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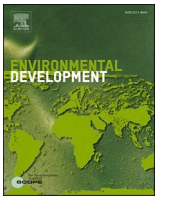

Approach on water-energy-food (WEF) nexus and climate change: A tool in decision-making processes

Gricelda Herrera-Franco [a,b,*], Harry Alberto Bollmann [c], Janaina Camile Pasqual Lofhagen [c], Lady Bravo-Montero [d,e], Paúl Carrión-Mero [d]

[a] Pontifícia Universidade Católica Do Paraná (PUCPR), Programa de Pós-graudação Em Gestão Urbana, Rua Imaculada Conceição, 1155, Curitiba, Brazil
[b] Facultad de Ciencias de la Ingeniería, Universidad Estatal Península de Santa Elena (UPSE), La Libertad, P.O. Box 240204, Ecuador
[c] Pontifícia Universidade Católica Do Paraná (PUCPR), Rua Imaculada Conceição, 1155, Curitiba, Brazil
[d] Centro de Investigaciones y Proyectos Aplicados a las Ciencias de la Tierra (CIPAT), ESPOL Polytechnic University, Guayaquil, P.O. Box 09-01-5863, Ecuador
[e] Facultad de Ciencias Naturales y Matemáticas (FCNM), Campus Gustavo Galindo, ESPOL Polytechnic University, Guayaquil, P.O. Box 09-01-5863, Ecuador

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ABSTRACT

Climate change has influenced the demand for natural resources, such as water, energy, and food. This study aimed to analyse the relationship between the Water-Energy-Food (WEF) nexus and climate change through a review and analysis of scientific publications to discern trends towards sustainability. The methodology adopted in this study involved i) selection, processing, and merging of databases; ii) a bibliometric analysis; and iii) a systematic literature review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses methods. The findings of this study reflect a strong relationship between the WEF nexus and sustainability influenced by climate change, which highlights the need to balance natural resource availability, growing population demand, and productive activities in a given territory. The bibliometric analysis performed in this study included interactions between the WEF nexus and climate change by considering 1,220 scientific publications from the Scopus and Web of Science databases that covered policy, sustainability, management, and governance aspects. Based on five keyword clusters of the WEF nexus, climate change, and sustainability, it also extracted the research directions from the systematic literature review of 104 documents. This study summarises the interest in the WEF nexus and highlights that the utilization and management of the natural resources of a region so as to balance the WEF nexus and climate change is among the most significant challenges of the 21st century.

1. Introduction

Climate change has caused severe impacts in recent years (Bunsen et al., 2021; Hua et al., 2020; Pueppke, 2021; Steffen et al.,

* Corresponding author. Pontifícia Universidade Católica Do Paraná (PUCPR), Programa de Pós-graudação Em Gestão Urbana, Rua Imaculada Conceição, 1155, Curitiba, Brazil.
E-mail addresses: grisherrera@upse.edu.ec (G. Herrera-Franco), harry.bollmann@pucpr.br (H.A. Bollmann), janaina@maxc.com.br (J.C. Pasqual Lofhagen), lkbravo@espol.edu.ec (L. Bravo-Montero), pcarrion@espol.edu.ec (P. Carrión-Mero).

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2015). Additionally, population growth, and economic growth drive resource demand, making the interrelationship among energy, food, and water relevant (Chai et al., 2020; Li et al., 2021). Major problems facing humanity include energy, food, water, health, the environment, education, war, and democracy. All of these, except for democracy, strictly depend on energy availability (Armaroli and Balzani, 2007; Paehlke, 1995). Owing to population and consumption growth under the limitations of water, energy, and food, the global focus of the 21st century is on sustainable development (Barbier and Homer-Dixon, 1999; Zisopoulou et al., 2018). Therefore, in recent years, there has been a paradigm shift in global thinking towards sustainability as significant challenges to a resilient global socio-ecological system remain to be met, as specified in the Sustainable Development Goals (SDGs) (Krauze and Wagner, 2019; ONU, 2018). Humankind is experiencing a series of challenges to the resilience of the global socio-ecological system and developing an expanding array of capabilities to better understand and manage its complex and coupled dynamics (Scott et al., 2015).

The energy-water nexus exists because water is involved in the production of many types of energy, and energy is used in water supply and wastewater treatment (Kirchem et al., 2020; Waughray and The World Economic Forum Water Initiative, 2011). Similarly, the water-food nexus emerges from the interaction of these resources in crop irrigation, food processing, and agricultural production (Bieber et al., 2018; Heard et al., 2017).

Understanding the nexus among water-energy-food systems governs our ability to meet current global challenges (Doherty et al., 2019). The formally accepted concept of the water-energy-food (WEF) nexus first appeared in 2008 (Hellegers et al., 2008), and the purpose of the WEF security Nexus was elaborated upon in the Water-Energy-Food-Security Nexus conference held in 2011 (Hoff, 2011; Keskinen and Varis, 2016). This nexus consists of "improving water, energy and food security, increasing efficiency, reducing compensation, creating synergies and improving governance in all sectors", ensuring that the interdependency between WEF security is "explicitly identified in decision-making" (Hoff, 2011).

Decision-making processes require effective tools that provide allocation strategies and a better understanding of the trade-offs between the different nexus systems (Daher and Mohtar, 2015; Lawford, 2019). Some tools that address the WEF nexus are described below.

1. Water Evaluation and Planning uses an integrated approach to water resource planning (SEI, 2014).
2. The Long-range Energy Alternatives Planning System is associated with energy policy analysis and assessment of climate change mitigation (SEI, 2013).
3. Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism is a method used to characterise the flows of different systems within society (FAO, 2013).
4. Climate, Land, Energy, and Water Strategies further developed an integrated systems approach to determine the interactions among interconnected sectors (OpTIMUS, 2013).

An essential aspect of the water crisis is the competition for this resource between the food and energy industries, which could dominate the debate on water security for decades to come (D'Odorico et al., 2018). For example, a food crisis occurred in June 2008 due to increased prices (McMichael, 2009; Rosset, 2008), financial speculation, depreciation of the United States (US) dollar, low interest rates, and reductions in grain stocks (Headey, 2011).

Various factors influence an energy crisis, including demand growth, challenges, environmental impacts of energy use, and supply security (Armaroli and Balzani, 2007; Schlachter, 2010). Therefore, given the rapid growth rates of population and consumption and the limited natural resources, it is crucial a perform the WEF nexus analysis and develop technological innovations to respond to the increasing demand (Brown et al., 2019; Derby et al., 2020; Dossey et al., 2016; Knorr and Augustin, 2021).

The concept of the WEF nexus is not unified as the nexus changes depending on the sectoral integration approach and the geopolitical context (Salam et al., 2017). The main variations in this nexus are three-fold. First, the WEF nexus, which promotes the water and sustainability issues, helps to strengthen communication mechanisms and approaches to collaborative governance (Biggs et al., 2015; Lawford et al., 2013). Second, the food-energy-water (FEW) nexus is the interconnection of the leading resources in a region, showing a strong relationship with urban sustainability (Kurian, M., & Ardakanian, 2015) and the co-evolution of urban infrastructure systems (Chang et al., 2020). Finally, the water-food-energy (WFE) nexus is a new perspective on balancing the potentially conflicting sectoral imperatives of large-scale development investments related to energy, water, or food security (Smajgl et al., 2016).

