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Understanding the conceptual frameworks and methods of the food–energy–water nexus at the household level for development-oriented policy support: a systematic review

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Abstract

This paper undertakes a systematic review of the literature to understand current trends in the food–energy–water (FEW) nexus for development-oriented policy support. The paper follows three steps: (a) a bibliometric analysis of FEW nexus research, (b) a content analysis of FEW nexus research, and (c) development of a framework that fills existing gaps in FEW nexus research. The review found that FEW nexus approaches have gained ground in academia as a resource management tool and policy guide; however, the process does not have a robust conceptualization. The current FEW nexus approaches focus on national, regional, and international scales of analysis to understand the three sectors' interactions. Further, these approaches underline the nexus processes, which have been researched in detail, including synergies and tradeoffs. However, research on the FEW nexus has not adequately explored the social factors that form part of the nexus, especially at the local household scale. Factors such as the gender dynamics of resource ownership, work roles at different scales, household incomes, and culture are essential components that are yet to be explored in FEW nexus research. Most of the existing frameworks on the FEW nexus overemphasize models and the quantitative measurement of processes while paying limited attention to social aspects. Still, these social aspects are crucial, especially on the household scale; therefore, to overcome these gaps, this paper proposes a FEW nexus framework at the local household scale that includes socio-economic determinants.

1. Introduction

Driven by the need to understand the interactions between food, energy, and water at various scales globally, research in the food–energy–water (FEW) nexus is expanding within academia [1]. The FEW nexus assesses synergies and tradeoffs that occur in the interactions between the food, energy, and water sectors [2, 3]. The FEW nexus approach is an important tool for increasing our understanding of resource utilization and management [4]. Current nexus frameworks show the geopolitical underpinnings that influence and result from interactions such as national strategies to achieve sustainable development goals (SDGs) [5, 6]. They also explore the policy options that can be obtained from understanding the FEW nexus [7, 8]. They are therefore very useful for informing policy strategies that can best address resource management and utilization at various levels [2, 4, 9]. To add to this, research on the FEW nexus has provided a comprehensive foundation for a better conceptualization of resource governance, especially on the distribution processes and how stakeholders can be active participants [2, 3, 6, 10]. The existing nexus approaches also provide useful information on how global challenges (especially climate change) affect the FEW interactions at various scales and how they directly impact social, economic, and political discourse [4, 11, 12]. The FEW nexus is thus very important as it provides an integrated framework that is useful for unpacking the intricate interconnections and interdependencies that exist between the three crucial sectors for human sustenance.

The FEW nexus approach is an emerging framework that can be improved in terms of in-depth conceptualization [13, 14]. It is a multi-sectoral tool that shows interdependency between the food, energy, and water sectors [15, 16]. Traditional policy frameworks have typically focused on sectoral analysis, producing segregated strategies that ignore the intricate interrelations that exist between sectors, stakeholders, and resource systems [17]. Prevalent FEW nexus approaches have focused on identifying the different processes existing between the three sectors at different scales depending on the research being conducted [3, 5, 18, 19]. The FEW nexus means different things to different people [20]. For some scholars, it means evaluating the footprints of various technologies as well as production processes [20]. They examine how water and energy processes interact (or water and food or energy and food) and build models and matrices that explain the distribution and utilization so as to inform policy [1]. To other scholars, the FEW nexus is not easily quantifiable but is best expressed in terms of the potential impacts of various forms of structural development on the economy, societal health, and biodiversity [20, 21]. For the FEW nexus to be a robust policy making tool, there is a need for the development of a framework that adequately captures the synergies existing between different sectors while reducing the tradeoffs present in the interactions [1, 16]. These synergies can be assessed in FEW nexus processes between the three sectors at various scales; this has been clearly shown in existing frameworks. They can also be expressed through examining how people determine and are impacted by resources [22]. However, limited research has addressed householdlevel factors and their assessment in FEW nexus frameworks.

Household-level analysis is important for understanding societal dynamics [23]; indeed, the household has long been used as a unit of study [24]. Societal systems influencing how individuals interact with each other and their environments are influenced by household factors [23, 25]. The key factors that directly determine household food, energy, and water security are as follows: income, employment, education, health, age, gender, and family size [26–28]. For example, household roles may be gendered, with women carrying out the majority of household chores while men are recognized as owners of land [23, 29, 30]. These dynamics have a direct impact on the FEW nexus since, in some areas, women perform farming, but men, taking the role of heads of the household, determine the use of the produce [23, 25, 29]. Research on the household level has

also produced sectoral analysis, such as the household food insecurity scale (HFIAS) [31], household dietary diversity score (HDDS) [32], and household water insecurity access scale (HWIAS) [27]. Householdlevel analysis enables researchers to explore this layer of interactions using both qualitative and quantitative methods and provide an understanding that helps to shape policy formulation. Incorporating householdlevel factors into the FEW nexus frameworks help to better understand local dynamics. It will also encourage the development of indices capturing all three sectors in FEW nexus approaches. This paper presents an attempt to enhance the FEW nexus approach by incorporating household factors into the FEW nexus framework.

Existing FEW nexus assessment methods have focused on modeling and quantifying the processes of the nexus; however, they have paid little attention to the factors that affect the human agency at the local/micro level [17]. Various quantitative models have been utilized in FEW nexus assessments, such as life cycle assessment (LCA), input-output analysis, water evaluation and planning systems, geographical information systems (GISs), and remote sensing [1, 33, 34]. This tends to limit our understanding of the nexus interactions and processes, such as how these affect stakeholders at different levels, and vice versa [35]. Ultimately, the views of the stakeholders are relegated to generalized outcomes based on processes rather than the actual experiences of the stakeholders. It is also undisputed that the various stakeholder activities and interactions in food, energy, and water utilization often result in tradeoffs, e.g. land and water needed for food production can be channeled toward sugarcane farming for bioethanol [20, 21, 36]. This can lead to conflicts of interest, e.g. a large biofuel producing company may require a large amount of land and water for its feedstock while a local community may require the same resources for subsistence agriculture. These issues can only be addressed when FEW nexus studies employ both quantitative and qualitative methodologies of assessment, either concurrently or within a continuum [37]. It is therefore important to clearly show the interface between qualitative and quantitative methodologies within the FEW nexus framework.

Perhaps drawing from its genesis, FEW nexus research has typically focused on institutional, transboundary, and regional scales; when referencing the 'local' scale, studies in this field are not typically referring to small geographical spacing or small units of study [1, 17]. Much of the literature refers to a local scale in which the focus is on the processes and how stakeholders are involved in determining resource management and sustainable utilization, with very limited research having been conducted on how household factors and dynamics affect the FEW nexus [3, 35, 38]. There are no clear methodologies in the literature to show how FEW nexus interactions affect society at the household level. Understanding how the nexus is expressed at the household scale is key to understanding nexus interactions at all other scales because the household is the basic unit of society [2]. Though some studies have been conducted at a local level, these refer to populations at a city, district, or even country scale [1, 17]. A major conclusion from existing review articles is that there is a need for an integrated framework that incorporates micro scale factors into FEW nexus analysis [22, 39]. This gives weight to the aim of the current review, i.e. to establish and illustrate FEW nexus factors at the household scale.

The FEW nexus framework is a vital emerging tool for policy making and implementation [34]. Existing FEW nexus frameworks have clearly demonstrated the importance of nexus thinking to resource management, policy drafting, and implementation to ensure environmental conservation in terms of distributional equity and justice [40]. One issue that is of note with current FEW frameworks is that they are discipline-oriented, i.e. researchers from the field of econometrics tend to use econometric models when attempting to show the interactions, whereas researchers in hydrology or chemistry, for example, will use models and quantitative analysis that suit their disciplines [1, 38]. This means that current research in the FEW nexus tends to follow a sectoral or siloed approach to assessment [16, 41, 42]. There is no consistent framework or standard method for explaining or understanding FEW nexus interactions [41, 43]. This leads to 'FEW nexus' becoming a 'buzz' phrase that researchers use while continuing with mono-disciplinary modeling of the factors [44]. This has resulted in articles with a variety of methodologies that are only connected by the phrase 'FEW nexus.' There is still a need for the development of nexus tools and methods that are accessible to all stakeholders in decision making [38, 45]. This can be attained through the development of a framework that is versatile enough to capture all FEW processes while being simple enough for all stakeholders to understand and use. This paper employs insights gained from existing frameworks to propose an approach which fills existing gaps through the inclusion of income, employment, age, family size and gender dynamics at the household level into the FEW nexus approach.

Another issue highlighted in this review is that the FEW nexus is determined by specific contexts, i.e. the physical, political, cultural, and economic characteristics of an area or region [46, 47]. Establishing the specific characteristics of different regions is important for the development and utilization of relevant strategies tailored to their needs. This is best achieved when local knowledge is utilized on its own or combined with other knowledge systems to address problems [48]. To add to this, existing FEW nexus concepts are framed based on western knowledge, while they are predominantly employed in areas in the global south [48]. The inclusion of local knowledge into understanding the FEW nexus is only possible when a transdisciplinary approach is employed in research [49, 50]. Transdisciplinary approaches help to promote understanding between human laws and the laws of nature, between natural sciences and social sciences, and between different stakeholders to design an integrated approach for solving problems [51–54]. They entail the collaboration of researchers from diverse fields (interdisciplinary), together with practitioners who possess knowledge relevant to the issues to be solved. It also involves participation by local stakeholders who may not have scientific knowledge but do have extensive experience with the issues being explored [52, 55]. This review established that there are limitations in existing FEW nexus research owing to a lack of interdisciplinary and transdisciplinary approaches [1, 14, 33, 50]. It is important to further explore transdisciplinary approaches in FEW nexus research.

This paper therefore aims to establish the variables that scholars focus on in the FEW nexus, i.e. the quantitative processes, qualitative factors, or a hybrid of the two [49]. The paper also seeks to examine the scales of assessment employed for existing FEW nexus frameworks, identifying regions where research has been undertaken and how this influences FEW nexus framing. The paper proposes a new framework with elements that capture concepts at all scales, which will add robustness in analyzing FEW nexus resource governance and utilization. The proposed framework will also propose a transdisciplinary approach to FEW nexus research.

