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Bibliometric analysis of water–energy–food nexus: Sustainability assessment of renewable energy

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Abstract

Water–energy–food nexus has received global attention, as the interdependency of these resources is crucial to developing conceptual tools for environmental sustainability. Thus, water–energy–food nexus underpins economic development and improves life and well-being. We provide a critical assessment of extant literature on water–energy–food nexus using bibliometric analysis within the last 2 years. Using the keyword "*Water-Energy-Food*" from 2017 to 2020 in Scopus, data on 235 documents after preprocessing were used for further investigations. We found that scholarly research on water–energy–food nexus is expanding rapidly because of its policy implications. However, results and policy effects were heterogeneous because of a lack of a common conceptual framework of water–energy–food nexus—making the conceptual tool more challenging. Although renewable energy technologies have been described as the antidote for achieving environmental sustainability, however, a sustainability assessment revealed that while fossil fuel energy technologies compete with water withdrawal and consumption, some renewables compete with food for land-use—a situation that requires cost and benefits policy estimation. This article thus highlights that the effect of water–energy–food nexus on environmental sustainability depends on several socioeconomic factors that require attention.

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Water–energy–food nexus, Sustainability assessment, Livelihoods, Sustainable development, Bibliometric analysis.

Introduction

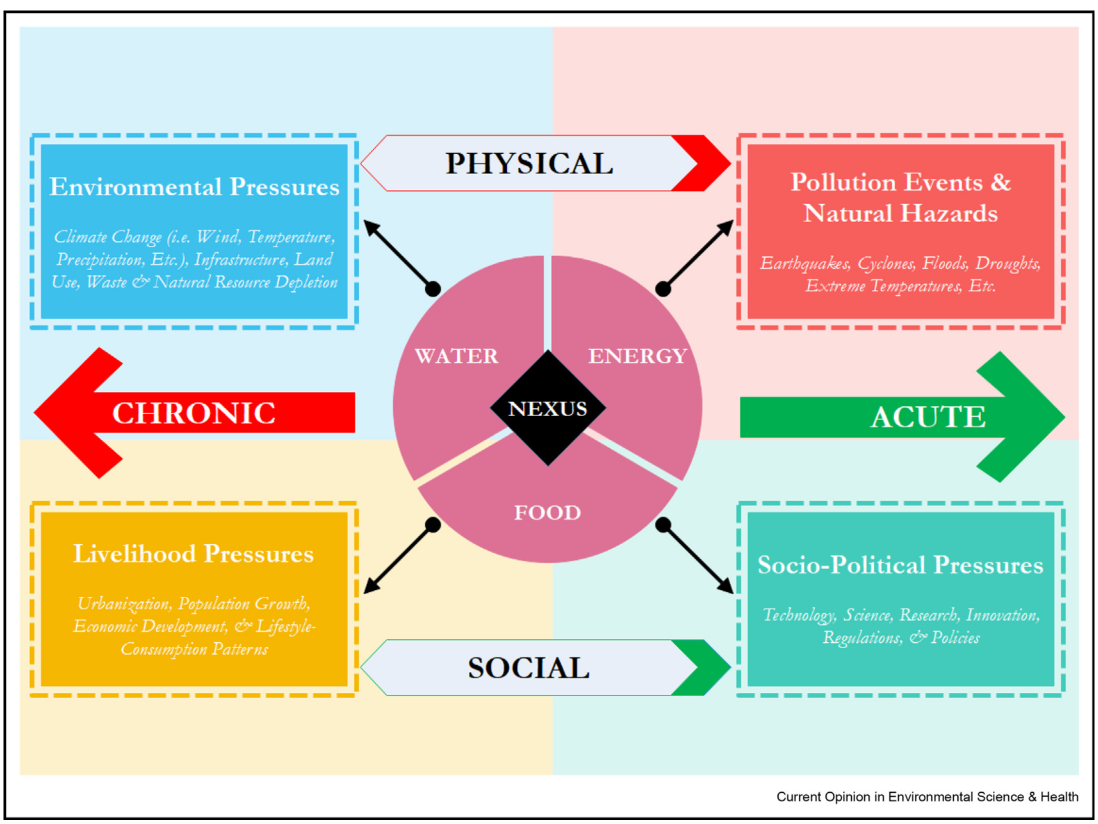
The trilemma of water—energy—food nexus is increasingly becoming complex to achieving sustained economic growth, sustainable water productivity, energy, and food security while mitigating climate change and its impact. This means that achieving sustainable management and efficient use of water—energy—food help in achieving Sustainable Development