The energy-water-food nexus: Concept, challenges and prospects

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The energy-water-food nexus has increasingly drawn the attention of studies due to concerns about the future security of energy, water, and food and the inherent and undeniable relationship among them. Lack of knowledge of such systematic thinking will have unpredictable and conflicting results. In this paper, the definition and concept of the nexus as well as the impact of external factors on these systems in two physical and social categories were investigated and analyzed from different perspectives. Also, the empirical studies conducted on the energy-water-food nexus system at various scales were reviewed. Finally, the prospects and challenges of the energy-water-food nexus were fully examined. Each of the mentioned issues is a challenge in evaluating the sustainability and resiliency of a nexus system. The presence of different dimensions and aspects of evaluating a system such as economic, environmental, and sociological dimensions to evaluate the nexus system performance can also be challenging. © 2021 Journal of Energy Management and Technology

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1. INTRODUCTION

Based on the predictions, the global demand for water, energy, and food in 2050 will be 50 percent higher than that in 2015 due to population growth, urbanization, and climate change. This issue has caused significant pressure and sensitivity on available water, energy, and food systems in many parts of the world. The important point on the mentioned issue is that water, energy, and food are interconnected. For example, severe drought caused by climate change due to the increasing water supply tension can lead to significant problems in the area of food security and energy [1, 2].

According to statistics provided in the United States, about 3 to 4 percent of all used electrical power is related to water distribution systems, water treatment plants, and sewage installations. About 80% of total electrical power is used for pumping and distributing water and about 20% of it is used in sewage installations. Also, the services related to the provision of the drinking water and the sewage applications include the largest part of the energy consumed by municipalities, accounting for 30 to 40 percent of total energy consumed. The water and electrical power systems have traditionally been considered as two separate systems. However, when these systems are investigated from the energy point of view, they are interdependent [3].

We need water for mining, producing fuel and hydroelectric power, cooling of power plants, collecting, treating and discharging of wastewater, and generally meeting the energy requirements. Hence, in today's economy, energy, and water are highly interdependent [4, 5].

The relationship among water, energy, and food is undeniable and the availability of sufficient water resources has a significant impact on the availability of energy and food resources. Energy and electrical power generation activities are affected by the quality and availability of water. Under these conditions, the concept of the energy-water-food nexus was comprehensively developed for investigating the global resource systems and management. Such systematic thinking is very valuable, since lack of knowledge on the relationship among these three sectors may lead to unpredictable and conflicting results [6, 7].

In the following, in Section 2, the definition and concept of the nexus are fully analyzed. Also, in Section 3, the empirical studies on the energy-water-food nexus are reviewed. The future challenges and prospects in the area of energy-water-food nexus are discussed in Section 4 and the conclusion of the study is presented in Section 6.

2. CONCEPTS OF NEXUS

The nexus's popularity dates back to the World Economic Forum in 2008 when global challenges related to economic development were identified from the perspective of the energy-water-food nexus. Various definitions and interpretations have

been introduced for the nexus by different organizations and authorities [8].

various aspects such as the interdependent physical and chemical processes, the relationships between input and output, the interactions among different institutions and organizations, infrastructure, economic issues, and so on. The important point from the security point of view is that a problem and a failure in one sector have caused disruption and pressure in the other two sectors, indicating the importance of having comprehensive management across different sectors.

In short, the recent definition has focused on the interactions among different sectors of the nexus, and the general characteristics of the system are explained by the interactions among its various components.

Fig. 1 illustrates the relationship and interaction among different sectors of a nexus.

In another definition, the nexus is defined as an analysis-based approach that determines the relationships among different sectors of the nexus such as energy-water-food nexus. Different views have been proposed by different individuals and sectors on this definition. For example, Reference [11] argues that the nature of the nexus is for resource recovery and uses other resource products to improve system performance. Reference [12] argues that the relationships among the different sectors of the nexus are so large that they cannot be examined only from one aspect and must be evaluated from different aspects.

Despite the different interpretations and definitions, it can be briefly stated that in a nexus system with an integrated management among different sectors (that were previously managed independently), we seek to cut the operating costs and increase the sustainability of each sector.

There are different research approaches on the energy-water-food nexus. However, many factors such as goals, data availability, scales, and so on are crucial in selecting these approaches. As illustrated in Fig. 2, there are also specific research approaches and priorities for each scale of the nexus.