2. Methodology

2.1. Methods of identifying FEW nexus articles

This paper used both quantitative and qualitative reviews to achieve its set objectives. The quantitative review was carried out through a bibliometric analysis of the literature to capture the research topic's development and trends, and to identify areas for further research [56]. The bibliometric analysis focused on: (a) the number of articles reviewed, (b) the sources of the articles, (c) the types of articles, (d) author countries, (e) collaborations, (f) citations, (g) keywords used, and (h) years that the search topics were found in academia. This bibliometric analysis helped to identify: (a) the key areas that are being researched, (b) the most cited papers, which demonstrates some influence and (c) the countries and institutions that have undertaken the most research in this area. This review made use of the Scopus database, which is considered to be the largest repository

keywords and their clusters.

of citations and literature summaries [34, 56]. There are two major databases that provide large repositories of literature, namely, Scopus and Web of Science [57]. Scopus was selected as it has more indexed articles and has more overlap with articles from Web of Science [34, 56, 57]. Scopus, like Web of Science, also comes equipped with tools that enable researchers to conduct primary analysis, e.g. trends in publications, most productive countries and institutions, journals with the most publications, disciplines of study with the most publications, as well as number of citations for each article. In addition, for a more rigorous bibliometric analysis, Scopus offers an option to export its database using different data formats, e.g. research information systems (RIS), comma-separated values (CSV), bibliography tex (BibTex), plain text, as well as Mendeley. The data files were exported using Bibtext, CSV, and RIS for further analysis and Vosviewer and R package 'cluster' analysis [58]. Keywords were identified using a keyword search in Vosviewer according to the following steps: (a) create keyword co-occurrence, (b) read data from the bibliographic database file, (c) select Scopus database and input CSV file, (d) select co-occurrence as type of keyword analysis, (e) set the minimum number of occurrence of keywords, and (f) choose the number of keywords. Vosviewer calculates the strength of cooccurrence links between keywords, selecting those with the greatest total link strength [59]. Vosviewer was also employed to produce visualization maps for

Article selection was conducted in March 2020 utilizing the following phrases in the Scopus search: 'food energy water nexus,' 'water energy food nexus,' or 'energy food water nexus.' Expectedly, these terms apply to several disciplines and as such the sample selection was further limited to fields relevant to the objectives of the paper. The review sample was thus limited to the subject areas of 'Environmental Sciences,' 'Social Sciences,' 'Energy,' 'Earth and Planetary Sciences,' 'Agricultural and Biological Sciences,' 'Materials Science,' 'Arts and Humanities,' 'Decision Sciences,' 'Multidisciplinary,' and 'Psychology.' A second filter, i.e. type of document, was employed to select only those that had been through rigorous review. As such, 'Articles' and 'Review' papers were selected, i.e. research and review journal papers, respectively. Because the research topic covers a new area of research, it was found prudent to include other documents with a less rigorous review process as these could offer useful conceptualizations and frameworks [1]. As such, other documents types included were 'Book chapter' and 'Conference Paper.' Based on these parameters, 287 papers were identified for analysis, as summarized in (figure 1). From these papers, the review identified highly cited papers that were not found in Scopus. These included five Reports, four Working Papers, and one Discussion Paper. These constitute

'gray literature,' not listed in the Scopus database; therefore, they were found on Google Scholar, but they were not part of the bibliometric analysis. They were selected as they presented influential concepts and frameworks relevant to the topic under review. The search did not limit articles based on period of publication.

The following criteria were used to select papers for qualitative review: (a) they utilize all components of the FEW nexus in their research, title, and methodology; (b) they offer clear methodologies and tools to capture the FEW interactions; (c) they explain scales of analysis for the FEW nexus; and (d) they provide policy recommendations on resource utilization using the FEW framework. Studies that met at least three of these criteria were selected for review. Based on these criteria, 60 research articles and 14 review articles were selected for qualitative review from the Scopus database. In addition, a snowball search of the most cited papers was conducted to identify useful gray literature for qualitative analysis. While gray literature articles do not undergo rigorous review, they can be useful sources of concepts and frameworks [1]. Cognizant of the fact that the Scopus database does not capture gray literature, the review of the Google Scholar database provided this gray literature. Utilizing this snowballing method, ten articles were added for content review (five reports, four working papers, and one discussion paper). Adding these to the Scopus articles gave a total of 84 articles for review. A deductive content analysis was used for qualitative review in order to add to the existing FEW nexus conceptual frameworks. Content analysis was conducted following three steps: (a) collection of data from review articles, after which decisions were made based on latent content of the FEW nexus and developed into themes; (b) coding and forming categories of analysis to provide a description of trends and gaps in FEW nexus research; and (c) reporting on the process by reshaping the conceptual framework of the FEW nexus by filling knowledge gaps (figure 1) [60].

2.2. Utilizing different methodologies in assessing the FEW nexus

To gain a better understanding of the factors that determine FEW nexus interactions, using quantitative or qualitative methods alone is not sufficient [1, 33, 49, 61]. There is a need to examine qualitative aspects that affect the household FEW nexus, such as cultural beliefs, political backgrounds, and other societal factors that may be hard to quantify [13, 49, 62]. As such, FEW nexus assessment can be conducted using a continuum approach in which qualitative and quantitative assessments are combined [49]. Foran [49] proposed that qualitative analysis should take place at the start of the continuum whereas quantitative analysis should occur at the end. Abulibdeh and Zaidan [63] provided a framework for scale analysis.



In this review, we propose that both quantitative and qualitative analysis should be conducted at all scales of the continuum in order to capture all aspects of the FEW nexus (figure 2). Analyses at different scales are interdependent and provide useful corroborative data. For instance, household information, such as income, age, gender, and family size provides important data for analysis at national and global levels. National level policies determine the FEW nexus of households, e.g. the government passes land tenure acts determining the ownership of resources, an act that directly impacts society at the household level. Governments also interact with each other at the global level to define international conventions with a bearing on the FEW nexus at all levels. Globalscale issues, such as climate change, affect the FEW nexus even at the household scale. Analyses at the global level primarily depend on large amounts of data obtained at the national level, particularly from

households. Analysis of the FEW nexus can benefit from applying the continuum to understand all scales and their relationships, as reflected by the connected circles from the household to the global scale in figure 2.

2.3. Assessing the FEW at the local household level

To obtain a better understanding of the household factors associated directly and indirectly with FEW Nexus, a search was conducted on Scopus and Google Scholar. It was imperative to use Google Scholar in addition to Scopus so as to augment the search as well as to access any gray literature that was not captured in the Scopus database.

The following key words were employed: 'Factors affecting household food energy water security,' 'Factors affecting household food energy security,' 'Factors affecting food water security,' 'Factors affecting household water energy security,' 'Factors



affecting household food security, 'Factors affecting household energy security,' and 'Factors affecting household water security.' The articles were selected using the following criteria: (a) they clearly outline the variables used to assess the FEW nexus at the household scale and (b) they establish a clear methodology for assessing at least two sectors in the FEW nexus. Using these criteria, two articles were found to show assessment methodologies for the food and water sectors [27] and [64]. This yielded eight articles that clearly highlighted the factors, mainly in the food sector. A snowball approach was utilized on the references of the articles to identify four additional articles; two on household water security and other two on household food and energy security.

3. Results and discussion

3.1. Year-wise publications on FEW nexus

Publication of FEW nexus approaches has grown steadily over the past nine years, with increasing publications each year, reaching 94 publications in 2020 from 1 in 2012 (figure 3). The earliest journal article found on Scopus was published in 2012, with the first documents that conceptualized the FEW nexus being published in 2011. Growing interest in the FEW nexus is a result of increasing demand for policies and strategies that address complexities and tradeoffs when resources are utilized [1, 22, 62]. Limited research has focused on the FEW nexus at the household level, totaling only three articles

(1% of the publications). The articles were published in 2017 [28], 2018 [65] and 2019 [66]. Developing a conceptual framework which proposes household factors will thus contribute to making the FEW nexus approach more robust. This review included articles published by March 2020, in which month there were 30 publications, which is more than the total number for 2016. The average number of authors per article was four for the period 2012-2018. FEW nexus research articles have used 18721 references; these were from different fields and disciplines, indicating the multidisciplinary nature of the subject. The total number of citations for FEW nexus articles was 3942 for the 9 years since the concept gained ground in academia. The years 2016 and 2015 had the highest numbers of citations for FEW nexus articles, with 973 and 846 citations in those years, respectively. This could be connected with the ending of the millennium development goals and the adoption of the SDGs. There was also increased interest in academia during this period in the nexus approach to resource management, climate change and sustainable development issues in academia which would have bearing on FEW nexus research. The article with highest numbers of citations (213) was published in 2015 by Biggs et al [22]. That article gives a clear outline of the FEW nexus processes in the context of local livelihoods as well as environmental sustainability. This multifaceted approach in the paper makes it applicable to various subject areas and disciplines.



3.2. Country-wise publications on FEW nexus

The FEW nexus is affected by geographical, regional, and local conditions [5, 35]. The review found that the majority of research on the FEW nexus has been conducted by researchers affiliated to institutions in developed countries (figure 4). Of the 287 papers that were identified for this review, 201 articles (70%) were on research conducted by researchers affiliated to institutions in developed countries, with developing countries accounting for only 86 (30%) of the research output. Moreover, out of the 60 corresponding authors of the research papers selected for review, 45 (75%) are from institutions in developed countries, whereas 15 (25%) are from developing countries. 36 studies (60%) were conducted in developing countries, whereas 24 (40%) were conducted in developed countries (appendix B). A better understanding of the FEW nexus can be obtained through an analysis of trends in different areas [67, 68]. Local knowledge is imperative to understand the FEW nexus interactions at the household level where issues such as culture and dynamics impact resource access, utilization and governance [48–50, 53]. It also helps us to understand the important factors that affect FEW interactions in different areas [3, 44, 69]. This is especially important in terms of the political, cultural, economic, and social factors that affect the FEW nexus at different scales of analysis [13, 62]. Identifying how these factors determine FEW nexus interactions from the local household to the global level through a conceptual framework will improve our understanding and influence both resource governance and policy making.