Goal 12. However, the rate of population growth and industry-driven economic development put pressure on the available natural resources to meet the growing demand for energy, water, and food [1]. The availability of water is critical to the effectiveness and efficiency of most energy technologies, whereas energy in effect is essential to power water supply for food production (agricultural activities), industrial and household supply in areas with water scarcity [2]. Although the nexus concept is promising, counterfactual changes determine its effectiveness to either achieving sustainable development or negating sustainability. The conceptual framework of the external factors affecting water—energy—food nexus is presented in Figure 1. Two forms of shocks have been identified, namely physical and social change, which may have chronic or acute consequences on the nexus framework. Environmental pressures such as climate change—in the form of intermittency and fluctuations in weather patterns like changes in wind, temperature, radiation, precipitation hamper the productivity of energy, food, and water. Poor infrastructural management, land-use, waste generation, and natural resource depletion are equally examples of environmental pressures that affect the nexus structure. Pollution events and natural hazards such as, inter alia, earthquakes, cyclones, flood, extreme temperatures, and droughts disrupt the ecological system, hence, affecting the functionality of water—energy—food. Livelihood pressures such as urbanization, population growth, economic development, lifestyle-consumption patterns, among others, exist alternatively as drivers of anthropogenic greenhouse gas emissions—the resulting effect that disrupts food, water, and energy security. The effect of sociopolitical pressures such as technology, science, innovation, research and development, regulations and policies appear to cushion the water—energy—food nexus and spur its functionality. The conceptual framework of external factors reveals that the water—energy—food nexus is not a stand-alone concept but depends on several physical and social factors to serve its purpose.

