFE-CYCLE	25	198	18
WATER-MANAGEMENT	64	485	12

4. CONCLUSION

The theme water-energy-food nexus shows an increasing evolution in its area of research, mainly from 2012 after the conference “The Bonn 2011: Water, Energy and Food Security Nexus – Solutions”. An impact was observed among the most varied areas of scientific studies due to a greater understanding of the interrelationships of water, energy, and food resources, which allowed a more systemic view of the subject. However, even with the recognition of these interdependencies, there are still many topics that need to be developed. In addition, it was possible to notice that the evolution of the approach to the topic in question has an innovative character due to the significant variation of words, especially between the years 2015 to 2020.

Currently, the most developed themes are related to the management of water resources and water supply. However, it is worth mentioning that these themes have direct impacts on other resources (energy and food), but due to the complexity of this interconnection, relations among them are still very limited, especially when the analysis chain increases. Therefore, to facilitate this understanding, the approach should also guide countries to include these relationships mainly in environmental policies and in resource management, topics that have been underdeveloped, but essential for the area of study.

On the other hand, several studies have shown that the water-energy-food nexus may have been influenced by the economic structure of a given country. More industrialized countries invest more in energy technologies, while countries that depend on agriculture invest more in water resources. In this way, structural adjustments in economic development may determine the importance of the water-energy-food nexus in sustainable development.

Finally, this research sought to show through the distribution of words involving the main terms of the Nexus that there is a lack of research aimed at this area. The resources, water and food, have strong relationships between them according to the diagrams, while the energy appears in less sections and with less development. However, for the nexus approach, bringing energy, mainly renewable energy, to other resources is a challenge that still requires strong research.

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6. RESPONSIBILITY NOTICE

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