A systematic empirical normalization approach was adopted from Aznar-Sánchez et al [56] and used for country-level comparisons. A total of 63 countries published during the period under review. Their publication productivity trends are summarized in (appendix D). This analysis revealed that the United States of America (USA) is the most productive country in terms of FEW nexus research, with 118 articles. This is followed by the United Kingdom (UK), with 61 articles. Thailand is the only developing country in the ten most productive countries; it is ranked ninth, with a total of nine article for the period (table 1). Although the USA has the highest number of articles produced, the UK has a higher productivity per million inhabitants (A/M), with 0.913 articles produced per each million, followed by Australia with 0.760. The UK is the only country to have published in every year from 2012 to 2020 while the US published no articles in 2012 and 2014. The USA has the highest number of citations, with 1510, followed by UK with 1266; however, in terms of the average number of citations per article (T/AC) for the period studied, Japan has the highest with 22.20 citations, followed by the UK with 20.75, while the USA is fifth with 12.80. The influence of a country is obtained by considering both the number of articles produced and the number of years and citations per article.

We compared these trends by analyzing the productivity of each country in terms of research output



Rank	Country	FEW (A)	Citation FEW	Sustainability sciences	Population (in million)	A/M	T/AC	A/SS
1	United States	118	1510	4326	328	0.359	12.80	2.7
2	United Kingdom	61	1266	1400	67	0.913	20.75	4.4
3	Germany	39	627	1046	83	0.469	16.08	3.7
4	China	34	302	1192	1398	0.024	8.88	2.9
5	Australia	19	382	1170	25	0.749	20.11	1.6
6	Italy	16	201	801	60	0.265	12.56	2.0
7	Netherlands	13	103	589	17	0.750	7.92	2.2
8	Japan	12	270	329	126	0.095	22.50	3.6
9	France	10	122	663	67	0.149	12.20	1.5
10	Thailand	10	186	114	70	0.144	18.60	8.8

Table 1. Most	productive	countries in	FEW	nexus	research
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Key: FEW (A)—Total number of FEW related articles; A/M—Total number of FEW related articles published per million inhabitants; T/AC—Average citations per article (FEW related articles); Percentage of FEW related articles in sustainability science related articles. NB: Full list is available in table appendix D

using the keyword 'sustainability sciences,' under which the FEW nexus falls. We used the same search parameters we utilized for FEW nexus research. The USA is the most productive with 4326 articles, UK is second with 1400 publications and China is third with 1192 articles.

3.3. Most frequently used keywords in FEW nexus research

Figure 5 gives a summary of the 20 most frequently used keywords in FEW nexus research. 'Sustainable Development,' with 74 occurrences, was the most frequently employed keyword. The keyword gained its first use in 2014 and has seen increasing usage since. The second most widely used keyword is 'Water Supply,' which was used a total of 56 times. The three earliest keywords that are most frequently used are 'Water Supply' (56), 'Climate Change' (45), and 'Energy Use' (25), which were used in 2012. No keyword has been used every year, highlighting the wide variety of issues explored in FEW nexus research [1, 34, 67]. The keywords are important in the development of the FEW nexus framework (figure 8). In the framework, 'Climate Change' is a direct driver, whereas 'Irrigation,' 'Water Use,' 'Water Use,' 'Hydropower,' and 'Water Supply' are processes. The term 'Integrated Approach' relates to the strategies that can be employed for effective FEW nexus resources management. 'Food Security' and 'Sustainable Development' are key outcomes of the FEW nexus within the framework.

The 287 hits from the Scopus database were exported into Vosviewer and R Studio packages for bibliometric analysis to assist in the selection of the most relevant articles. The Vosviewer package was useful as it produced a bibliometric data map from the CSV files exported from the Scopus database. The establishment of keyword clusters is important to identify important articles and related research [1, 34]. The research analyzed the co-occurrence of keywords in the articles, with the minimum occurrence set at five to show links and clusters in the FEW



research. The results are shown as a bibliometric map (figure 6).

The map (figure 6) reveals six clusters in FEW nexus research. The first cluster (red) has 52 keywords, with seven from the 20 most frequently used in FEW research (Sustainable Development, Food Security, Integrated Approach, Food Supply, Resource Management, Decision Making, Sustainability). This cluster has the most frequently used keywords on the map, with Sustainable Development ranked first. This shows that FEW nexus research is primarily concerned with policy, governance, food supply, and sustainability in the development approaches. The second cluster (green) has 33 items, with three keywords from the 20 most frequently used (water supply, energy use, environmental impact). The cluster shows that research on the FEW nexus is influenced by how water determines the other sectors and their impact on the environment. The third cluster (blue) has 28 keywords, with eight from the 20 most used (water management, water resources, water energy, water use, irrigation, agriculture, economic and social effects). The fourth cluster (yellow) has 27 keywords, with one from the 20 most used (climate change). This includes keywords such as benchmarking, resource allocation, and environmental protection, which shows a growing interest in conserving natural resources in FEW nexus research. The fifth cluster (purple) has 25 keywords, with none from the most frequently used. This cluster shows

that FEW nexus research is exploring ecosystem services, water footprints, and energy efficiency. The sixth cluster (light blue) has 15 keywords with one (energy resource) from the 20 most frequently used. The cluster shows a focus on energy resources, energy yield, and their connection to ecosystems. An analysis of these clusters was useful to establish the current issues that scholars are exploring and to identify the gaps that need to be filled [56, 67]. This reveals that FEW nexus research anchors itself within the fields of sustainability and sustainable development.

Content analysis revealed that the FEW nexus approach traces its origins to integrated resource management approaches, in particular the integrated water resources management (IWRM) framework [18, 70-72]. The FEW nexus is an attempt to address the shortfalls of the IWRM approach to resource management [69, 70, 73]. This explains why water resources, water management, and water use are dominant in the keyword co-occurrence parameter (figure 5). Knowing the historical background of the FEW nexus is important for us to gain a better understanding of the methods of analysis used as they are influenced by the disciplines of the relevant scholars [1, 13, 71]. 'Energy' is the least used of the three primary words of the FEW nexus, whereas 'Water' is the most frequently used ('Food' is second). 'Energy' is mostly used in relation to another sector, especially 'Water,' with 'Water Energy' being the most frequently used keyword. This can be explained



Figure 6. Co-occurrence in interlinkages among keywords in FEW. (This keyword map was generated using Vosviewer. Type of analysis: co-occurrence; unit of analysis: all keywords; counting method: full counting; minimum number of occurrences of a keyword: 5; total words selected: 180. The size of the circles correlates with the number of articles using that keyword such that a higher number of articles is represented by a bigger circle. Circle color denotes different clusters. The map reviews six clusters (red, green, purple, light blue, blue, yellow). Lines show links between keywords. Similar results were obtained using R.)

by differences in the processes characterizing specific sectors. In the case of 'Water Energy,' it refers to both hydropower production and the cooling function of water in hydropower production. This may be explained by the fact that research has primarily focused on reducing global risks such as hunger and providing clean water to every human being [74]. The keywords also show that research has focused on resource management, distribution, processes, and governance, all of which are examined at scales above the household level. Keyword co-occurrence also shows the need to include the household-level factors identified in table 3.

3.4. Frameworks and methods of the FEW nexus

3.4.1. Conceptual framework of the FEW nexus

For this review, articles that present concepts to articulate the FEW nexus interactions without giving methodological insights or field data are referred to as conceptual papers. From these conceptual papers, this review established the prevailing frameworks (appendix A). There are four influential frameworks that drive FEW nexus thinking: the FEW Conference Background Paper [5]; the World Economic Forum Paper [10, 75]; FEW with affecting parameters [76]; and the Food and Agriculture Organization (FAO) approach to the FEW nexus [3]. This study analyzed the frameworks and categorized them as follows: drivers, institutions/structures, intermediary factors/processes, scales, goals, and utility (table 2).

Table 2 reveals that the frameworks focus on the same drivers of the FEW nexus and these relate to the macro level [22]. Population growth is identified as a driver in all the frameworks. Climate change appears in three frameworks [3, 5, 76], while [10] uses environmental pressure in a broad sense. The FAO approach to the FEW nexus [3] identified more drivers that can be explained by the fact that it examines the FEW nexus in a localized context. The conceptualization of the FEW nexus in the frameworks is reflective of the target audience and stakeholders involved [49]. The FEW Nexus Conference Background Paper Hoff [5] and the World Economic Forum [10] target global institutions, whereas Mohtar and Daher [76] and the FAO approach Flammini et al [3] are directed toward FEW nexus at local to national levels. This has an impact on the drivers, factors, and goals of the frameworks. In terms of methods of analysis, all the papers proposed quantitative and qualitative analysis. They assess the FEW nexus interactions from the local to global scale. At the local level, there is no analysis on how household dynamics influence and are affected by FEW nexus interactions. This limitation tends to limit FEW nexus understanding of the social and political factors that directly affect the FEW interactions at all levels