The water–energy–food nexus assessment strategy used in this study is presented in Scheme 1. We first examined the sustainability effect of disaggregate energy technologies (fossil fuels, clean and renewable energy) on water and land-use—a proxy used to assess its impact on food. Second, we examined extant literature using the bibliometric technique—where bibliographic pieces of information on published work were extracted, checked for data quality, and applied quantitative techniques to empirically investigate scholarly documents.

Sustainability assessment of energy–water–food nexus

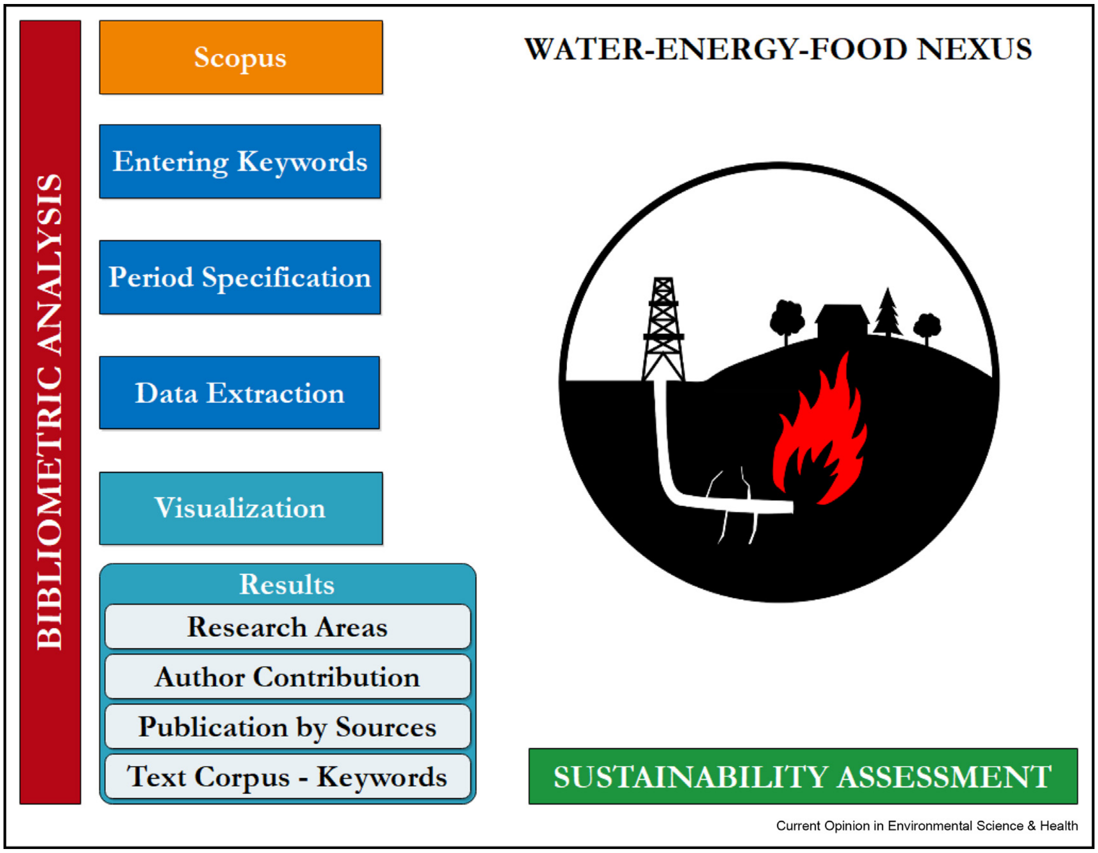
We present the sustainability assessment of the various energy technologies with a focus on water and land-use—an alternative for food metric assessment. Water withdrawal and consumption by the various energy technologies depend on efficiency; lifetime; climatic conditions like humidity, air, and water temperature [3]. Almost all fossil fuel energy technologies are thirsty for water to be more efficient in production. For instance, water withdrawal and consumption per energy produced is barely minimum for wind, geothermal, biomass, solar photovoltaic, and natural gas–based dry-cooled technology, whereas more gallons of water are required for efficient plants with recirculating cooling systems like concentrating solar power, oil, coal, natural gas, and nuclear power [4]. Energy aside its impact on available water resources competes with land-use that could be used for food production [5]. In terms of competition between energy and food for land-use, nuclear, coal, oil, and natural gas energy production have a minimum land-use footprint, typically between ~0.13 and 8.19 km^2/TWhr compared with wind, geothermal, solar photovoltaic, hydropower, solar thermal, biofuel, and biomass ranging from ~1.31 to 809.74 km^2/TWhr [6]. Meaning that renewable energy technologies have higher land-use footprint compared with conventional or extractive energy technologies. Among the renewables, wind energy is the most land efficient (~0.34–1.37 km^2/TWhr) in terms of direct footprint, whereas biomass energy is the least land efficient—with a higher land-use footprint (~558–1254 km^2/TWhr) [6].

Figure 1



Conceptual Framework of the External Factors of water–energy–food nexus.

Scheme 1



Water–energy–food nexus assessment strategy.