The WEF nexus is mainly used in academia as it is vital for developing a sustainable and secure future for all nations and regions (Gulati et al., 2013) and achieved only with adaptive management approaches based on Integrated Water Resources Management (IWRM), social learning, and resilience (Allan et al., 2013). Therefore, the WEF nexus is essential for developing a region, avoiding risking the security of one resource over another, and looking for alternatives that can help increase the response or efficiency of the region (Medeiros et al., 2020).

There is a growing interest in the WEF systems, as they provide new research directions and opportunities in the future growth of sustainable bioproducts and innovative research and development (Hersh et al., 2019). Although it is essential to explore this new topic in scientific and literary reviews and bibliometric analysis, a bibliometric mapping of knowledge structure and pathways about the WEF nexus remains poorly explored (Fernandes Torres et al., 2019; Opejin et al., 2020; Sarkodie and Owusu, 2020; Zhu et al., 2020). In this study, we integrated a bibliometric analysis with a literature review to analyse the emerging WEF nexus within the framework of climate change. Previous studies have developed different methodologies to approach the WEF nexus, such as management models of resources (Rosa et al., 2018), governance policies (Li et al., 2019a; Sharma and Kumar, 2020), and watershed management-oriented sustainability (Fader et al., 2018; Yi et al., 2020).

Considering the above background, the following two research questions were formulated: what are the research trends and their

key lines of study pertaining to the WEF nexus and climate change? And how are the studies on the WEF nexus and climate change related to decision-making? This study aimed to answer these research questions to analyse the relationship between the WEF nexus and climate change through a review of scientific publications to discern trends towards sustainability.

The primary resource applications involved in the WEF nexus are summarised in Fig. 1. Water is used in various processes, including irrigation (Siebert et al., 2010), food processing (Cath et al., 2006), extraction (Herrero et al., 2006), mining (Szkokan-Emilson et al., 2014), hydropower (Ellabban et al., 2014), bioenergy feedstock production (Ciolkosz and Wallace, 2011), transportation (Uibu et al., 2009), waste disposal (Grimm et al., 2008), emission control (van Vuuren et al., 2011), and construction (Khayat, 1998). Energy is used in fertilizer production (Galloway et al., 1995), agricultural machinery (Pretty, 2008), food preservation and processing (Datta and Henry, 2006), transport (Nykvist and Nilsson, 2015), water supply (Jacobson, 2009), water pumping and distribution (Oberle et al., 2017), water and wastewater treatment (Mohan et al., 2014), seawater desalination (Elimelech and Phillip, 2011), operating and maintaining water-supply facilities (Vilanova and Balestieri, 2014), pumping irrigation water (R. Lal, 2001), and the fulfilment of end uses (Sadeghi et al., 2020). Finally, food is used in commodity markets (Gilbert and Pfuderer, 2014), financial capacity (Bosona and Gebresenbet, 2013), importation (Barrett et al., 1999), agricultural growth (Infante Amate and González de Molina, 2013), national exports (Karlova and Serova, 2020), and health safety education (Redmond and Griffith, 2003).

2. Materials and methods

The methodology adopted in this study consisted of a systematic literature review and a bibliometric analysis (Herrera-Franco et al., 2021b), with the following three stages: i) selection, processing, and merging of databases; ii) bibliometric analysis; and iii) systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Fig. 2).

2.1. Selection, processing and merging of database

The databases most frequently used in bibliometric analyses are Web of Science (WoS) and Scopus (Echchakoui, 2020; Gorraiz and Schloegl, 2008). In this study, WoS was used as it provides information since 1900, covering approximately 13,000 journals and 256 disciplines (Archambault et al., 2009; Emmer, 2018; Martín-Martín et al., 2021; Moral-Muñoz et al., 2020). Scopus was used owing to its global coverage of abstract and citation indices of peer-reviewed literature, including multidisciplinary and emergent research approaches (Baas et al., 2020; Sánchez et al., 2017; Sweileh, 2018). Search and database compilation criteria were the strategies used to obtain relevant results (Palacios-Marqués et al., 2013; Saunders et al., 2009). Keyword selection was based on the WEF nexus and its combinations because they represented the same concept towards the sustainable development and management of natural resources

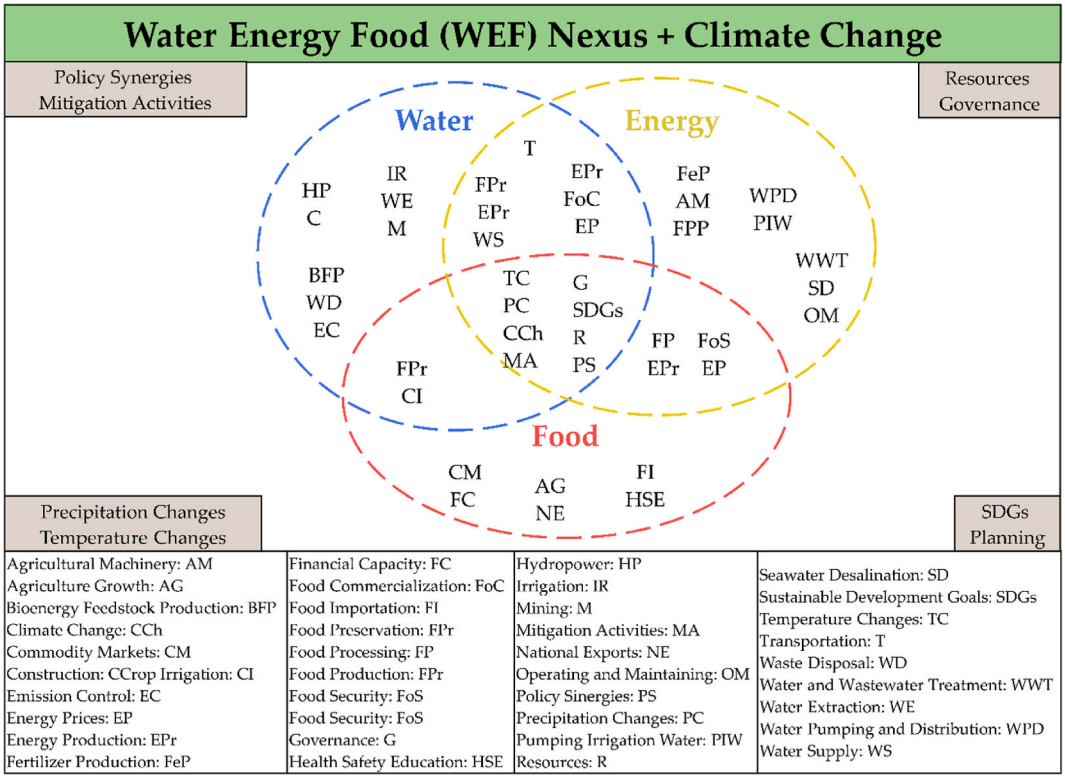

Fig. 1. Conceptual scheme of the relation between WEF Nexus and climate change.