		Table 2. Concepts r	loted in FEW nexus framewo	orks.		
Framework	Drivers	Structure/Institutions	Intermediary factors/Processes	Scale	Goal	Utility
Understanding the nexus. background paper for the Bonn 2011 Nexus Confer- ence (Hoff [5])	 Urbanization Population growth Climate change 	 Society Environment Economy 	FinanceGovernanceInnovation	 Global 	 Food, energy, water security for all Equitable sustainable growth Resilient productive environment 	 International institutions Governments
Global risks 2011 sixth edition (WEF [10])	 Population and economic growth Environmental pressure	• Governments	Global failuresEconomic disparities	GlobalNational	 Eradicate chronic food, water, energy shortages Reduce geopolitical conflicts 	International institutionsGovernments
Water, energy, and food: the ultimate nexus (Bergendahl <i>et al</i> [53])	 Governance International trade Global population Rising economies Climate change 	 Governments Local authorities 	 Fertilizers Harvesting Storage Biofuels Water quality Energy generation Cooling Extraction Cooling Extraction Pumping Water distribution Irrigation Processes Tillage 	 National Local 	 Identify and reducing tradeoffs in nexus interactions Improve resource management 	• Governments • Local authorities
Walking the nexus talk: assessing the water-energy- food nexus in the context of the sustainable energy for all initiative (Flammini <i>et al</i> [3])	 Population growth Diversifying and changing diets Cultural and societal beliefs and behaviors Culimate change Governance Governance Sectoral policies and vested interests International and regional trade Markets and prices Industrial development Agricultural transformation Technology and Innovation 	 International organizations Governments Local organizations Local communities 	 Resources Capital Labor Stakeholders Governance 	GlobalNationalLocal	 Stakeholder participation Equitable resource Distribution Local community well-being 	 International institutions Governments Local Authorities Local communities

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[33, 49, 67]. There is therefore a need to increase the FEW nexus concepts to adequately capture and conceptualize the social and political factors; thus making the framework more robust [43]. This must be undertaken in a manner that will not add to the complexities that already exist in the FEW nexus Leck *et al* [67]; rather, it should make the framework simpler and more usable across all scales and disciplines [1, 33, 49].

Researchers have proposed new approaches to conceptualize the FEW nexus. Artur et al [16] proposed the use of integrated indicators of the FEW nexus sectors (appendix A). Albretch et al [1] and Bergendahl et al [53], advocated for a transdisciplinary approach to the FEW nexus. Biggs et al [22] focused on environment and livelihood in the FEW nexus by applying the environmental livelihoods security framework. Abulibdeh and Zaida [63] noted the importance of scale-relevant analyses in their holistic geographical framework. Gunda and Tidwell [43] proposed the resource-product-waste cycle, highlighting the need to include the social and governance issues that determine FEW nexus interactions [43]. Based on these studies, this work explores FEW nexus dynamics adopting the household as the scale of analysis. We utilize insights from existing frameworks to propose the inclusion of dynamics such as gender, culture, social safety nets, seasons, age, and employment in order to determine how these affect linkages in the FEW nexus.

In addition, the frameworks considered in this review focused on an understanding of the FEW nexus at scales from global institutions to local communities (table 2). There is no framework that addresses local household issues, e.g. ecosystem service provision, gender issues, and household incomes [6], which determine and are influenced by the FEW nexus [22]. The household forms the basic unit of a micro analysis to understand society [3, 77]. The inclusion of factors that affect the household FEW nexus is imperative to provide a robust framework. This is not a simple task as household dynamics are not easy to measure and require carefully formulated assessment tools [28]. However, devising such tools is imperative to making the FEW nexus approach relevant to all scales across the societal spectrum, providing a more robust framework for resource governance and management.

3.4.2. Assessment methods of the FEW nexus

Our review found that FEW nexus articles employed various methodologies for assessment. The methodologies used in the FEW nexus were found to be heavily dependent on the disciplines of the authors/researchers; for example, those from economic backgrounds used econometric models, those from engineering would use engineering models. The same observation was made by Albrecht *et al* [1], Shannak et al [39], Endo et al [14], Kurian et al [78] in their reviews. This review found that FEW nexus research methodologies are diverse and they adopt various methodologies based on the research and background of the researchers. To get a perspective of the prevailing FEW nexus methodologies we categorized them into the three methodological sets; qualitative, quantitative and mixed methods research. In this review papers that are classified under qualitative follow were those whose methodologies employed qualitative analysis such as document analysis, document analysis, policy analysis, stakeholder analysis. The documents also utilized qualitative data collection tools i.e. interviews, focus group discussions, expert interviews in their studies. Quantitative research papers were those which employed statistical modeling, GIS modeling, hydrological models and big data in their collection and analysis (appendix B). Articles classified under mixed methods are those which combined quantitative and qualitative such as interviews and experts opinions in data collection then employed some quantitative analysis and vice versa.

Our review found that 22 (37%) of previous research articles employed qualitative methods, 35 (58%) used quantitative methods, and 3 (5%) used mixed methods (figure 7). Document analysis was the most frequently used qualitative method, accounting for seven studies [11, 49, 60, 69, 78-80] (appendix C). The second most widely used qualitative method was content analysis, with four [78, 81-83]. Stakeholder analysis and transdisciplinary approach were each utilized in three articles. Institutional analysis was employed in two studies, and a number of other methods were mentioned in single studies, such as ecological modernization, sustainable supply chain, social network analysis, knowledge co-production approach, participatory building, actor ecosystem services approach, and global production networks. Some articles used two or more approaches, for example transdisciplinarity combined with ecological modernization and the sustainable supply chain [53]. The majority of research articles (32, i.e. 53%) utilized quantitative methods, with the most frequently used being quantitative modeling, employed in 20 articles. Various researchers used different modeling techniques according to their discipline, such as the optimization model [41, 54, 84–86], data envelopment model [87, 88], hydro-economic modeling [89, 90], integrated modeling [28, 91], GIS modeling [92], multi-criteria decision making modeling [93], biogeochemical process model [94], and crop modeling [72]. The second most used method was LCA, which was employed in five articles [95–99], followed by input-output analysis in three articles [100–102]. Various other methodologies were utilized in single studies, namely water-energy and carbon footprint analysis, risk characteristic analysis,

index analysis, energy footprint analysis, multistochastic fuzzy random programming, multivariate calibration, multivariate calibration, roof mosaic design, agricultural production efficiency, and tradeoff analysis. Only 3 (5%) articles utilized a mixed methods approach. Two of these employed document analysis, network analysis [80], and socio-ecological network analysis [42]. Endo et al [54] used several qualitative and quantitative methods, i.e. ontology engineering, integrated maps, physical models, cost benefit analysis, integrated index, and optimization management models. This clearly demonstrates that no standard methodology applies to FEW nexus assessment; instead, researchers employ various methods from different disciplines. These findings agree with those of Albretch et al [1] and Newell et al [33]. The use of various methodologies influenced by the cross-cutting nature of FEW nexus issues necessarily makes conceptualization of the FEW nexus challenging. A net impact of different and diverse interpretations of the FEW nexus approach makes it less robust as a framework of analysis [103]. To answer this challenge, researchers have recommended that the FEW nexus be assessed using a transdisciplinary approach based on cooperation between researchers from various disciplines and using the co-production of knowledge with other stakeholders [1, 33, 53, 104, 105]. The current situation in FEW nexus research clearly demonstrates that need for a transdisciplinary approach such that diverse expertise and a rich array of methodologies and approaches may be brought to FEW nexus research.

Research articles were further categorized using a scale of analysis enabling an understanding of current trends. Papers were grouped according to the scale used in their study. Three scales were established: (a) the local scale, which encompassed households and small geographical areas, e.g. villages; (b) the mesoscale, including larger areas, e.g. towns, cities, and districts, up to the country level; and (c) the macroscale, which covers transboundary areas up to the global level (appendix C). In terms of scale, the majority of papers were found to focus on large areas, with the macroscale accounting for 18 studies, the mesoscale 30, and the local scale 12 (figure 7). At the local scale, only three articles, Hussien et al [28, 65], and Foden [66] made direct reference to households as a unit of analysis. As such, the FEW nexus approach does not have strong focus on local scale factors, since households are largely ignored. Of note, Hussien et al [28, 65] conducted studies in developing countries whereas Foden [66] conducted research in a developed country. These three articles explored the characteristics of households, albeit in different socio-economic, geographical, and political contexts. They show that a standard conceptualization can be used while being adapted to suit different contexts. Understanding FEW nexus interactions at the household level is thus imperative because transdisciplinarity and knowledge co-production require the involvement of all stakeholders at all levels [53]. To achieve this, stakeholders at the household level need to actively participate. The first step is to identify factors that influence FEW nexus interactions at the household level and integrate these into the FEW nexus framework.

To gain a better understanding of the factors that determine FEW nexus interactions, the use of quantitative or qualitative methods alone is not sufficient [1, 33, 49, 61]. There is a need to examine the qualitative aspects that affect the household FEW nexus such as cultural beliefs, political backgrounds, and societal factors that cannot be quantified [13, 49, 62]. As such, FEW nexus assessment can be conducted in a continuum were qualitative and quantitative assessments are utilized together [49]. Foran [49] proposed that qualitative analysis should be at the start of the continuum and quantitative analysis should be at the end. This paper proposes that both quantitative and qualitative analysis be conducted at all scales of the continuum to capture all aspects of the FEW nexus (figure 2).

3.4.3. Assessment methods of the FEW nexus at the household level

It was found that only three articles Hussien et al [28, 65], Foden et al [66] referred to household food, energy, and water issues (appendix B). Of the three papers, one Foden et al [66] conducted research in a developed country, whereas Hussien et al [28, 65] studied developing countries. Hussien et al [65] assessed household utilization of water energy and food across a city using models. Hussien et al [28] employed a model that assessed household food, energy nexus. These variables were family size, seasonal variability, and income within food, energy and water consumption end-use parameters. These produced water demand, energy demand, food demand, food waste, and wastewater as outputs [28]. The seasonal variability of food, energy and water demand and consumption at the household level was also explored [65]. Foden [66] examined the household FEW nexus by considering human behavior. They established that household FEW nexus interactions and behavior are influenced by resource contexts. These papers showed the importance of assessing the household level in the FEW nexus. To obtain a better understanding of the household factors, a search was conducted on Scopus and Google Scholar. It was imperative to use Google Scholar in addition to Scopus so as to access gray literature that was not captured in the Scopus database (table 3).