Current research on water–energy–food nexus

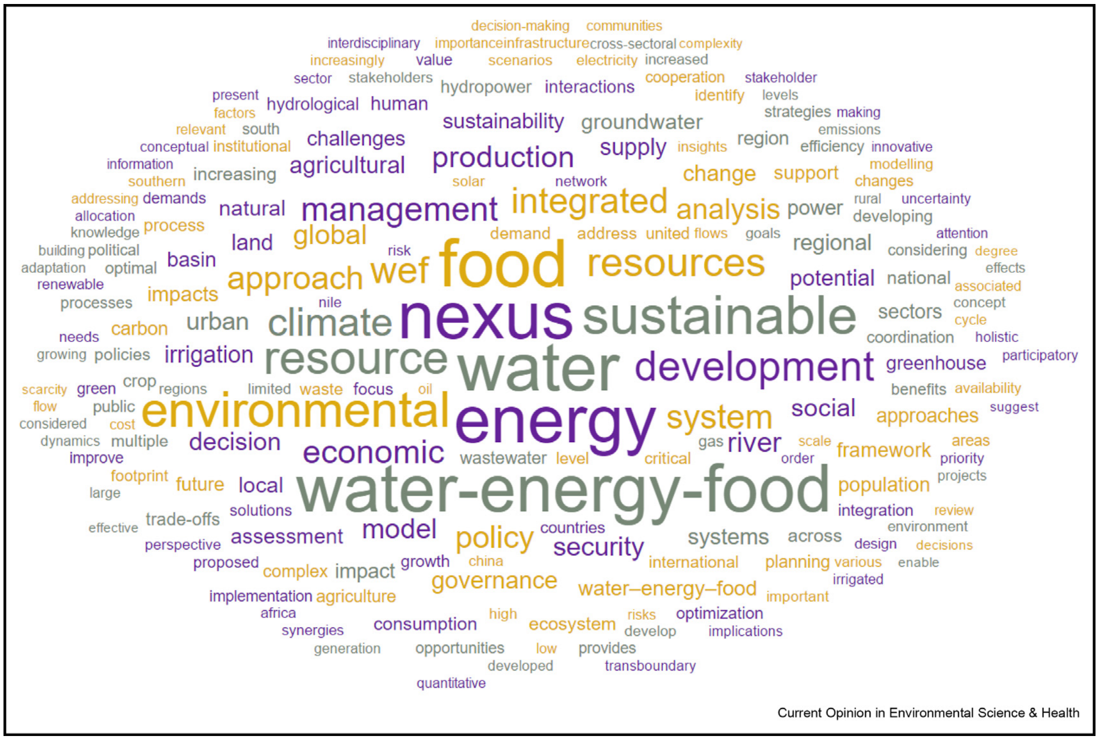
Water—energy—food nexus is topical in recent times, hence, has received much attention in different disciplines. For that reason, we conducted a bibliometric investigation of the extant literature using the Scopus database[1] rather than Web of Science with limited coverage. We searched the word "*water-energy-food*" within article title, abstract, and keyword section from 2017 to 2020 and limited the language to English while excluding errata document type. A visual inspection is done to weed out documents that take advantage of keywords without substantial evidence on the scope of the study. The resulting output showed 235 documents, which comprised articles (168), reviews (20), book chapters (17), conference papers (14), books (4), editorials (3), notes (3), short surveys (2), conference reviews (1), and letters (1). Documents published in 2018 (100) were more than 2019 (76), 2017 (58), and 2020 (1). Study areas that have examined the *water—energy—food nexus* concept include environmental science (188), social sciences (71), energy (53), engineering (34), earth and planetary sciences (34), agricultural and biological sciences (31), biochemistry, genetics, and molecular biology (20), business, management, and accounting (15), chemical engineering (14), computer science (10), medicine (10), chemistry (6), economics, econometrics, and finance (6), materials science (3), multidisciplinary (2), arts and humanities (1), decision sciences (1), mathematics (1), and psychology (1).

We adopted text corpus to analyze the most frequent keywords used in studies related to water—energy—food nexus. In the order of weight presented in Figure 2, the top 10 words within title, author keywords, abstract, and index keywords include water (appears 1017 times), nexus (761), energy (457), food (449), resource(s) (420), water—energy—food (344), sustainable (273), environmental (241), development (196), resources (189), and climate (182).