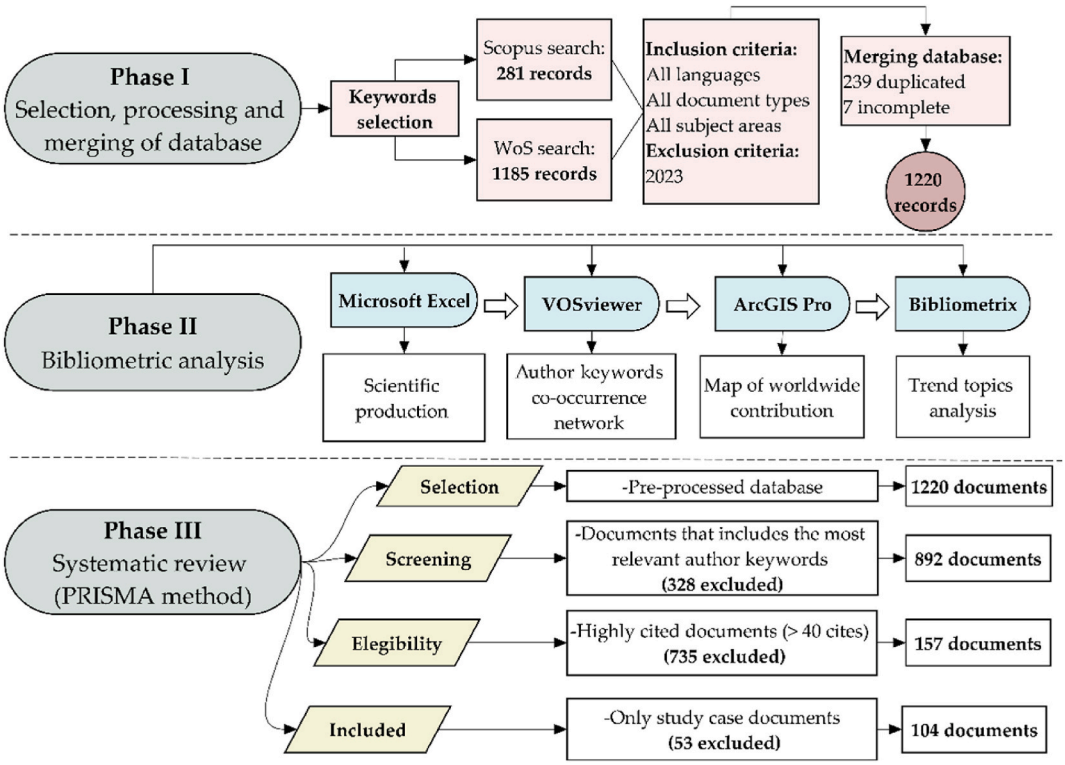

Fig. 2. Methodological scheme.

(Chang et al., 2020; Greer et al., 2020; Gulati et al., 2013; Kurian, M., & Ardakanian, 2015; Zhang et al., 2018a).

This study related the WEF nexus to various issues, such as climate change impacts and livestock production (WEF nexus) (Abulibdeh and Zaidan, 2020; Sobrosa Neto et al., 2018; Zhang et al., 2018b), hydroelectric project impacts (WFE nexus) (Amjath-Babu et al., 2019), circular economy services (FEW nexus) (Allan et al., 2015), and bibliometric studies (Zhu et al., 2020). Thus, the topic search included these three nexus combinations and the term "climate change" as a criterion related to the nexus variables (Endo et al., 2017; Kurian, M., & Ardakanian et al., 2015; Smajgl et al., 2016). The topic search was conducted in December 2022, and the downloaded databases (Scopus and WoS) were merged using RStudio, the integrated development environment for R software, and the package "bibliometrix" using the WoS format (Aria and Cuccurullo, 2017).

2.2. Bibliometric analysis

Bibliometric analysis enables a better understanding of the intellectual structure and dynamics of the knowledge domain of a specific field (Gaur and Kumar, 2018) and the evaluation and quantification of its performance (do Prado et al., 2016; Pritchard, 1969). Bibliometric maps present a two-dimensional scenic structure in a given field (van Eck and Waltman, 2010) and have been applied in various knowledge domains (Homrich et al., 2018; Hou et al., 2018; Luz, 2021). These analyses emerged in the mid-twentieth century (Huang et al., 2014) and have since ventured into some fields of study (Herrera-Franco et al., 2021a; Juan F. Velasco-Muñoz et al., 2018). After the databases were merged, the following softwares were used for bibliometric analysis.

1) Microsoft Excel was used for data tabulation and analysis of scientific knowledge production and was used for database post-processing (Kovačević and Hallinger, 2020; León-Castro et al., 2021; Najmi et al., 2017).
2) VOSviewer, a free application to create maps of bibliometric networks connected by nodes, was used to map the co-occurrence of keywords and analyse clusters of elements, such as authors, countries, keywords, and journals (Herrera-Franco et al., 2022; Shah et al., 2019; van Eck and Waltman, 2017; Yu et al., 2020).
3) ArcGIS Pro was used to generate a map of contributions of countries worldwide.
4) Bibliometrix, an RStudio package, was used to generate the graphs of top trending topics and their evolution.

2.3. Systematic literature review (PRISMA method)

A literature review serves to characterise the intellectual state of a topic, compile information based on eligibility criteria, reduce biases and errors, and identify possible knowledge gaps in research efforts (Higgins and Green, 2019; Marchiori and Franco, 2020;

Mentzer et al., 1995; Tranfield et al., 2003). A traditional literature review assesses the mastery of a pre-determined topic (Boell and Cecez-Kecmanovic, 2015). However, a systematic literature review comprehensively analyses all available information to answer a research question (Kitchenham et al., 2009; Morante-Carballo et al., 2021). Combining a systematic literature review and bibliometric methods provides research hot topics, main research trends, and influential actors (journals, authors, institutions, or articles) (Herrera-Franco et al., 2021b; Oh and Lee, 2020; Solórzano et al., 2022).

This study developed a systematic literature review using the PRISMA method. Publications for the systematic review were selected according to the following three criteria.

1) Publications that included the most relevant keywords were obtained from the co-occurrence analysis of authors' keywords, selecting the most representative clusters.
2) The documents had a citation range of 0–432, of which those with the highest number of citations (>40) were selected, which represented 8.52% of the entire database.
3) Case studies focused on the relationship between the WEF nexus and climate change.

Subsequently, a recognition matrix was developed that included the main items for the systematic review analysis (e.g., publication year, authors, research variables, study area, methodology, findings, number of citations, and references), which comprised 104 publications.

3. Results

3.1. Database analysis

The topic search used "titles, abstracts and author keywords" as a search variable in Scopus and "title, summary, author's keywords, and keyword plus" in WoS. Additionally, the search strategy included all languages, document types, and subject areas (Table 1).

Bibliometrix enabled the deletion of duplicate and incomplete records; ultimately, 1,220 publications from 2012 to 2022 were obtained (Fig. 3).

3.2. Analysis of scientific knowledge production

The publications on the WEF nexus included 848 articles, 138 reviews, 39 editorial materials, 19 meeting abstracts, 53 book chapters and books, 87 proceedings, and 87 conference papers. In recent years, the scientific knowledge production on WEF Nexus has shown an increasing trend (Fig. 4).

2012–2015: Interest in this topic arose in 2011 with the WEF Security Nexus conference (Hoff, 2011). In the databases used in this study, the first publication related to the WEF nexus was Voulvoulis (2012), which reviewed water reuse through desalination process as a management strategy for the WEF nexus. In 2013, Lawford et al. (2013) concluded that the WEF nexus is an effective vehicle to promote water and sustainability issues and received 91 citations. Finally, in 2014, Daccache et al. (2014) explored the political implications of understanding the WEF nexus and strategies to save water, reduce CO_2 emissions, and intensify food production.