The review found that siloed research on household food security has advanced in academia. This explains why there are more articles from the food

Author	Title	Country/ Case	Sector (s)	Method	Factors
Abdullah <i>et al</i> [106]	Factors affecting household food security in rural northern hinterland of Pakistan	Pakistan	Food	Binary logistic regression technique	Age, gender, education, remittances, unemployment, inflation, assets, and disease, resource ownership, credit, food aid, food prices, social nets
Ahmed <i>et al</i> [107]	Status and determinants of small farming house- holds' food security and role of market access in enhancing food security in rural Pakistan	Pakistan	Food	Logistic regression	Age, education, household size, income, distance to road, health expenses, debt, crop diseases, bad climate
Allam <i>et al</i> [108]	Drivers of food security of vulnerable rural households in Bangladesh: implications for policy and development	Bangladesh	Food	Calorie intake model	Age of household head, gender of household head, education of household head, household size, cultivated land size, adoption of livestock, access to non-farm income, access to safety net, health of household head
Asghar and Muhammad [26]	Socio-economic determinants of household food insecurity in Pakistan socio-economic determin- ants of household food insecurity in Pakistan	Pakistan	Food	Logistic regression model	Household size, income, household head age, household head education, gender, female education, livestock ownership, employment, irrigation availability
Mannaf and Uddin [109]	Socioeconomic factors influencing food security status of maize growing households inselected areas of Bogra district Maksuda	Bogra district	Food	Food security index	Farm size, age of household head, household size, educational level, income, food expenditure, livestock ownership
Zakari <i>et al</i> [110]	Factors influencing household food security in west Africa: the case of southern Niger	Niger	Food	Logistic regression model	Household head age, household head sex, household head educa- tion, Household size, assets, drought, diseases and insects, distance from main road, labor
Mergesa <i>et al</i> [111]	The role of livestock diversification in ensur- ing household food security under a changing climate in Borana, Ethiopia	Ethiopia	Food	Household food insecur- ity access scale (HFIAS); Logistic regression model	Livestock ownership, size of farm, Off-farm income, family size, polygamy, district, livelihood source diversification
					(Continued)

			Table 3. (Con	tinued).	
Author	Title	Country/ Case	Sector (s)	Method	Factors
Majumder <i>et al</i>	Food security of the hill tracts of Chittagong in Bangladesh	Bangladesh	Food	Logit model	Farm category, education, profession, road distance, family size, NGO service, micro-credit, livestock
Subbaraman <i>et al</i> [113]	Multidimensional measurement of household water poverty in a Mumbai slum: looking beyond water quality	Mumbai	Water	Perception analysis mul- tivariate logistic regres- sion model	Employment, education, Social relationships, health, price of water, religion, safety nets, household size, income, method of collecting water, frequency of collecting water
Bisung and Elliot [114]	Improvement in access to safe water, house- hold water insecurity, and time savings: a cross- sectional retrospective study in Kenya	Kenya	Water	Household water insecur- ity access scale (HWIAS)	Gender, employment, education, wealth, water source, sufficient quantity of water for household use, time spend fetching water, number of women, number of girls, household size, age of house- hold head
Tsai <i>et al</i> [27]	Population-based study of intra-household Gender Differences in Water Insecurity: Reli- ability and Validity of a Survey Instrument for Use in Rural Uganda	Uganda	Food and water	HFIAS; HWIAS	Gender, age, source of water, quantity of water collected, distance to water source, household size, educational attainment, seasonal changes
Fabinyi [64]	Food and water insecurity in specialized fishing communities: evidence from the Philippines	Philippines	Food and water	HFIAS; HWIAS	Stressors: financial problems, sickness, expenses for children, food, water, bad weather, alcohol/vices
Hussien <i>et al</i> [28]	An integrated model to evaluate water-energy- food nexus at a household scale	Iraq	Food, energy and water	Integrated model	Family size, seasonal variability, income, consumption of each food commodity, duration of cooking session of each food commodity, water consumption per cooking session of each food commodity, no. of cooking sessions of each food commodity, fuel/electricity consumption per hour of using hob ring for cooking, percentage of waste from each type of food



Figure 7. FEW nexus research articles categorized according to scale and methodology.



sector and these have clearly established factors. Research on household water is also gaining ground and it was established that this research is adopting and modifying factors from the food sector. Research on energy security is still largely being conducted at the community level upwards. There is still very limited assessment of the two sectors combined; only one article was found, in which a food assessment tool was modified to measure both food and water security.

Bisung and Elliot [114], Fabinyi [64], Tsai *et al* [27] are important as they introduce methods for assessing two components of the WEF nexus. They employ the HFIAS, Coates *et al* [31] and the HWIAS

[27]. From the review, only one article Hussein et al [28] had an assessment method for all the three sectors combined. However, that paper was limited in the number of household factors utilized in the analysis. It is also clear that there is limited research on the FEW nexus at the household scale [28, 66]. Establishing intermediary factors in the FEW nexus at the household scale is a primary objective of this review and an important component in the development of a robust conceptual framework. We selected the following factors: age, gender, income, education, seasonal variations, education, household size, ownership of resources, distance to resources, safety nets, and employment. Selection was based on frequency of use in the articles, e.g. family size was identified as the determining factors in ten articles, age and education in nine articles, gender in six, and household income in five. Selection was also based on the inference of meaning of factors, e.g. remittances, inflation, and financial problems have a direct link to household income, whereas sickness, alcohol/vices, and diseases are attributes of household health. Micro-credit, NGO service, livelihood diversification, and credit lines are linked to household safety nets. Factors can be analyzed using both quantitative and qualitative tools and techniques [31, 64]. These factors were included in the reshaped FEW conceptual framework in two categories, which indicates seven direct factors (age, health, income, education, family size, gender, and employment) and four indirect factors (distance to resources, safety nets, seasonal changes and ownership of resources) (figure 8).

4. Reshaping the few nexus framework to incorporate household variables

This review proposes the inclusion of the identified household factors in existing conceptual frameworks. The framework encompasses key drivers from the four selected influential frameworks [3, 5, 10, 76]. The framework adopts the FEW nexus processes of Mohtar and Daher [76] into the reshaped framework. To show the importance of the micro scale in FEW nexus thinking, the household is the core of this paper's framework (figure 8). The framework identifies the key drivers and categorizes them into global and local factors (a). The drivers have an overall external influence on the FEW nexus at all scales and are also influenced by the interactions at various levels. The processes and factors involved in the FEW nexus interact across all scales, starting with the household at the micro level (b). The last component of the framework proposes two categories, i.e. strategies and outcomes derived from the FEW interactions (c). This section highlights the major issues that influence micro scale interactions and shape policy at the macro level within strategies. These

strategies have a direct bearing on the outcomes category and can be constantly improved upon through monitoring and evaluation of programs to improve the FEW nexus at various scales.

The reshaped FEW nexus framework (figure 8) utilizes concepts from existing frameworks [3, 5, 6, 10], (table 2) and household factors selected from (table 3). In section (a), drivers are divided into global and local factors, which determine institutional and individual interactions in the FEW nexus. The drivers (a) are obtained from Hoff [5], the World Economic Forum [10], and Mohtar and Daher [76]. Key concerns in the three sectors shown are indicated in large squares, i.e. food security (brown square), energy security (gold square), and water security (blue square), as denoted by Hoff [5], the World Economic Forum [10], and Mohtar and Daher [76]. Arrows indicate processes between sectors. These are shown within the solid line since they influence FEW nexus interactions at all scales, i.e. from the local to global levels. For the household level, we utilized factors selected from table 3.

Households form the core of our framework of analysis. Household factors were selected from table 3 and are categorized into those factors that directly affect FEW nexus interactions in the households (within the solid green line), and those with an indirect impact on households but that are linked to FEW processes (within the dotted green line). Factors identified as having a direct impact on households are important for understanding household attributes that affect resource access, utilization, and participation in governance [3, 22]. We utilized evidence, scenario development, and response options, denoted by Flammini et al [3] as key analysis components at all scales. Evidence refers to data collected and analyzed to understand interlinkages between sectors in different contexts, thereby helping to identify constraints that inform policies with the objective of improving the well-being of stakeholders at all levels. Scenario development involves establishing the benefits and tradeoffs of interventions and policy on society, economy, and environment, and should be considered when developing interventions for different stakeholders at different scales in the FEW nexus [3]. Response options follow the evidence-based outcomes of scenario development. In the modified framework, we used the household level as the core that can help to analyze the FEW nexus using both quantitative and qualitative methods.

The dotted lines in (b), connecting (a) and (c), reflect the overall context of the FEW interactions. Section (c) identifies strategies and outcomes expected in FEW nexus interactions at all levels. The reshaped FEW nexus framework is versatile and allows the utilization of different methodologies, amongst which are quantitative modelling methodologies and stakeholder analysis for qualitative analysis.

5. Conclusion

Food, energy, and water are vital components for human well-being. Conceptualizing the nexus approach is an important step in designing a robust framework that adequately captures the dynamic interfaces occurring in FEW interactions. This review found that most research on the FEW nexus has focused on the national, regional, and global scales. At the local scale, there is a need for further research. Much research on the FEW nexus is also influenced by the disciplines of researchers, leading to several methodologies that are specific to individual disciplines. The majority of articles on the FEW nexus utilize quantitative methods, whereas a minority use qualitative methods. Very few studies have used mixed methods. Previous studies have done much to highlight key features in the FEW nexus and guide our understanding of the approach; however, forming a framework for the FEW nexus has largely focused on processes and stakeholders in which the latter are included as a component of the processes rather than as a separate facet whose complexity has some major impacts on how nexus interactions occur. There is clearly a need for a transdisciplinary approach to FEW nexus research. Using such an approach would impact how we interpret resource distribution, resource management, and policy framing. This approach will also assist in the framing of assessment tools that capture all facets of the nexus. In turn, this will influence the strategies employed at different levels to enhance synergies and reduce tradeoffs in the FEW nexus. Reducing tradeoffs, such as resource conflicts, while improving synergies can assist countries in meeting the SDG targets in a practical and sustainable way. In this case, robust synergies and reduced tradeoffs in the FEW nexus will help countries attain SDGs 1, 2, 6, and 7 directly. In addition, robust FEW nexus approaches will indirectly influence SGD 17, as institutions work together at various levels with different organizations to promote good

management of resources for the betterment of the society.