It is observable in Figure 3 that water—energy—food nexus project can be categorized under regions, namely Europe (totaling 46.7%), Asia (20.9%), North America

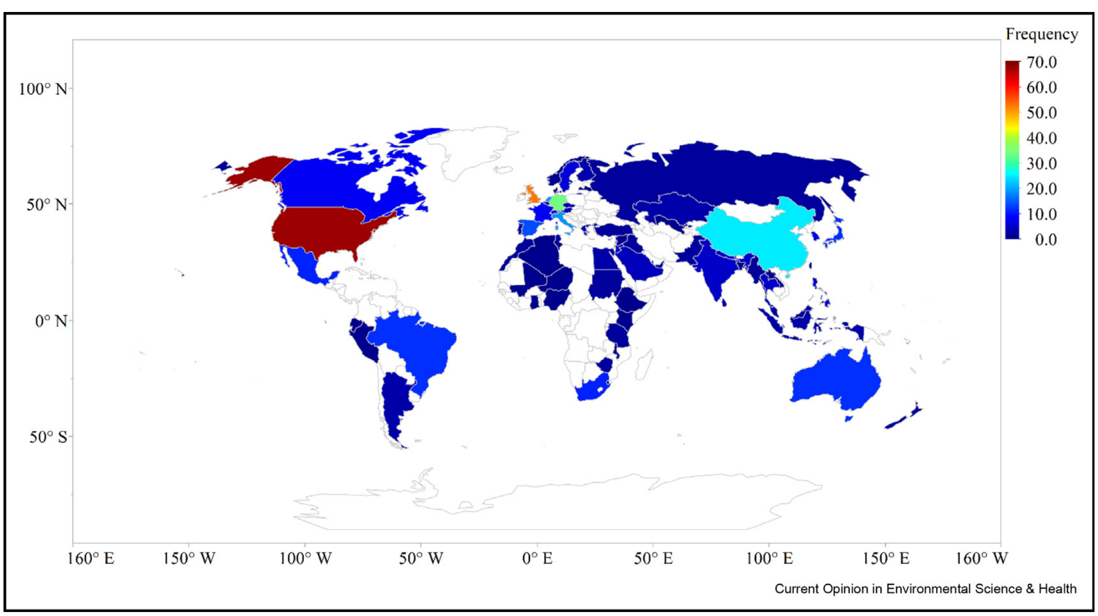
[1] RSS-Feed of the searched word "water-energy-food": https://syndic8.scopus.com/getMessage?registrationId=CHFEDJMECHFECHFFEHGNCQHFDHGHDLLIFLHMLJMJGN.

Figure 2



Text corpus on water–energy–food nexus.

Figure 3



Geographical representation of water–energy–food nexus project across countries.

(17.9%), Africa (7.4%), South America (3.9%), and Oceania (3.2%). Top 10 countries with the highest nexus project include the United States (78 projects), the United Kingdom (53), Germany (38), China (25), Italy (19), the Netherlands (19), Spain (14), Lebanon (13), Australia (12), and Brazil (12). Scientific journals with the highest published work on water–energy–food nexus include *Water Switzerland* (17 documents), *Science of the Total Environment* (16), *Frontiers in Environmental Science* (15), *Environmental Science and Policy* (11), *Sustainability Switzerland* (11), *Journal of Cleaner Production* (8), *Energy Procedia* (6), *Journal of Hydrology Regional Studies* (6), *Earth's Future* (5), and *International Journal of Environmental Research and Public Health* (5).