2016–2018: Interest in this subject increased during this period. The most cited publication (276) was Biggs et al. (2015), who proposed an integrated framework to measure and monitor environmental safety, thus meeting the requirements of the WEF nexus. Furthermore, Conway et al. (2015) highlighted the strong connections between climate change and the WEF nexus in South Africa. Rasul et al. (2016) proposed a conceptual framework that considered the WEF nexus and its relationship with adaptation to climate change in South Asia. Additionally, Smajgl et al. (2016) identified the advantages of a balanced and dynamic approach to the WFE nexus in the Mekong River Basin, Asia. Moreover, Al-Saidi and Elagib (2017) showed the need to incorporate problems into the WEF

Table 1
Final topic search.

Database	TR	Search Strategies	TD
Web of Science	Search basic	TS=("Water-Energy-Food Nexus") OR TOPIC: ("Water-Food-Energy Nexus") OR TOPIC: ("Food-Energy-Water Nexus") OR TOPIC: ("WEF nexus") OR TOPIC: ("FEW nexus") OR TOPIC: ("WFE nexus") AND TOPIC: ("climate change") Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI–S, CPCI-SSH, BKCI–S, BKCI-SSH, ESCI, CCR-EXPANDED, IC. Timespan: All years Documents: All documents Exclusion criteria: 2023	1185
Scopus	Documents search	TITLE-ABS-KEY ("water-energy-food nexus") OR TITLE-ABS-KEY ("water-food-energy nexus") OR TITLE-ABS-KEY ("food-energy-water nexus") OR TITLE-ABS-KEY ("WEF nexus") OR TITLE-ABS-KEY ("FEW nexus") OR TITLE-ABS-KEY ("WFE nexus") AND TITLE-ABS-KEY ("climate change") Timespan: All years Documents: All documents Exclusion criteria: 2023	281

TR: Types of Research; TD: Total of Documents.

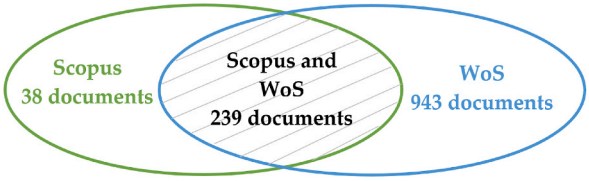

Fig. 3. Database cleaning.

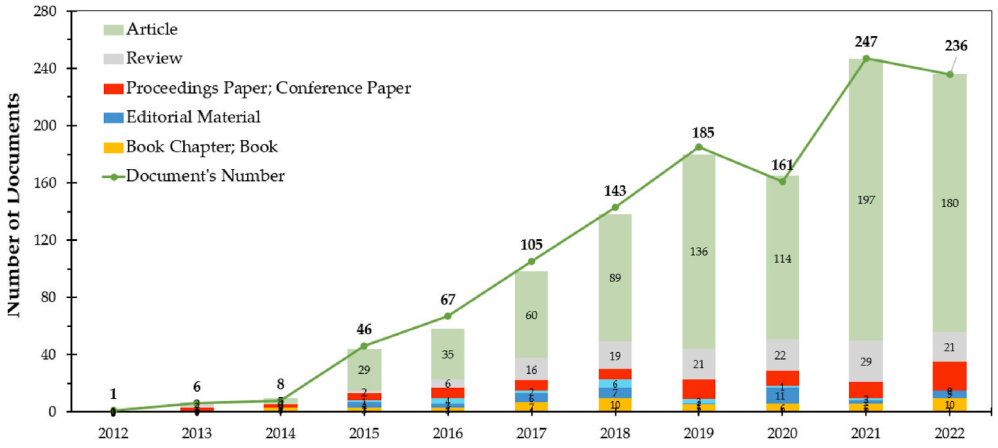

Fig. 4. Scientific production during 2012–2022.

nexus using nexus governance. Wichelns (2017) demonstrated that implementing the WEF nexus approach did not improve the policy processes of natural resources. Finally, Albrecht et al. (2018) showed that mixed methods and transdisciplinary approaches are required to address complex resource and development challenges by incorporating the social and political dimensions of the WEF nexus.

2019–2022: In this period, the study by Pahl-Wostl (2019) stood out with 84 citations, exhibiting the transformative potential of the SDGs in the WEF nexus approach. Li et al. (2019)a,b developed a multi-objective non-linear programming model for the sustainable resource management of the WEF nexus in an agricultural system in China. Furthermore, Chen et al. (2020) analysed the implementation of Green Chemistry Principles policies among governance, industries, and the WEF nexus education by integrating the concept of circular economy and governance strategies. Finally, during 2021–2022, some studies addressed collaborative governance, resource linkages for water management, and policy-governance dynamics (Lazaro et al., 2021; Möck et al., 2022; Voelker et al., 2022).

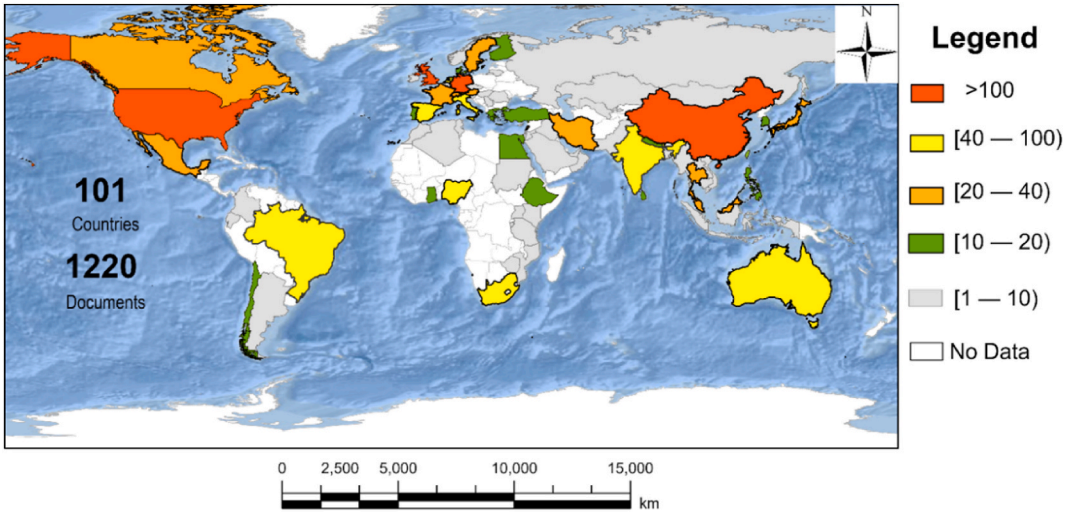

Fig. 5. Global contribution by number of publications.

3.3. Global contribution

The contributions of countries demonstrated the relationship between knowledge of this subject and their institutions (Andreo--Martínez et al., 2020). In the bibliographic coupling analysis, 101 countries met the established threshold of at least one document per country (Fig. 5). The countries with the most publications on the WEF nexus were as follows: the United States (429 publications and 9, 455 citations), China (217 publications and 3,948 citations), the United Kingdom (154 publications and 4,495 citations), and Germany (121 publications and 3,227 citations).