To gain a better understanding of the drivers that occur among stakeholders, this study recommends the following:

- (a) FEW nexus assessment should be conducted from the household scale to adequately capture issues that affect society at the local scale.
- (b) Nexus assessment can adopt a continuum where both qualitative and quantitative methods are utilized. Qualitative analysis can be employed at the micro level of the assessment, especially at the household scale, whereas quantitative analysis can be utilized at the macro levels, which involve large amounts of data.
- (c) It is imperative that integrated FEW nexus assessment indicators/indices that can be applied across disciplines is developed. This will help make the FEW nexus a more robust as a policy guide.
- (d) FEW nexus research should adopt transdisciplinary approaches so as to include all stakeholders and utilize diverse knowledge sources. Such an approach is important to drive a deeper understanding of FEW nexus thinking wherein stakeholder engagement begins with an analysis of the issues that shape stakeholder activities at the household level.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Authors	Title	Methodology	Novel concepts covered	Key FEW nexus recommendations
Albrecht <i>et al</i> [1]	The water–energy–food nexus: a systematic review of methods for nexus assessment	Bibliometric analysisContent analysis	 Reasons why studies employ the FEW nexus approach Key features of FEW nexus analytical approaches 	There is need for employing interdisciplinary and mixed-methods in FEW nexus research The FEW nexus research should incorporate Transdisciplinary approaches
Abulibdeh and Zaidan [63]	Managing the water- energy-food nexus on an integrated geograph- ical scale	Case studies	Introduces the geographical scale	Identifies the need of assess- ing the FEW nexus at differ- ent geographical scales
Biggs et al [22]	Sustainable develop- ment and the water– energy–food nexus: a perspective on livelihoods	Content analysis	 Introduced Sustainable livelihood approach to FEW nexus thinking Environmental Livelihood Security approach to FEW nexus 	Need for an integrated framework which includes micro factors into the FEW nexus approach
Dargin <i>et al</i> [38]	Complexity versus sim- plicity in water energy food nexus (WEF) assessment tools	Content analysis	Identify nexus assessment tools	 There is need to create nexus tools which are accessible to all stakehold- ers in decision making sectors There should be integra- tion of participatory and collaborative approaches in nexus meth- ods and tools
Endo et al [103]	Dynamics of water– energy–food nexus methodology, methods, and tools	Quantitative ana- lyses of keywords	 Categorizes nexus research articles by various stages of interdisciplinary research Identifies indicators to assess nexus methods and tools 	 There is need to formulate a nexus methodology which combines different methodologies and tools these should be inclusive of both qual- itative and quantitative analysis FEW analysis should cap- ture natural, social science and mixed methods
Mannan et al [45]	Quantifying the energy, water and food nexus: a review of the latest developments based on life-cycle assessment	Meta-analysis	The paper reviews the inter- connecting factors and pro- cesses in the FEW nexus	The life cycle assessment is a feasible analytical tools for FEW nexus
Newell <i>et al</i> [33]	A 40 year review of food–energy–water nexus literature and its application to the urban scale	Bibliometric analysis	Analyses the FEW nexus approaches for urban areas	There is a need for qualitative approaches, and co-production strategies to go bey- ond traditional tools to capture relationships between nexus sectors to understand FEW nexus in cities
Sarkodie and Owusu [34]	Bibliometric analysis of water– energy–food nexus: Sustainability assess- ment of renewable energy	Bibliometric analysis	Research on FEW nexus is growing because of its grow- ing influence on policy	 FEW is a useful tool for policy implementation There is need to focus on renewable energy techno- logies as a key variable in FEW nexus

Appendix A. Existing FEW nexus review articles

Authors	Title	Methodology	Novel concepts covered	Key FEW nexus recommendations
Shannak <i>et al</i> [39]	Moving from theory to practice in the water–energy–food nexus: An evaluation of existing models and frameworks	Content analysis	Analysis of integrated resource management tools relevant for the FEW nexus	 Need for more sophistic- ated modelling of the FEW nexus There is a need to examine the interdependencies across resource systems in their spatial and temporal scopes.
Zhang et al [41]	Food–energy–water (FEW) nexus for urban sustainability: A comprehensive review	Content analysis	Assessment of existing FEW concepts and methods at various scales	 Proposes a three- dimensional conceptual framework of the FEW nexus in an urban context Establishes three points of analysis: (a) Resource interdepend- ency (b) Resource provision (c) System integration.
Wiegleb and Bruns [48]	What is driving the water-energy- food nexus? discourses, know- ledge, and politics of an emerging resource governance concept	Discourse analysis	They establish that the FEW nexus discourse is driven by natural scientific world- views grounded in neo- Malthusian thought	They note that the FEW nexus is a western construct but is predominantly applied in the global south
Arthur <i>et al</i> [16]	Urban food–energy– water nexus indicators: A review	Content analysis	 Reviews urban FEW nexus indicators Categorizes the indicators into four groups	There is a need to develop further indicators which take into account different flows in systems
Torres <i>et al</i> [15]	A literature review to propose a systematic procedure to develop 'Nexus Think- ing' considering the water–energy–food nexus	Bibliometric analysis Content analysis	Proposes a procedure for nexus thinking through utilizing a mind map.	Nexus concepts can be understood as a multisector tool which shows interde- pendencies between water energy and food
Chen <i>et al</i> [115]	Recent progress on the water–energy–food nexus using bibliometric analysis	Bibliometric analysis	Analysis of the current trends in FEW nexus research	The paper gives an overview of FEW nexus research and identifies gaps for future studies

Appendix B. FEW nexus research articles

Author	Title	Methods	Scale	Author (Country)	Study area (Region/Region)
Allam and Eltahir [93]	Water–energy–food nexus sustainability in the Upper Blue Nile (UBN) Basin	FAO framework for land evaluation multi-criteria decision making (MCDM) model	National	USA	Africa Upper Blue Nile Basin
Bergendahl <i>et al</i> [53]	Transdisciplinarity and the food energy and water nexus: ecological modernization and supply chain sustainab- ility perspectives	Case Study FEW nexus Transdisciplinarity, ecological moderniza- tion, Sustainable supply chains	Local	Germany	North East Africa
					(Continued)

Author	Title	Methods	Scale	Author (Country)	Study area (Region/Region)
Bhattacharyya et al [79]	A bottom-up approach to the nexus of energy, food and water security in the Economic Com- munity of West African States (ECOWAS)	Case study policy analysis, document analysis	Regional/ Global	Germany	Germany
Bieber et al [84]	region Sustainable plan- ning of the energy– water–food nexus using decision making teals	Optimization model	National	UK	West Africa
Bielicki et al [116]	Stakeholder perspect- ives on sustainability in the food–energy–water	Stakeholder analysis	Regional/ Global	UK	Ghana
Basheer et al [117]	Quantifying and eval- uating the impacts of cooperation in trans- boundary river basins on the water–energy– food nexus: the Blue Nile Basin	Modeling scenario building	Regional/ Global	USA	USA
Daher et al [118]	Towards bridging the water gap in Texas: a water–energy–food nexus approach	Water, energy, carbon footprint analysis	Local	USA	USA
Daher et al [119]	Toward creating an environment of cooper- ation between water, energy, and food stake- holders in San Antonio	Social network analysis	Local	USA	USA
Damerau <i>et al</i> [120]	Water saving potentials and possible trade-offs for future food and	Modeling shared economic pathways (SSPs)	Regional/ Global	Switzerland	Africa, Latin America, Asia, Europe
Deng et al [100]	Managing the water- energy-food nexus in China by adjusting critical final demands and supply chains: an input-output analysis	Input–Output analysis (IO) Structural path analysis	National	China	China
De Vito, Portoghese, Pagano, Fratino, and Vurro [121]	An index-based approach for the sus- tainability assessment of irrigation practice based on the Water- Energy-Food Nexus framework	Case Study Index Analysis Irrigation Water Footprint Index Energy Footprint Index Irrigation Water Cost Index	Local	Italy	Italy
Endo <i>et al</i> [54]	Methods of the Water- Energy-Food Nexus	Ontology engineering Integrated maps Physical models Cost benefit analysis Integrated index Optimization man- agement models	Regional	Japan	Japan, Philippines
Foden et al [60]	The water–energy–food nexus at home: New opportunities for policy interventions in house- hold sustainability	Case Study Document analysis Transdisciplinary approach	Local/ Household	USA	USA

Author	Title	Methods	Scale	Author (Country)	Study area (Region/Region)
Foran [49]	Node and Regime: Interdisciplinary Analysis of Water- Energy-Food Nexus in the Mekong Region	Document Analysis Case Study	Regional	Australia	Mekong Basin (Cambodia, Lao PDR, and Myan- mar, Thailand, Vietnam, Yunan Browingo (china)
Franz, Schlitz, and Schumacher [83]	Globalization and the water-energy-food nexus—Using the global production networks approach to analyze society- environment relations	Content Analysis Global Production Networks Approach (GPN)	Local	Germany	Germany
Gain, Giupponi, and Benson [69]	The water-energy-food (WEF) security nexus: the policy perspective of Bangladesh	Document Analysis Case Study	National	USA	Bangladesh
Ghani, Silalertruksa, and Gheewala [95]	Water-energy-food nexus of bioethanol in Pakistan: A life cycle approach evaluating footprint indicators and energy performance	Life Cycle Analysis (LCA)	National	Thailand	Pakistan
Gondhalekar and Ramsauer [92]	Nexus City: Opera- tionalizing the urban Water-Energy-Food Nexus for climate change adaptation in Munich, Germany	FEW Approach Systems Perspective	National	Germany	Germany
Halbe, Pahl-Wostl, A Lange, and Vel- onis [122]	Governance of trans- itions towards sustain- able development—the water–energy–food nexus in Cyprus	Stakeholder analysis Integrated model	National	Germany	Cyprus
Hannibal and Portney [123]	Correlates of Food– Energy–Water Nexus Awareness Among the American Public	Awareness Index	National	USA	USA
Hoffmann, Sander, Brüntrup, and Sieber [124]	Applying the Water- Energy-Food Nexus to the Charcoal Value Chain	Value chain Analysis	Regional/ Global	Germany	Sub-Saharan Africa
Howarth and Monasterolo [105]	Understanding barriers to decision making in the UK energy-food - water nexus: The added value of interdisciplin- ary approaches	Transdisciplinary Approach	National	UK	UK
Howarth and Monasterolo [104]	Opportunities for knowledge co- production across the energy-food-water nexus: Making inter- disciplinary approaches work for better climate decision making	Co-production Approach	National	UK	UK
Hussien, Memon and Savic [28]	An integrated model to evaluate water-energy- food nexus at a house- hold scale	Integrated Model	Local/ Household	UK	Iraq