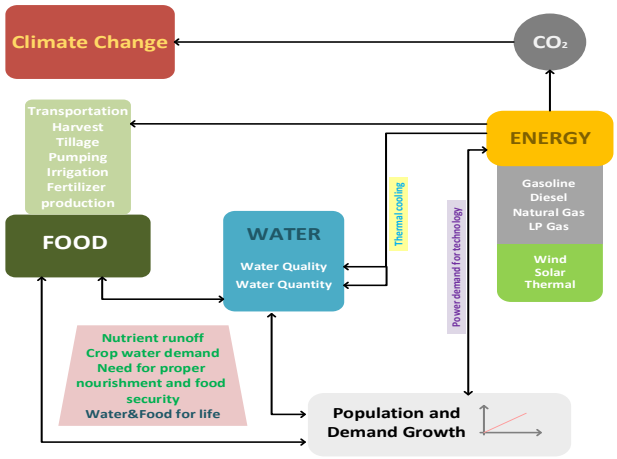

Fig. 1. Interaction among different sectors of a nexus

3. THE IMPACT OF EXTERNAL FACTORS ON THE NEXUS

Several external factors can have great impacts on the performance of the nexus, which is mainly regulated under certain conditions. External factors that can affect the nexus are generally divided into physical and social categories. Fig. 3 illustrates this classification clearly.

Climate changes, as well as natural disasters, can have an impact on the process of production of energy, water, and food. These factors are physical factors related to the nexus.

References [13] and [14] have shown that climate change and events such as drought and floods have a very negative impact on agriculture due to their changes in water availability. Reference [15] has shown the negative impact of climate change on energy production.

Areas with warm climates due to the need for high water consumption and areas with humid climates due to a greater potential for agriculture have separate impacts on the nexus [16]. Due to reduced access to water in areas where water evaporation level is high, electricity production through hydroelectric power plants as well as irrigation of agricultural areas is affected [17].

In investigating the social factors affecting the supply nexus, the focus shifts from supply to demand. Changing people eating habits and patterns can have a great impact on water and energy consumption [18]. The development of technology and the presence of rules and policies in an area can have a great impact on the nexus. Reference [19] shows that changes in rules of the agriculture sector occurred with the aim of declaring a lack of need for the production of agricultural crops that have greatly reduced groundwater resources in an area in China.

In investigating the external factors affecting the nexus, we can provide another classification of them based on the time of their occurrence. Severe climate changes and natural disasters can cause significant changes in the nexus system.

Reference [20] suggests that the level of electricity generated by a hydroelectric power plant in southwestern Europe has reduced by 40% due to drought. Comparing the governing conditions of different years, reference [21] has shown that increasing demand for cereals due to population growth requires more land and water use, while climate changes threaten the availability of groundwater and surface water resources seriously.

Reference [22] has shown that an increase in temperatures due to climate changes over the last few years have resulted in more energy consumption in the southwestern United States. These factors play a key role in agriculture. Investigating a nexus system in Mauritius, reference [23] has shown the impacts of decision-making about the development of biofuels to maintain energy security and reduce greenhouse gas emissions on the nexus. Investigating a nexus system is crucial to realize to what extent the nexus system can continue its normal function or return to its normal function in the shortest possible time after the occurrence of an external event. This issue, known as system resilience, is one of the crucial issues that should be addressed by researchers in relation to the nexus system for better management of the system [24–26].

4. THE EMPIRICAL RESEARCHES ON THE ENERGY-WATER-FOOD NEXUS

In addition to different arguments on the nexus, analyzed in the previous section, empirical studies are also increasingly performed at different nexus scales. Besides the energy, water, and water sectors, the nexus includes other sectors such as Earth and the environment.