3.4. Co-occurrence network of author keywords

The co-occurrence network of author keywords reveals the most frequent terms in a study field and enables the exploration of topics (keywords) and thematic groups (clusters) (Herrera-Franco et al., 2021a; 2022). Of the 2,750 keywords, 84 had at least five co-occurrences. Fig. 6 shows eight clusters with 84 nodes, 890 links, and a total link strength (TLS) of 2,544. The analysis showed that five of the eight clusters were most representative based on the number of links with other keywords from the databases. The keywords highlighted within the selected clusters were as follows: i) WEF and WFE nexus, ii) FEW nexuses, iii) sustainability, iv) climate change and SDGs and v) governance.

In Cluster II (green), the most prominent term was 'WEF and WFE nexus' with 81 links, a co-occurrence of 414, and a TLS of 604. The WEF nexus approach was an interdisciplinary fusion of IWRM and communities of energy and food (Cai et al., 2018; Scanlon et al.,

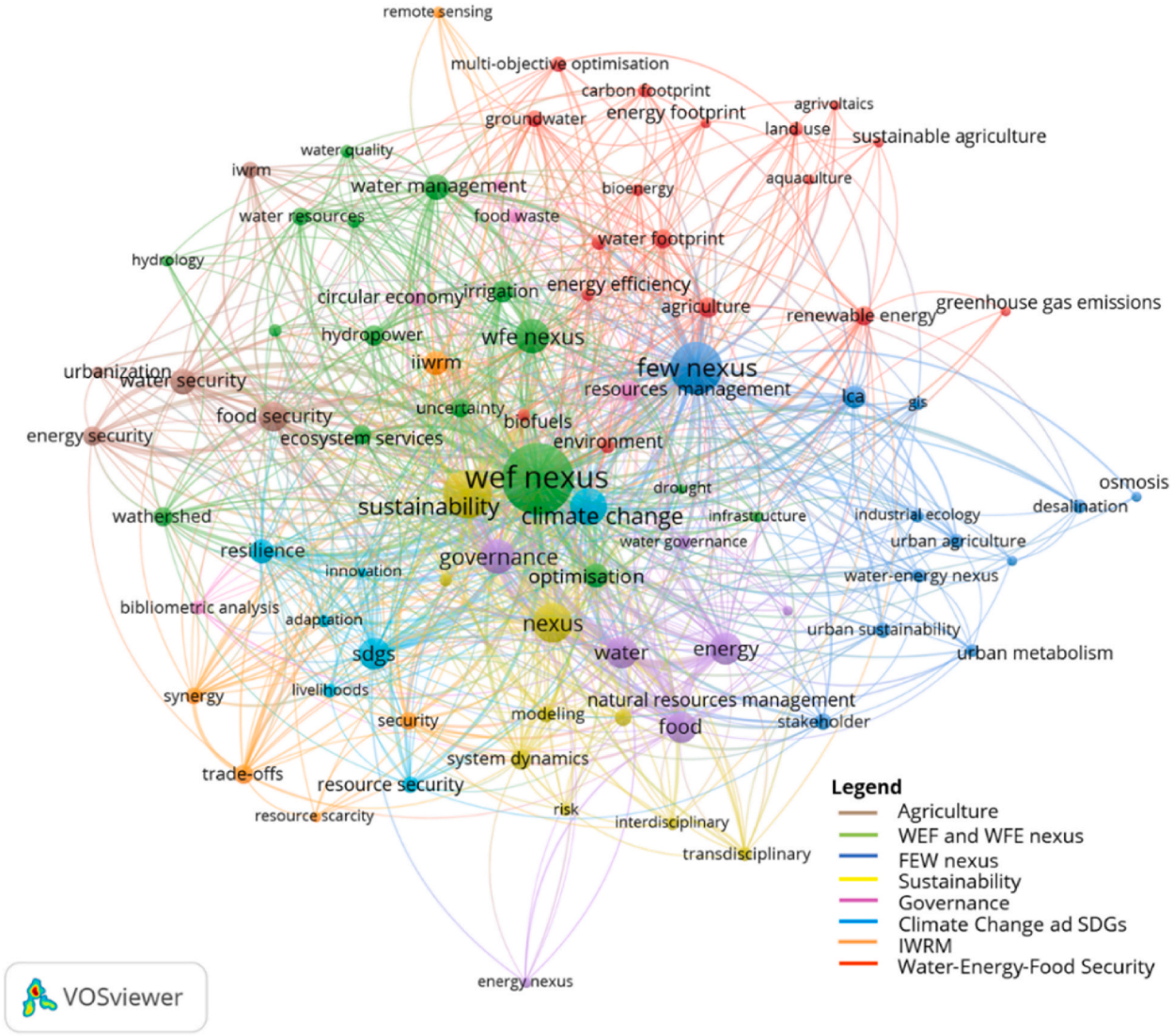

Fig. 6. Co-occurrence of author keywords.

2017). The formulation of environmental and sustainable urban development strategies and policies also considered the importance of the WEF nexus (Allan et al., 2015; Li et al., 2019b; Uen et al., 2018). The WFE nexus addressed the relationship among flood damage control at the transboundary basin scale (Amjath-Babu et al., 2019), irrigation assessment, and desalination systems (Serrano-Tovar et al., 2019) as well as the benefits of achieving sustainability and the conservation of natural resources (Zeng et al., 2019).

The most prominent term of Cluster III (blue) was the 'FEW nexus' with 70 links, a co-occurrence of 197, and a TLS of 273. The FEW nexus was related to food production practices and food processing (Compton et al., 2018; Marvinney et al., 2020). This nexus also linked social, economic, and political concerns due to scarcity of water resources, energy, and food (Johnson and Karlberg, 2017; Perrone and Hornberger, 2016; Ramaswami et al., 2017).

The most prominent term of Cluster IV (yellow) was 'sustainability' with 65 links, a co-occurrence of 166, and a TLS of 357. Thus, the nexus showed a strong relationship with sustainability (Venghaus and Dieken, 2019). The results showed that it was feasible to construct synergies and extract perspectives from the biophysical and institutional dimensions of the WEF interactions (Kurian et al., 2019) within the framework of the SDGs (Antwi-Agyei et al., 2018; Fader et al., 2018).

The most prominent term of Cluster V (violet) was 'governance' with 52 links, a co-occurrence of 79, and a TLS of 192. This cluster included studies related to knowledge gaps in the governance of the WEF nexus (Weitz et al., 2017), emerging challenges in water security (Jiang, 2015), and urban governance (Artioli et al., 2017).

The most prominent term of Cluster VI (light blue) was 'climate change and SDGs' with 49 links, a co-occurrence of 90, and a TLS of 178. The number of studies on the relationship between the nexus and climate change has increased in recent years. Thus, studies have been conducted on the impacts of climate change on biogas use in agribusiness (Pasqual et al., 2018), water quality (Schull et al., 2020), interdisciplinary analytics aimed at the household FEW nexus (Berman et al., 2019), and overdependence on natural resources (Said et al., 2019).

In Cluster I (red), the most prominent term was 'agriculture' with 29 links, a co-occurrence of 24, and a TLS of 57. The most prominent term in Cluster VII (orange) was 'IWRM' with 37 links, a co-occurrence of 33, and a TLS of 87. Finally, the most prominent term in Cluster VIII (brown) was 'WEF security' with 20 links, a co-occurrence of 20, and a TLS of 74.

3.5. Trend topics analysis

This analysis presented the frequency distribution of the main themes that enabled the analysis of the evolution of the selected topic (Fig. 7). The longest period corresponded to decision-making (2016–2022). Additionally, the most frequent keywords were WEF nexus (424), FEW nexus (197), and sustainability (105).