Author	Title	Methods	Scale	Author (Country)	Study area (Region/Region)
Hussien, Memon and Savic [59]	A risk-based assessment of the household water- energy-food nexus under the impact of seasonal variability	Water-Energy-Food Nexus Model	Local/ Household	UK	Iraq
Jalilov, Keskinen, Varis, Amer, and Ward [89]	Managing the water– energy–food nexus: Gains and losses from new water development in Amu Darya River Basin	Hydro-economic Models	Local	Finland	Tajikistan and Uzbekistan
Ji, Zhang, Huang, and Lu [125]	Multi-stage stochastic fuzzy random pro- gramming for food- water-energy nexus management under uncertainties	Multi-Stochastic Fuzzy Random Programming (MSFRP) Model	Regional/ Global	China	China
Jiang, Chen, Hao, Fu, and Ding [94]	Assessing the Sustain- able Development of Bioenergy from Cassava within 'Water-Energy- Food' Nexus Frame- work in China	Biogeochemical Process Model	National	China	China
Johnson and Karlberg [126]	Co-exploring the Water-Energy-Food Nexus: Facilitating Dia- logue through Particip- atory Scenario Building	Participatory Scenario Building	Regional/ Global	Kenya	Rwanda and Ethiopia
King and Carbajales-Dale	Food–energy–water metrics across scales: project to system level	Life Cycle Analysis (LCA)	Regional/ Global	USA	USA
Koppa and Gebremichael [90]	Improving the Applic- ability of Hydrologic Models for Food– Energy–Water Nexus Studies Using Remote Sensing Data	Multivariate Calibration Hydrological Model	Local	USA	USA
Kurian <i>et al</i> [78]	One Swallow Does Not Make a Summer: Siloes, Trade-Offs and Synergies in the Water- Energy-Food Nexus	Content Analysis Document Analysis	Regional/ Global	Germany	Brazil
Lebel and Lebel [127]	Nexus narratives and resource insecurities in the Mekong Region	Policy Analysis Narrative Policy Framework	Regional/ Global	Singapore	Mekong Basin (Cambodia, Lao PDR, and Myan- mar, Thailand, Vietnam, Yunan Province-China)
G Li, Huang, and Li [88]	China's Input-Output Efficiency of Water- Energy-Food Nexus Based on the Data Envelopment Analysis (DEA) Model	Data envelopment analysis model (DEA)	National	China	China
M Li et al [91]	An optimal modelling approach for managing agricultural water- energy-food nexus under uncertainty	Integrated model	National	China	China

Author	Title	Methods	Scale	Author (Country)	Study area (Region/Region)
Li and Ma [97]	Evaluating the envir- onmental impacts of the water-energy-food nexus with a life-cycle	Life cycle analysis (LCA)	National	Taiwan	Taiwan
Märker, Venghaus, and Hake [68]	Integrated governance for the food–energy– water nexus—The scope of action for institutional change	Institutional analysis and development framework	Regional/ Global	Germany	Germany
Marttunen, Mustajoki, Sojamo, Ahopelto, and Keskinen [61]	A Framework for Assessing Water Secur- ity and the Water- Energy-Food Nexus The Case of Finland	Case Study Participatory Process framework	National	Finland	Finland
Miller-Robbie et al 2017 [128]	Wastewater treatment and reuse in urban agriculture: exploring the food, energy, water, andhealth nexus in Hyderabad, India	Life cycle analysis	National	USA	India
Namany et al [85]	Optimization of the energy, water, and food nexus for food security scenarios	Economic and Envir- onmental Assessments Optimization Model	National	Qatar	Qatar
Nie et al [86]	A Food–Energy–Water Nexus approach for	Case study design mod- eling Optimization	Local	China	China
Ozturk [129]	The dynamic relation- ship between agricul- tural sustainability and food energy-water poverty in a panel of selected Sub-Saharan African Countries	Regression analysis	Global	Turkey	Sub-Saharan Africa
Pahl-Wostl [81]	Governance of the water-energy-food security nexus: A multi- level coordination challenge	Content analysis	Regional/ Global	Germany	Germany
Pardoe et al [130]	Climate change and the water–energy–food nexus: Insights from policy and practice in Tanzania	Case study Policy analysis	National	Netherlands	Tanzania
Portney <i>et al</i> [131]	Awareness of the Food—Energy– Water Nexus and Public Policy Support in the United States: Public Attitudes Among the American People	Case study Multivariate regression Awareness index	National	USA	USA
Ramaswami et al [132]	An urban systems framework to assess the trans-boundary food–energy–water nexus: implementation in Delhi, India	Environmental footprinting In-boundary FEW nexus analysis	National	USA	India

Author	Title	Methods	Scale	Author (Country)	Study area (Region/Region)
Rasul and Sharma [11]	The nexus approach to water–energy–food security: an option for adaptation to climate	Case study Document analysis	Regional/ Global	Nepal	Hindu Kish Him- alayan Region
Salmoral and Yan [99]	Food–energy–water nexus: A life cycle ana- lysis on virtual water and embodied energy in food consumption in the Tamar catchment, UK	Life cycle analysis (LCA)	Local	UK	UK
Schlör, Venghaus, Fischer, Märker, and Hake [82]	Deliberations about a perfect storm e The meaning of justice for food energy water- nexus (FEW-Nexus)	Content Analysis Case Study	National	Germany	Germany
Sherwood <i>et al</i> [101]	An extended envir- onmental input- output lifecycle assessment model to study the urban food–energy–water nexus	Environmental input– output life-cycle assessment	National	USA	USA
Shrestha, Adhikari, Babel, Perret, and Dhakal [72]	Evaluation of groundwater-based irrigation systems using a water–energy–food nexus approach: a case study from Southeast Nepal	Case study Performance evaluation Water emissions budget Aqua crop model (Crop Yields simulation)	National	Thailand	Nepal
Spiegelberg <i>et al</i> [42]	Unfolding livelihood aspects of the Water– Energy–Food Nexus in the Dampalit Water- shed, Philippines	Socio-ecological net- work analysis	National	Japan	Philippines
Stein, Pahl-Wostl, and Barron [80]	Towards a relational understanding of the water-energy- food nexus: an ana- lysis of embedded- ness and governance in the Upper Blue Nile region of Ethiopia	Case study Document analysis Network analysis	National	UK	Ethiopia
Taniguchi <i>et al</i> [133]	Tradeoffs in the water– energy—-food nexus in the urbanizing Asia- Pacific region	Trade-off analysis	Regional/ Global	Japan	Asia-Pacific Countries
Toboso-Chavero et al [134]	Towards productive cities environmental assessment of the food– energy–water nexus of the urban roof mosaic	Environmental assessment Roof mosaic design	Local	Spain	Spain
Villamayor- Tomas, Grundman, Epstein, Evans, and Kimmich [135]	The water–energy–food security nexus through the lenses of the value chain and the insti- tutional analysis and development frame- works	Value chain analysis Institutional analysis and development framework (IAD) Networks of action situations (NAS)	Regional/ Global	Germany	Germany

Author	Title	Methods	Scale	Author (Country)	Study area (Region/Region)
Xiao, Yao, Tang, and Sun [102]	Identifying critical sup- ply chains: an input– output analysis for Food–Energy–Water Nexus in China	Input–output analysis	National	China	China
Zhang et al [136]	Structure dynamics and risk assessment of water–energy–food nexus: a water footprint approach	Water footprint analysis Risk characteristics analysis	National	China	China
Zhang et al [137]	Optimization model for enhancing water- use efficiency from the perspective of water- energy-food nexus	Optimization model	National	China	China
Zheng <i>et al</i> [87]	Exploring the water- energy-food nexus from a perspective of agricultural production efficiency using a three- stage data envelopment analysis modelling eval- uation method: a case study of the middle and lower reaches of the Yangtze River, China	Data envelopment analysis (DEA) Agriculture produc- tion efficiency (APE)	National	China	China

Appendix C. FEW nexus research articles categorized according to scale and methodology

Scale	Methodology qualitative	Mixed	Quantitative
Global and	Bhattacharvya <i>et al</i> [79]	Endo <i>et al</i> [54]	Damerau <i>et al</i> [120]
regional-macro	Policy analysis,	Ontology engineering	Modelling
0	document analysis	Intergrated maps	Shared Economic Pathways
		Physical models	(SSPs)
		Cost benefit analysis	
		Integrated index	
		Optimization manage-	
		ment models	
	Foran [49]		Hoffmann et al [124]
	Document Analysis		Value chain Analysis
	Gragg et al [138]		Ji <i>et al</i> [125]
	Scenario Development		Multi-Stochastic Fuzzy Random
	Modelling		Programming (MSFRP) Model
	Johnson and Karlberg [126]		Ozturk [129]
	Participatory Scenario Building		Regression Modelling
	Kurian <i>et al</i> [78]		Taniguchi <i>et al</i> [133]
	Content Analysis		Trade-off Analysis
	Document Analysis		
	Lebel and Lebel [127]		Zheng et al [87]
	Policy Analysis		Data Envelopment Analysis (DEA)
	Narrative Policy Framework		Agriculture Production Efficiency (APE)
	Märker et al [68]		
	Institutional Analysis		
	And Development Framework		