The top 20 most cited studies in the order of priority include Endo, Tsurita [7], Wichelns [8], Kurian [9], White, Hubacek [10], Weitz, Strambo [11], Albrecht, Crootof [12], Zhang, Chen [13], Zhang and Vesselinov [14], Liu, Yang [15], Hussien, Memon [16], Giupponi and Gain [17], Pellegrini and Fernández [18], Li, Fu [19], Pahl-Wostl [20], Kaddoura and El Khatib [21], Pan, Gao [22], Martinez-Hernandez, Leach [23], de Amorim, Valduga [24], Closas and Rap [25], and Gondhalekar and Ramsauer [26]. We elaborate on the top 10 studies in the field within the past two years. Endo, Tsurita [7] assessed existing studies on water–energy–food nexus using bibliographic assessment based on 37 published documents as sample size. Among other findings of the study include water–food nexus—efficient water utilization for food production, water–energy nexus—use of water resources for energy production and energy for water production technologies, and water–energy–food nexus—a trivariate indicator for assessing the feasibility and sustainability of projects. Wichelns [8] investigated the role of investment and policies to ensure sustainable water–energy–food nexus. However, Wichelns [8] revealed that water–energy–food nexus has issues with omitted variable bias, hence, fails to address challenges such as labor, land tenure, and financial assistant in agricultural production to boost food security. Another limitation revealed is the absence of evidence of success with policy analysis based on water–energy–food nexus contrary to earlier attempts. Thus, the paucity of a common conceptual framework of water–energy–food nexus makes the concept challenging. Kurian [9] examined the role of governance, institutional policy, and available tools for integrated policy analysis of water–energy–food nexus. The paper argued that the inferences of scientific support of the water–energy–food nexus were not automatic that its implementation would be successful. In the same way, Weitz, Strambo [11] argued that environmental governance mechanisms underpin the sustainability of the water–energy–food nexus. White, Hubacek [10] demonstrated that globalization through trade openness, economic development, increasing prosperity through income levels, lifestyle changes in consumption patterns, and population growth (including migration) influence the production and consumption of water–energy–food. Albrecht, Crootof [12] assessed 245 scientific articles on the water–energy–food nexus and highlighted the following: (1) there are limited studies on the nexus concept and the application of methods from distinct disciplines; (2) literatures using both qualitative and quantitative estimation methods are sporadic; (3) there are tons of studies on the water–energy–food nexus from quantitative methods; (4) very few studies use social science–related methods; (5) the nexus concept fails to capture relationships among energy, water, and food; and (6) lack of common, detailed, and reproducible methods used for nexus assessment. The strength of this paper captures inter- and intradisciplinary methods to nexus modeling using socioeconomic and political components of the water–energy–food nexus. Zhang, Chen [13] examined the concept and estimation methods used for investigating the water–energy–food nexus. The concept of nexus was explained in two forms: first, the nexus explained as independent relationships between water, energy, and food; second, the nexus used as an analytic technique to measure the links between water, energy, and food. The strength of this paper is in the assemblage and detailing of all existing assessment methods for water–energy–food nexus. The estimation methods used thus far include econometric analysis, life-cycle analysis, computational general equilibrium modeling, agent-based modeling, integrated index modeling, system dynamics modeling, physically based modeling, mathematical and statistical analysis, and ecological network modeling. Liu, Yang [15] raised concerns about the paucity of systematic tools to tackle the trade-offs and synergies of the water–energy–food nexus. It appears that most studies on the water–energy–food nexus focus on a global, national, and urban scale; however, Hussien, Memon [16] focused on the household scale. The strength of the paper is the usefulness for policy formulation in the household level but will be problematic at the national level because of varying economic levels across households.

Conclusion

The nexus concept of water–energy–food is a useful tool for policy formulation when considered as a composite indicator of environmental sustainability rather than the individual or interaction effect. Although water–energy–food nexus has received much attention after the Bonn conference, many studies have raised concerns with regards to the lack of consensus on the conceptual framework of water–energy–food nexus. Renewable energy technologies have been described as the magic bullet to achieving environmental sustainability; however, it appears many studies fail to account for the role of renewable energy production and consumption in the water–energy–food nexus approach.

Thus, because renewable energy technologies are localized and cannot be traded internationally, a country-specific policy analysis based on the water—energy—food nexus is essential to augment environmental and energy security. Many studies demonstrate that the water—energy—food nexus is not a stand-lone conceptual tool, hence, its related positives can be fruitful through a strong institutional framework. Other studies revealed that the sustainability of water—energy—food nexus is influenced by the economic structure. For example, countries with high dependence on agriculture for food production often invest more in water resources, whereas industrialized economies often invest heavily in energy technologies, especially fossil fuels to increase industrial productivity. Thus, structural adjustments in economic development will determine the role of water—energy—food nexus in environmental sustainability.

Conflict of interest statement

None declared.

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