3.6. Systematic review (PRISMA method)

A literary review was performed of 104 documents met the three selection criteria established in the methodology section. The most relevant keywords selected from the predominant clusters of the co-occurrence of authors' keywords were: i) WEF and WFE nexus, ii) FEW nexus, iii) sustainability, iv) governance, and v) climate change and SDGs.

3.6.1. WEF and WFE nexus

This cluster comprised 73 publications, of which 60 were theoretical studies, and the remaining were empirical. Fig. 8 shows that the WEF nexus was evident in the issues of environmental assessment and global development challenges related to socio-economics and ecological protection.

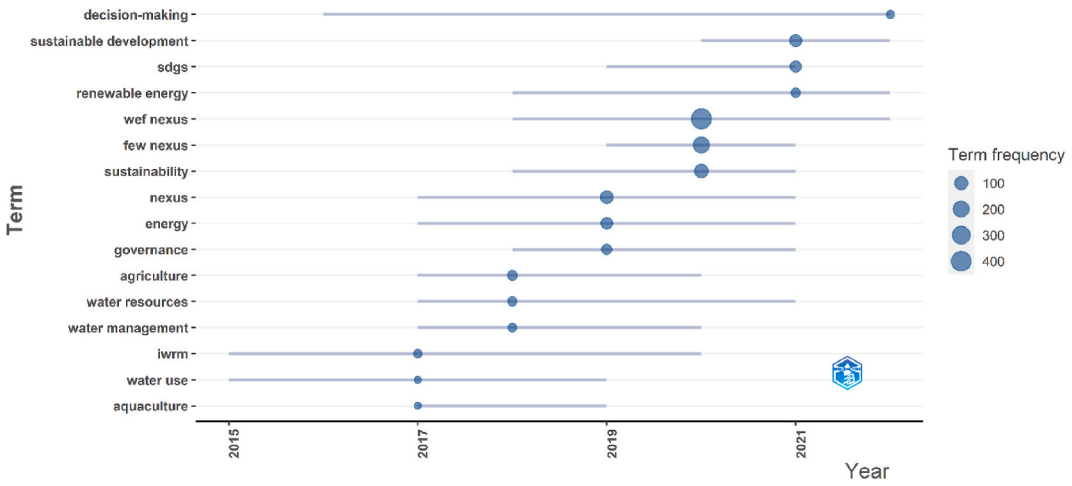

Fig. 7. Trend topics in WEF nexus and climate change.

3.6.2. FEW nexus

This cluster comprised 25 documents, of which 18 were theoretical studies, and the remaining were empirical studies. Fig. 9 indicates that the FEW nexus was integrated in the concepts of resilient security, waste management issues, and agriculture. The FEW nexus also became relevant in business and industrial management owing to its importance to economic development.

3.6.3. Sustainability

This cluster comprised 21 publications, of which 11 were theoretical studies, and the remaining were empirical studies. Fig. 10 shows that the WEF nexus was also relevant to the topics of sustainability as the nexus strengthened the concepts of use and management of natural resources and related them to the SDGs.

3.6.4. Governance

This cluster comprised 11 publications, of which seven were theoretical studies, and the remaining were empirical. Fig. 11 shows that the WEF nexus was also relevant to the governance and decision-making processes.

3.6.5. Climate change and SDGs

This cluster comprised 27 publications, of which nine were empirical studies, with the remaining studies being theoretical. Fig. 12 shows the importance of the WEF nexus to climate change as the rapid growth rates of population and industrial production have raised the demands for new resource use and the pressure on the economic-environmental balance.

4. Discussion

Multiple decision-making processes are happening simultaneously and those related to the WEF nexus do not only occur globally, reflecting situations of local realities. The link between the WEF nexus and policy-making remains weak; thus, each knowledge domain linked to the nexus must generate a lobby group that includes scientists and the community to influence the decision-makers for integral strategies toward resources management (Camilla Adelle, 2012; Daher and Mohtar, 2015). The contributions of scientists and decision-makers strengthen communication mechanisms and capabilities to facilitate and improve decision-making related to acceptable limits to balance water, energy, and food demands and supplies (Medeiros et al., 2020). Thus, sustainable economic, environmental, and social strategies can be generated by avoiding the depletion of natural resources caused by population growth, economic development, and climate change (Damerau et al., 2016; Owusu and Asumadu-Sarkodie, 2016). In this context, decision-making referred to choices related to the socio-economic development of the nexus, such as the construction of hydropower systems (Do et al., 2020), integrated methods in irrigated agriculture (de Vito et al., 2019), social debate in sustainable policy (da Silva et al., 2020), and the water distribution network in the agricultural sector (González-Bravo et al., 2018b). As climate change substantially alters hydrological cycles (Gleick, 1989; Tang et al., 2008), water management challenges have become increasingly complex when considering the relationship among water, energy use, and food production (Voulvoulis, 2012). Tempelhoff (2018) was among the most relevant publications in the databases, where the WFE nexus was integrated as a strategy that took into account both governance and water use, considering the relationship among these three resources.

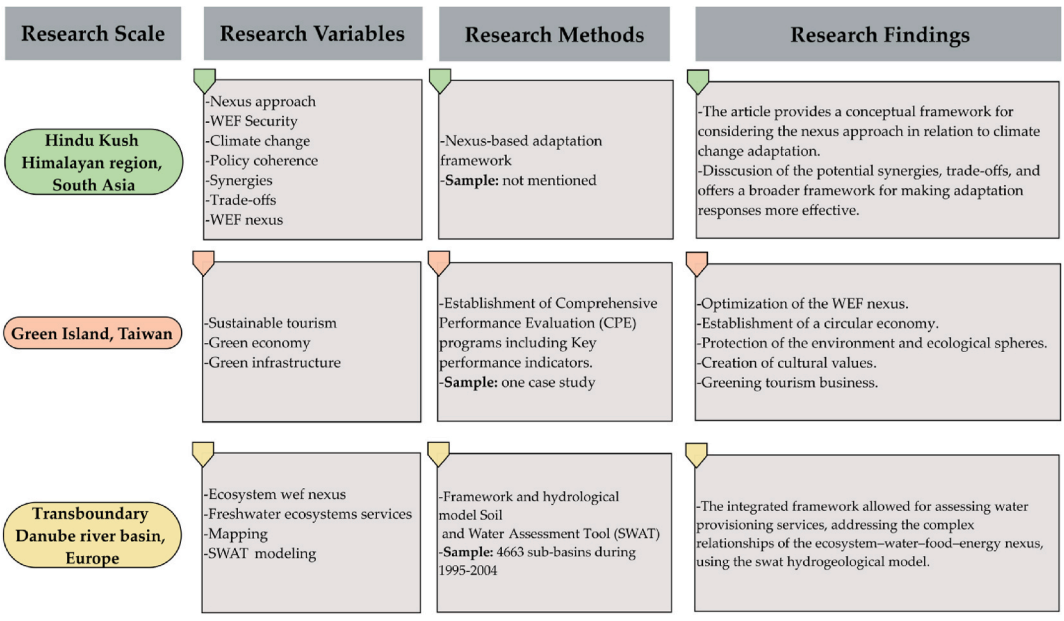

Fig. 8. Systematic review of WEF and WFE nexus cluster II.