Investigating an energy-water nexus in the United States, Refer-

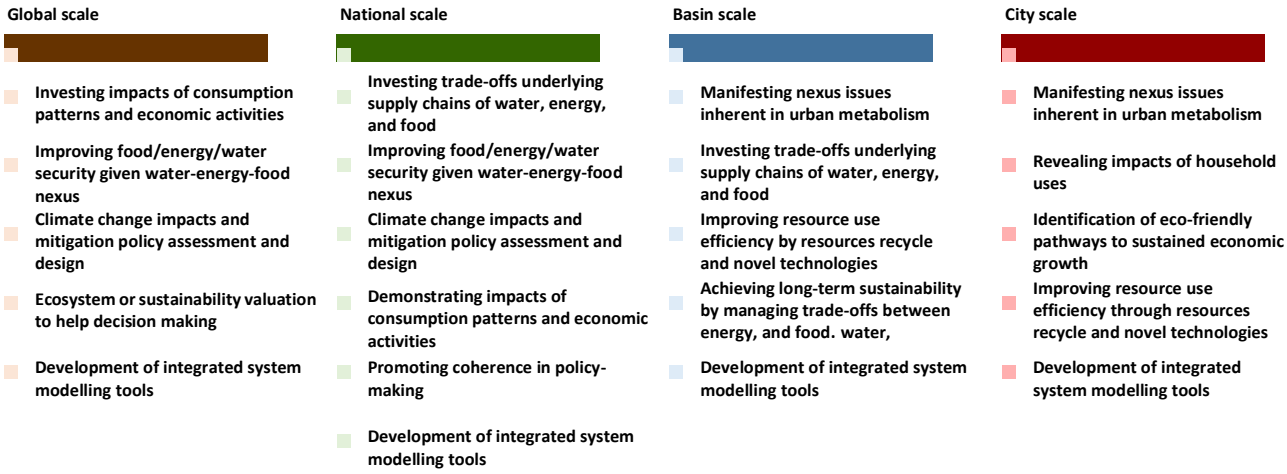

Fig. 2. The research priorities for each scale of the nexus

ence [27] has referred to many interactions between the

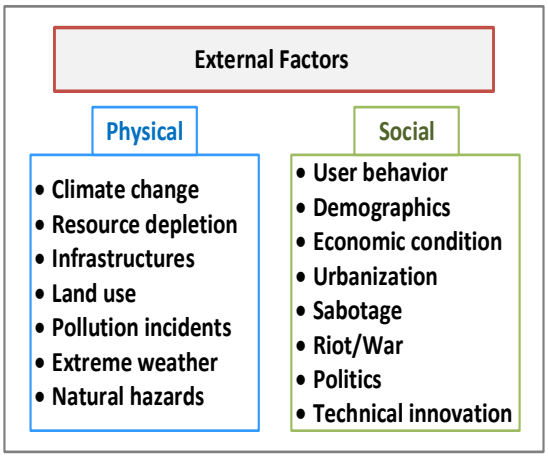

Fig. 3. The impact of external factors on the nexus

electrical energy and the water distribution system. It has also minimized the cost of operating the system by knowing the level of water demand and electrical power price for the next day and by optimizing the performance of the pumps and water tanks in a sample water distribution system. Reference [28] had compared and analyzed the level of water consumed by urban people in the Netherlands and the level of food consumed in that city and referred to the existing links. Reference [29] has proposed a new risk-based approach to the energy-water-food nexus and showed that water treatment for non-drinking consumptions can cause an interaction between water and energy. Reference [30] has examined the socio-economic link between the energy-water-food nexus at the urban scale. Reference [31] has evaluated the interactions between the energy systems and water systems in a nexus for different scenarios in Hong Kong. Reference [32] has developed a dynamic model for the energy-water-food nexus for Beijing city and has investigated the level of its consumption. References [33–35] have modeled and evaluated these systems in various countries from Asia, Africa, and Europe, given the importance of security in the energy-water-food nexus. With a long-term analysis of environmental indicators related to the energy-water-food nexus in different countries, reference [36] has shown the energy-water interaction with food. Reference [37] investigated different interactions of each nexus sector by examining an energy-water-food nexus system for an area of Taiwan. Developing an energy-water nexus in Turkey, reference [38] tried to investigate its social, economic, environmental, and political outcomes. Reference [39] uses a set of analytical methods to describe the input-output relationship between electrical energy and water in an energy-water nexus. In reference [40], the relationship between water and electrical energy in an energy-water nexus to cut the costs related to desalination plants and hydropower plants was investigated.

5. CHALLENGES AND FUTURE PROSPECTS

The studies conducted on nexus have provided a promising perspective for energy-water-food interaction from various aspects [41, 42]. However, the present studies suffer some limitations, which can be divided into four areas, including system boundary, data and modeling uncertainty, nexus mechanism and system evaluation. Fig. 4 shows the recent issue.

A. System boundary

Determining the system boundary is important in performing the nexus analysis. Different definitions of the system boundary yield different results. Difficulty in defining the system boundary is related to the way of selecting an appropriate system boundary, since selecting

a small boundary may destroy some of the important links of the nexus [43].