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Scala	Mathadalagy qualitative	Mived	Quantitativa
Scale	wieinodology qualitative	IVIIXED	Quantitative
	Pahl-Wostl [81] Content Analysis Rasul and Sharma [11] Document Analysis Villamayor-Tomas, Grundman, Epstein, Evans, and Kimmich [135] Value Chain Analysis Institutional Analysis and Devel- opment Framework (IAD) Networks of Action Situations (NAS)		
	Bielicki, Beetstra, Kast, Wang, and Tang [116] Stakeholder Analysis		
National-Meso	Gain, Giupponi, and Benson [69] Document Analysis	Spiegelberg <i>et al</i> [42] Socio-Ecological Network Analysis	Allam and Eltahir [93] FAO Framework for Land Evaluation Multi-criteria Decision Making (MCDM) model
	Halbe, Pahl-Wostl, A. Lange, and Velonis [122] Stakeholder analysis Integrated model	Stein, Pahl-Wostl, and Barron [80] Document analysis Network Analysis	Bieber <i>et al</i> [84] Optimization Model
	Howarth and Monasterolo [105] Transdisciplinary Approach		Deng, Wang, Cai, Liu, and Zhang [100] Input-Output Analysis (IO) Structural Path Analysis
	Howarth and Monasterolo [104] Co-production Approach		Ghani, Silalertruksa, and Gheewala [95] Life Cycle Analysis
	Pardoe <i>et al</i> [130] Policy Analysis		Hannibal and Portney [123] Multivariate models Awareness Index
	Schlör, Venghaus, Fischer, Märker, and Hake [82] Content Analysis		Jiang, Chen, Hao, Fu, and Ding [94] Biogeochemical Process Model
	Marttunen, Mustajoki, Sojamo, Ahopelto, and Keskinen [61] Case Study Participatory Process Framework		G Li, Huang, and Li [88] Data Envelopment Analysis Model (DEA)
	Franz, Schlitz, and Schumacher [83] Content Analysis Global Production Networks		King and Carbajales-Dale [96] Life Cycle Analysis
	Approach		M Li <i>et al</i> [91] Integrated Model Li and Ma [97] Life Cycle Analysis (LCA) Miller-Robbie <i>et al</i> 2017 [128] Life Cycle Analysis Namany <i>et al</i> [85] Economic and Envir- onmental Assessments Optimization Model
			Portney <i>et al</i> [131] Multivariate Regression Awareness index Ramaswami <i>et al</i> [132] Environmental Footprinting In-boundary FEW nexus analysis

	Table A3. (Continued).						
Scale	Methodology qualitative	Mixed	Quantitative				
			Shrestha, Adhikari, Babel, Perret, and Dhakal [72] Performance Evaluation Water Emissions Budget Aqua Crop Model (Crop Yields simulation) Sherwood <i>et al</i> [101] Environmental Input-Output Life- Cycle Assessment Xiao, Yao, Tang, and Sun [102] Input-Output Analysis Gondhalekar and Ramsauer [92] GIS Modelling Zhang <i>et al</i> [136] Water Footprint Analysis Risk Characteristics Analysis				
Local and Household- Micro	Bergendahl, Sarkis, and Timko [53 FEW nexus Transdisciplinarity, Ecolo- gical modernisation, Sustainable Supply chains]	Zhang <i>et al</i> [137] Optimization Model Daher, Lee, <i>et al</i> [118] Water, Energy, Carbon Footprint Analysis				
	Daher, Hannibal, Port- ney, and Mohtar [119] Social Network Analysis Foden <i>et al</i> [60] Document analysis		De Vito, Portoghese, Pagano, Fratino, and Vurro [121] Index Analysis Irrigation Water Footprint Index Energy Footprint Index Irrigation Water Cost Index Hussien, Memon and Savic [28] Integrated Model				
	Transdisciplinary approach		Hussien, Memon and Savic [59] Water-Energy-Food Nexus Model Jalilov, Keskinen, Varis, Amer, and Ward [89] Hydro-economic Models Koppa and Gebremichael [90] Multivariate Calibration Hydrological Model Nie <i>et al</i> [86] Design Modelling Optimisation Salmoral and Yan [99] Life Cycle Analysis Toboso-Chavero <i>et al</i> [134] Environmental Assessment Roof Mosaic Design				
Total articles	22	3	35				

The table shows the scale and methodology employed in different FEW nexus research articles. There are three scale levels: (a) local and household or micro scale, that cover a small spatial study areas (b) national or meso scale, that cover research at country level (c) global and regional or macro scale, that cover research in two or more countries. There three methodological categories: (a) qualitative, (b) quantitative, (c) mixed that refers research articles which utilized both quantitative and qualitative methods.

Appendix D. Country productivity in FEW nexus research

Rank	Country	FEW (A)	Citation FEW	Sustainability sciences	Population (in million)	A/M	T/AC	A/SS
1	United States	118	1510	4326	328	0.359	12.80	2.7
2	United Kingdom	61	1266	1400	67	0.913	20.75	4.4
3	Germany	39	627	1046	83	0.469	16.08	3.7
4	China	34	302	1192	1398	0.024	8.88	2.9
								(Continued)

				Sustainability	Population			
Rank	Country	FEW (A)	Citation FEW	sciences	(in million)	A/M	T/AC	A/SS
5	Australia	19	382	1170	25	0.749	20.11	1.6
6	Italy	16	201	801	60	0.265	12.56	2.0
7	Netherlands	13	103	589	17	0.750	7.92	2.2
8	Japan	12	270	329	126	0.095	22.50	3.6
9	France	10	122	663	67	0.149	12.20	1.5
10	Thailand	10	186	114	70	0.144	18.60	8.8
11	Switzerland	9	40	356	9	1.050	4.44	2.5
12	Canada	9	125	912	38	0.239	13.89	1.0
13	Brazil	9	155	553	211	0.043	17.22	1.6
14	Lebanon	9	71	20	7	1.313	7.89	45.0
15	Spain	9	65	680	47	0.191	7.22	1.3
16	Nepal	7	40	21	29	0.245	5.71	33.3
17	South Africa	7	20	351	59	0.120	2.86	2.0
18	Mexico	7	171	199	128	0.055	24.43	3.5
19	India	7	201	834	1366	0.005	28.71	0.8
20	Sweden	6	187	521	10	0.583	31.17	1.2
21	South Korea	5	54	151	52	0.097	10.80	3.3
22	Taiwan	5	41	123	24	0.210	8.20	4.1
23	Sri Lanka	4	69	29	22	0.183	17.25	13.8
24	Austria	4	266	236	9	0.451	66.50	1.7
25	Finland	4	94	229	6	0.725	23.50	1.7
26	Belgium	3	35	252	11	0.261	11.67	1.2
27	Turkey	3	1	169	83	0.036	0.33	1.8
28	Portugal	3	10	305	10	0.292	3.33	1.0
29	Indonesia	3	30	302	271	0.011	10.00	1.0
30	Qatar	3	7	19	3	1.059	2.33	15.8
31	Norway	3	13	232	5	0.561	4.33	1.3
32	Myanmar	3	18	4	54	0.037	6	75.0
33	Pakistan	2	41	103	217	0.009	20.50	1.9
34	New Zealand	2	11	194	5	0.407	5.50	1.0
35	United Arab	2	0	49	10	0.205	0.00	4.1
26	Emirates	2	25	27	1	1 ((0	17.50	7 4
30 27	Cyprus	2	35 10	27	1	1.009	17.50	/.4
3/ 20	Jordan	2	18	25	10	0.198	9.00	8.0
28 20	Morocco	2	12	37	30 100	0.055	6.00	5.4
39	Philippines	2	9	66	108	0.018	4.50	3.0
40	Greece	2	22	1/5	11	0.187	11.00	1.1
41		2	57	111	19	0.106	28.50	1.8
42	lanzania	2	4	35	58	0.034	2.00	5.7
43	Singapore	2	5	/6	6	0.351	2.50	2.6
44	Hong Kong	2	20	99	8	0.266	10.00	2.0
45	Czech Republic	2	28	11/	11	0.18/	14.00	1./
40	Tunisia	2	218	59	165	0.012	109.00	5.4
47		2	1	30	12	0.1/1	0.50	6./
48	Ethiopia	2	24	42	112	0.018	12.00	4.8
49 50	Kazakhstan	2	18	24	19	0.108	9.00	8.3
50	Sudan	1	0	4	43	0.023	0.00	25.0
51	Ghana	1	7	70	30	0.033	7.00	1.4
52	Kenya	1	5	75	53	0.019	5.00	1.3
53	Malaysia	I	5	357	32	0.031	5.00	0.3
54	Saudi Arabia	1	2	72	34	0.029	2.00	1.4
55	Nigeria	1	5	99	201	0.005	5.00	1.0
56	Solomon Islands	1	2	8	1	1.493	2.00	12.5
57	Zimbabwe	1	0	29	15	0.068	0.00	3.4
58	Eswatini	1	0	3	1	0.871	0.00	33.3
59	Denmark	1	9	252	6	0.172	9.00	0.4
60	Palestine	1	3	3	5	0.198	3.00	33.3
61	Cambodia	1	13	6	16	0.061	13.00	16.7
62	Egypt	1	9	54	100	0.010	9.00	1.9
63	Iran	1	6	162	83	0.012	6.00	0.6

Key: FEW (A)—Total number of FEW related articles; A/M—Total number of FEW related articles published per million inhabitants; T/AC—Average citations per article (FEW related articles); Percentage of FEW related articles in Sustainability Science related articles.

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