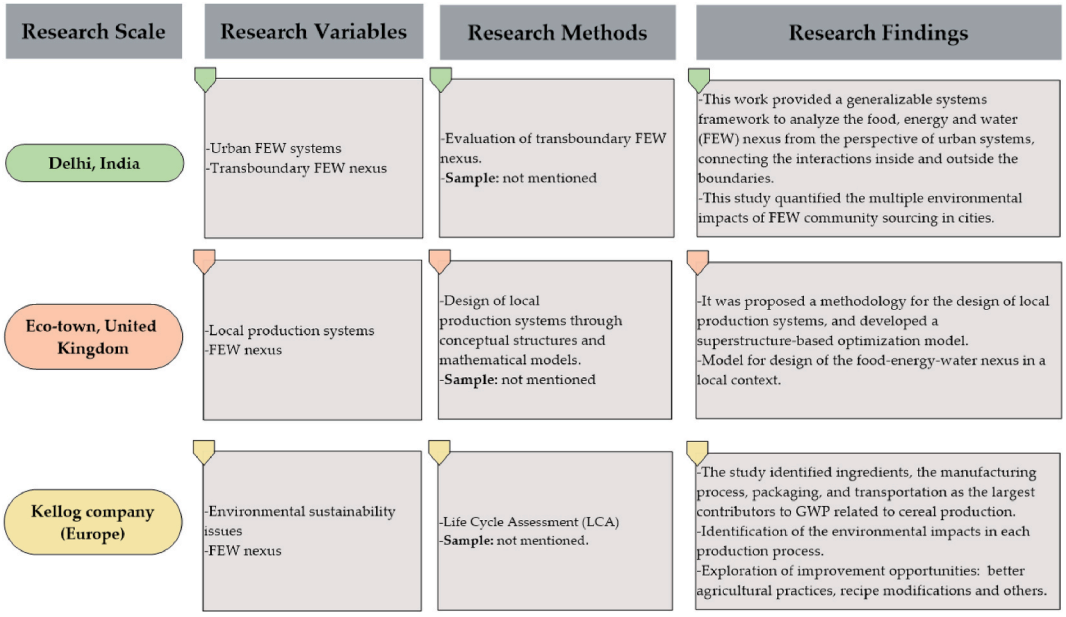

Fig. 9. Systematic review of cluster III.

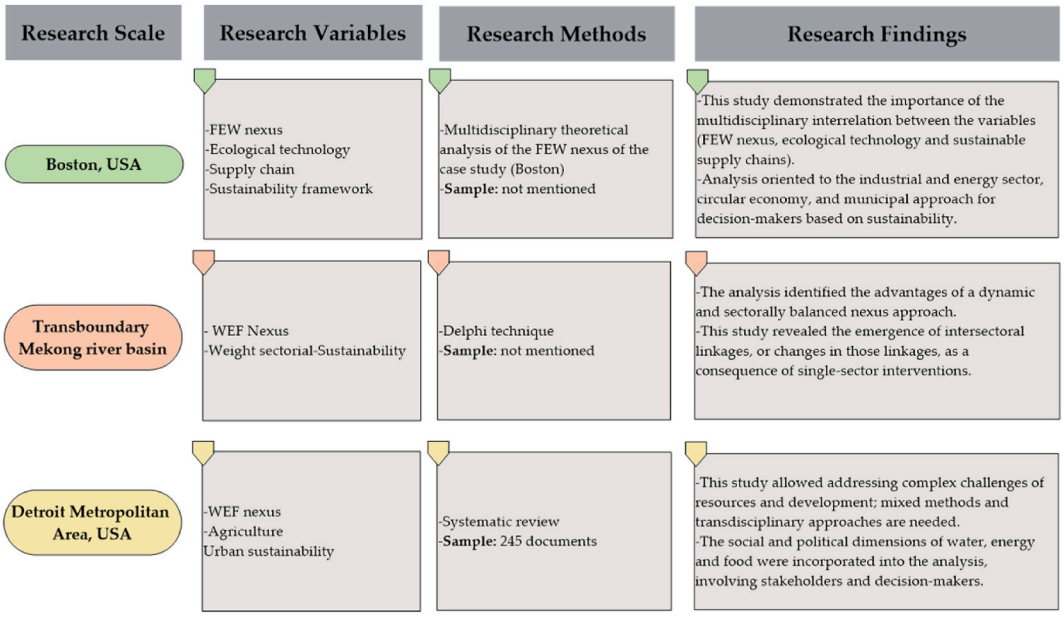

Fig. 10. Systematic review of cluster IV.

The literature review applied using the PRISMA method allowed us to discern the main axes that govern the relationship between the WEF nexus and climate change through the analysis of the most representative clusters of keywords, as described below.

4.1. WEF and WFE nexus

The WEF nexus was strongly related to stakeholders' approach to these resources (Daher et al., 2019), governance strategies (Harwood, 2018), and model building for the establishment of policies (Karnib, 2018; Mroue et al., 2019). In addition, they aimed to meet the SDGs (Matthews and McCartney, 2018) and contribute to the decision-making processes of local authorities (González-Bravo et al., 2018a).

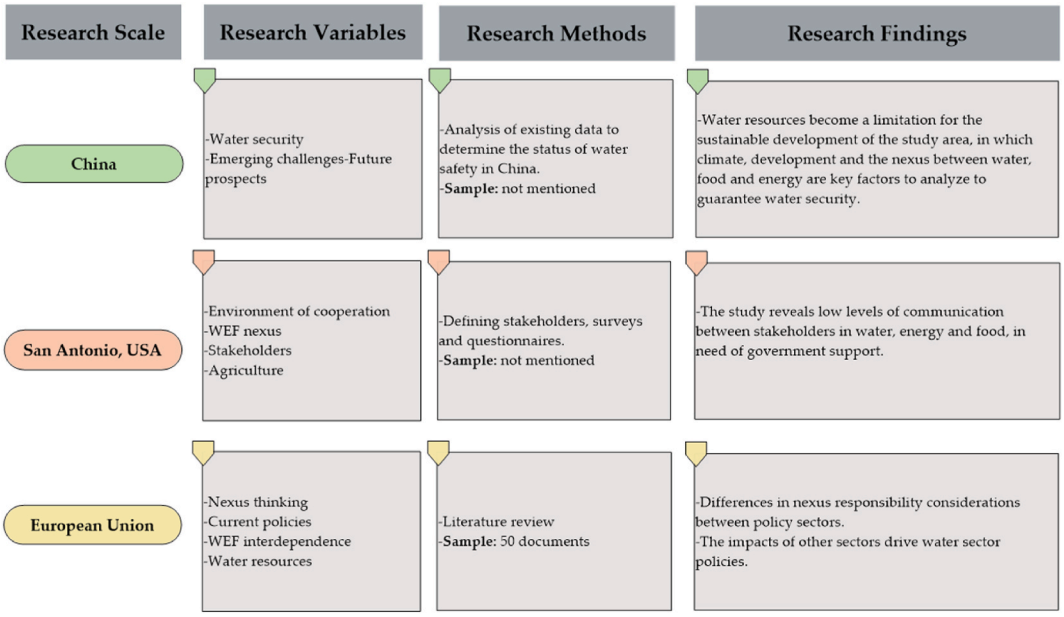

Fig. 11. Systematic review of cluster V.