Also, by selecting a large boundary for the nexus, more processes are included in the nexus system, so more data and hypotheses and a better understanding of the processes are needed to create a nexus model. In addition, it is very difficult to extract and synthesize valuable information from different sectors due to their interaction, since nexus boundary varies from resource management units to administrative boundaries. As a result, selecting the right system boundary for the nexus is crucial and requires further research.

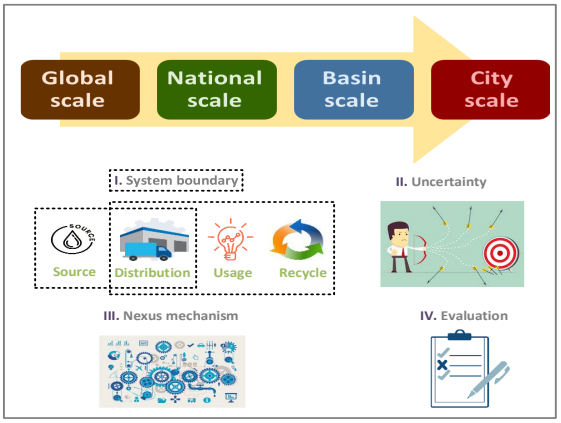

Fig. 4. Summary of challenges and future prospects

It has been highly accepted that the definition of system boundaries should be based on the research objectives and data availability [44]. It should also be noted that the energy-water-food nexus can go beyond the boundaries of its system. For example, following the research conducted on the urban nexus in Beijing, it was recommended to consider the significant effects of upstream activities such as water consumption outside of the city on the urban metabolism beyond the boundaries of the system [45].

B. Data and modeling uncertainty

On the global scale, the nexus studies focus more on the impact of climate change on agriculture and access to water. At the national scale, more attention is paid to the issues of resource security as well as their environmental impacts under different policies. However, the studies conducted on the energy-water-food nexus at the domestic level focus more on the behavioral factors.

The issues of different studies require different data. With increasing the system scale, the concerns on the economic and social data will be more. The presented reports and data have usually a different quality [46]. The way of access to them is also different since each of them is presented by different sectors with different goals and standards. As a result, the use of these data causes more uncertainty in nexus studies. The data collected at a larger scale are not suitable for use in small-scale studies. For example, this case in the studies related to climate nexus provides more uncertainty in the final results [47].

In most studies related to nexus research, hypotheses and simplifications are used to compensate for the data shortages. Although they help to overcome some data shortage problems, they can lead to changes in the final results in interactions among different sectors of the nexus. Also, in the models that are composed of different sectors such as energy, economy, product, and water, it can lead to uncertainty ranging from model inputs and structure to scenario hypotheses.

To solve the problems mentioned above, efforts should be made to improve access to data in the studies conducted on the nexus. Also, some measures such as data monitoring and collecting, data processing, and analysis of sources of uncertainty should be taken.

Recently, the use of new technologies [48], such as "remote sensing sensors" [49], has played a significant role in data provision. Also, the use of new techniques such as "machine learning", "cloud computing" [50], "Geographic Information Systems" [51], "correlation analysis", etc. accelerates the data collection and improves the analyses. The combination of techniques proposed for collecting and analyzing the data in the future can yield promising results.

C. Nexus mechanism

Most studies conducted so far have focused on supply chain and increasing the efficiency of using the resources of different sectors of the nexus. Hence, considering chemical, physical, and biophysical processes in different sectors of the nexus is essential [52].

The compilation of the nexus-specific models is essential for a better presentation of the nexus systems. The nexus model must be flexible enough to support the addition of modules and facilitate the analysis at a different time and spatial scales. Such models that can combine the quantitative data with the qualitative data are essential to reduce the extensive need for data during modeling.

D. System evaluation

One of the requirements of this research is better management of the energy-water-food nexus in order to expand sustainable development under the changing conditions. System evaluation is essential to understand the stability and performance of systems in the long term and the variable environments. In the nexus systems, resilience and sustainability not only depend on each sector of the system individually but also on the relationship among different sectors, since the change in one sector of the nexus can affect other sectors. It should be noted that the indicators used to evaluate each sector of the system may not be appropriate for the whole system [53].

Each of the mentioned issues is a challenge in evaluating the sustainability and resiliency of a nexus system. Different aspects and dimensions of evaluating a system such as economic, environmental, and sociological dimensions to evaluate the performance of the nexus can also be challenging [54].

6. CONCLUSIONS

Energy, water, and food, as the three main sources of human society, have an intrinsic relationship with each other. The availability of sufficient water resources has a significant impact on the availability of energy and food resources. The power generation activities are affected by the quality and availability of water. Under these conditions, the concept of the energy-water-food nexus was comprehensively developed for the study of the global resource systems and management. In this paper, different definitions and interpretations of the nexus were analyzed and the research priorities in this regard were also examined. Different empirical studies of the energy-water-food nexus at various scales were reviewed. Future challenges and prospects for the energy-water-food nexus were fully investigated in the four sectors of the system boundary, data uncertainty and modeling, nexus mechanism, and system evaluation.

REFERENCES

1. Z. Pengpeng, Z. Lixiao, C. Yuan, X. Ming, H. Yan, L. Sai, L. Gengyuan, Y. Zhifeng, and W. Can, "Food-energy-water (FEW) nexus for urban sustainability: A comprehensive review," Resources, Conservation & Recycling, vol. 142, pp. 215-224, 2019.
2. N. Taghizadegan, M. Ahangari Hassas, and K. Pourhossein, "Bibliographic Review and Comparison of Optimal Sizing Methods for Hybrid Renewable Energy Systems," Journal of Energy Management and Technology (JEMT), vol. 2, pp. 66-79, 2018.
3. O. Konstantinos, and P. Masood, "Optimal Coordination of Water Distribution Energy Flexibility with Power Systems Operation," IEEE Transactions on Smart Grid, vol. 10, pp. 1101-1110, 2018.
4. W. Xiaonan, D. Koen, T. Charalampos, K. Rembrandt, and S. Nilay, "Energy-water nexus design and operation towards the sustainable development goals," Computers & Chemical Engineering, vol. 124, pp. 162-171, 2019.
5. R. Kian, "A production planning problem with lost sales and nonlinear convex production cost function under carbon emission restrictions," Journal of Energy Management and Technology (JEMT), vol. 4, pp. 1-13, 2020.
6. Z. Chi, C. Xiaoxian, L. Yu, D. Wei, and F. Guangtao, "Water-energy-food nexus: Concepts, questions and methodologies," Journal of Cleaner Production, vol. 195, pp. 625-639, 2018.
7. P. Seyed Matin and H. Ghaebi, "Energy and exergy analysis of a multistage cooling cycle of scramjet to produce electricity and hydrogen," Journal of Energy Management and Technology (JEMT), vol. 4, pp. 49-59, 2020.
8. A. Smajgl, J. Ward, and L. Pluschke, "The water-food-energy Nexus -Realising a new paradigm," Journal of Hydrology, vol. 533, pp. 533-540, 2015.
9. P. Kyle, N. Johnson, E. Davies, D. L. Bijl, I. Mouratiadou, M. Bevione, L. Drouet, S. Fujimori, Y. Liu, and M. Hejazi, "Setting the system boundaries of “energy for water” for integrated modeling," Environmental Science & Technology, vol. 50, pp. 8930-8931, 2016.
10. X. Cai, K. Wallington, M. Shafiee-Jood, and L. Marston, "Understanding and Managing the Food-Energy-Water Nexus-Opportunities for Water Resources Research," Advances in Water Resources, vol. 111, pp. 259-273, 2018.
11. C. Scott, S. Vicuña, I. Blanco-Gutiérrez, F. Meza, and C. Varela-Ortega, "Irrigation efficiency and water-policy implications for river-basin resilience," Hydrology and Earth System Sciences, vol. 18, pp. 1339-1348, 2014.
12. M. Keskinen, J. H.A. Guillaume, M. Kattelus, M. Porkka, T. A. Räsänen, and O. Varis, "The Water-Energy-Food Nexus and the Transboundary Context: Insights from Large Asian Rivers," Water-Sui., vol. 8, pp. 1-25, 2016.
13. A. J. Challinor, E. S. Simelton, E. D. G. Fraser, D. Hemming, and M. Collins, "Increased crop failure due to climate change: assessing adaptation options using models and socio-economic data for wheat in China," Environmental Research Letters., vol. 5, pp. 1-8, 2010.