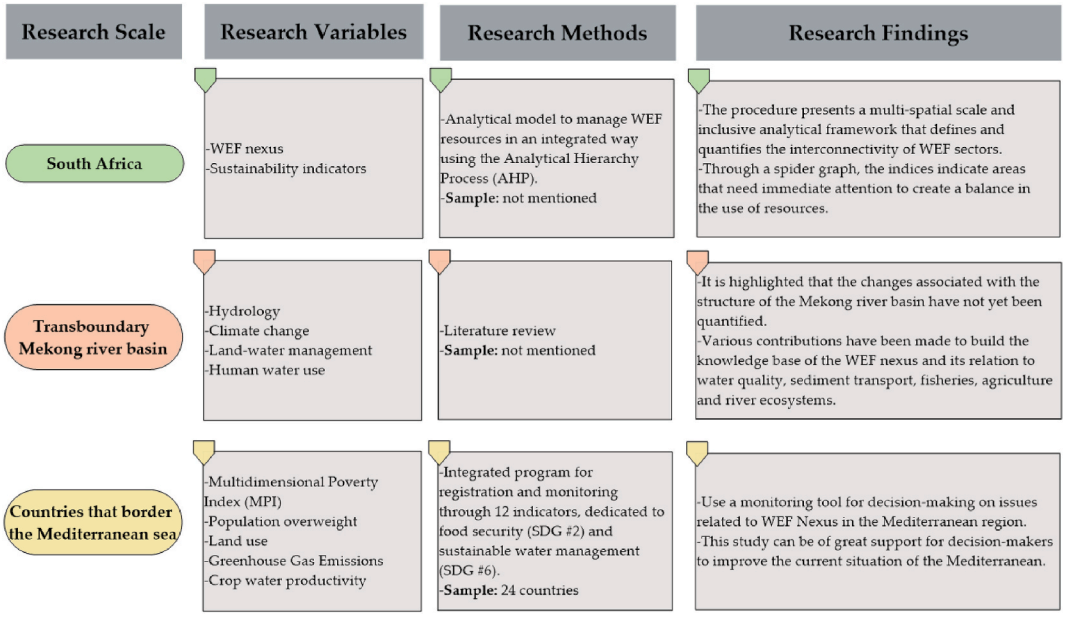

Fig. 12. Systematic review of cluster VI.

4.2. FEW nexus

The FEW nexus was mainly related to water management, integrating the interaction among these resources (Guan et al., 2020). Climate change interfered with the quality and quantity of these resources (Steel et al., 2019). The FEW systems met both urban sustainability (Chang et al., 2021) and circular economy criteria (Greer et al., 2020).

4.3. Sustainability

The advantages of this analysis were that the WEF nexus approach contributed to fulfilling the SDGs, protecting vulnerable populations (Gebreyes et al., 2020), and demonstrating that effective stakeholder participation in nexus governance is necessary

(Sharma and Kumar, 2020). In the scientific community, the nexus application is gaining popularity (Bhaduri et al., 2015). The importance of these factors, accompanied by lobby group strategies, guide decision-makers to fulfil the SDGs. The disadvantage was that the WEF nexus is not well recognised globally, and human-induced disturbances leave complex traces to be rectified (van den Heuvel et al., 2020). The WEF nexus provides sustainable access to natural resources, tackling the issues of energy, water, and food caused by climate change (Forbes et al., 2013). Therefore, the concept of sustainability in the nexus is crucial for better understanding the relationship between socio-economic development and environmental protection.

4.4. Governance

The WEF nexus-governance interaction was mainly associated with urban governance and integrative governance gaps to allow for intersectoral coordination and collaboration with all the stakeholders, community, and decision-makers (Artioli et al., 2017; Weitz et al., 2017).

4.5. Climate change and SDGs

The relationship among the WEF nexus, climate change, and SDGs indicate that changes in food and energy preferences could reduce water resource use despite the increase in population (Damerau et al., 2016; Endo et al., 2015). Additionally, some studies address forest resources management, disaster risk management, nexus governance, and urban socio-environmental issues (Bhave et al., 2016; Simpson and Jewitt, 2019).

5. Conclusions

The relationship between the WEF nexus and climate change was analysed through a bibliometric analysis and systematic literature review from the beginning of scientific knowledge production on the subject (2012) until 2022 in the Scopus and WoS databases. The contribution of scientific articles was 69.50% in the database. The first record of the WEF nexus appeared in 2011 during the Bonn Conference related to the WEF security nexus, followed by the study "Water and sanitation provision in a low carbon society: The need for a systems approach," by Voulvoulis (2012). The period of the last three years has been key in the development of this topic. The systematic literature review highlighted the importance of its recognition with the prominent names of the WEF, WFE, and FEW nexuses. These terms were related to climate change and inherently to sustainability challenges. Therefore, this study demonstrated that the WEF nexus provides a tool for informed decision-making in the face of global sustainability challenges.

The WEF nexus is a valuable tool for integrated management purposes for the resources of water, energy, and food, as opposed to sectorally compartmentalized management and/or management of finite natural resources as if they were infinite. The focus on the WEF nexus allows for a systematic and directed analysis of a given territory with its natural and socio-economic peculiarities, demands for its limited natural resources, and anthropogenic pressures on them. These considerations of the nexus facilitate diagnosis of their spatiotemporally multi-scale interdependency, knowledge co-creation, and search for solutions towards sustainability. Some cases have been applied mainly in the United States, the United Kingdom, and China, with territorial planning in these territories demonstrating the effectiveness of WEF nexus-based methods. The application of the three analyses based on scientific mapping of the WEF nexus led to the following conclusions.

1) The co-occurrence network analysis of the author keywords resulted in 84 nodes (topics) represented by the following eight clusters: (i) agriculture, (ii) WEF and WFE nexus (the most relevant area represented), (iii) FEW nexus, (iv) sustainability, (v) governance, (vi) climate change and SDGs, (vii) IWRM, and (vii) WEF security.
2) Eight percent of the publications analysed showed a strong relationship between the WEF nexus and climate change, pointing to the emerging importance of this topic, which needs to be developed to comply with the SDGs.

This study analysed the interactions between the water-energy-food nexus and climate change by covering aspects of policy, sustainability, management, governance, and decision-making processes and characterised the future research directions and trends based on a systematic literature review, demonstrating interest in the WEF nexus. The emerging research directions mainly related to synergies and policies oriented towards sustainability, natural resource management, and the environmental models of the WEF nexus. The trend topic analysis recognised the future research trends of decision-making, sustainable development, and the SDGs. These results provide insights into the current scientific knowledge growth of the nexus and climate change and enable the scientific community and decision-makers to develop an integrated and broad vision of this topic. The methodology adopted in this study paves the way for tailoring solutions to the issues of climate change, overexploitation, and depletion of natural resources. Therefore, in the future, adapting the SDGs by integrating them into a WEF nexus analysis by developing a matrix of indicators specific to local or regional conditions, e.g., local water indicators.

The main limitation of this study was that this topic is relatively new in academia. Therefore, African, Asian, and South American countries have conducted very little research on this topic and few countries have implemented WEF analysis. An additional limitation of this study is that it only included publications from scientific databases (Scopus and WoS) from international organisations (e.g., reports and web pages), whose inclusion may leverage a better understanding of the evolution of the scientific knowledge production. As a relatively new and highly relevant topic, the WEF nexus is expected to continue to attract widespread interest in the near future.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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