14. J. S. Bandara, and Y. Cai, "The impact of climate change on food crop productivity, food prices and food security in South Asia," Economic Analysis and Policy, vol. 44, pp. 451-456, 2014.
15. J. S. Famiglietti, "The global groundwater crisis," Nature Climate Change, vol. 4, pp. 945-948, 2014.
16. Y. C. E. Yang, C. Ringler, C. Brown, and M. A. H. Mondal, "Modeling the agricultural water-energy-food nexus in the indus river basin, Pakistan," Journal of Water Resources Planning and Management, vol. 142, pp. 1-13, 2016.
17. R. Zeng, X. Cai, C. Ringler, and T. Zhu, "Hydropower versus irrigation-an analysis of global patterns," Environmental Research Letters, vol. 12, pp. 1-9, 2014.
18. M. S. Tom, P. S. Fischbeck, and C. T. Hendrickson, "Energy use, blue water footprint, and greenhouse gas emissions for current food consumption patterns and dietary recommendations in the US," Environment Systems and Decisions, vol. 36, pp. 92-103, 2016.
19. B. Ghose, "Food security and food self- sufficiency in China: from past to 2050," Food and Energy Security, vol. 3, pp. 86-95, 2014.
20. R. García-Herrera, E. Hernandez, D. Barriopedro, D. Paredes, R. M. Trigo, I. F. Trigo, and M. A. Mendes, "The outstanding 2004/05 drought in the iberian Peninsula: associated atmospheric circulation," Journal of Hydrometeorology, vol. 8, pp. 483-498, 2007.
21. J. Mu, and S. Khan, "The effect of climate change on the water and food nexus in China," Food Security, vol. 1, pp. 413-430, 2009.
22. A. Berardy, and M. V. Chester, "Climate change vulnerability in the food, energy, and water nexus: concerns for agricultural production in Arizona and its urban export supply," Environmental Research Letters, vol. 12, pp. 1-13, 2017.
23. M. Howells, S. Hermann, M. Welsch, M. Bazilian, R. Segerstrom, T. Alfstad, D. Gielen, H. Rogner, G. Fischer, H. van Velthuizen, D. Wiberg, C. Young, R. A. Roehrl, A. Mueller, P. Steduto, and I. Ramma, "Integrated analysis of climate change, land-use, energy and water strategies," Nature Climate Change, vol. 3, pp. 621-626, 2013.
24. B. R. Scanlon, I. Duncan, and R. C. Reedy, "Drought and the water-energy nexus in Texas," Environmental Research Letters, vol. 8, pp. 1-14, 2013.
25. T. D. Nguyen, X. Cai, Y. Ouyang, and M. Housh, "Modeling infrastructure interdependencies, resiliency and sustainability," International Journal of Critical Infrastructures, vol. 12, pp. 1-24, 2014.
26. S. Suweis, J. A. Carr, A. Maritan, A. Rinaldo, and P. D'Odorico, "Resilience and reactivity of global food security," Proceedings of the National Academy of Sciences of the United States of America, vol. 112, pp. 6902-6907, 2015.
27. O. Konstantinos, P. Masood, and B. Steven, "Integrating water distribution energy flexibility in power systems operation," IEEE Power & Energy Society General Meeting, pp. 1-5, 2017.
28. D. Vanham, T. N. Mak, and B. M. Gawlik, "Urban food consumption and associated water resources: the example of Dutch cities," Science of The Total Environment, vol. 565, pp. 232-239, 2016.
29. W. A. Hussien, F. A. Memon, and D. A. Savic, "A risk-based assessment of the household water-energy-food nexus under the impact of seasonal variability," Journal of Cleaner Production, vol. 171, pp. 1275-1289, 2018.
30. D. Gondhalekar, and T. Ramsauer, "Nexus city: operationalizing the urban water-energy-food nexus for climate change adaptation in Munich, Germany," Urban Climate, vol. 19, pp. 28-40, 2017.
31. C. P. Chen, V. Alvarado, and S. C. Hsu, "Water energy nexus in city and hinterlands: multi-regional physical input-output analysis for Hong Kong and South China," Applied Energy, vol. 225, pp. 986-997, 2018.
32. G. J. Li, Y. L. Li, X. J. Jia, L. Du, and D. H. Huang, "Establishment and simulation study of system dynamic model and sustainable development of water-energy-food nexus in Beijing," Management Review, vol. 28, pp. 11–26, 2016.
33. D. Conway, E. A. van Garderen, D. Deryng, S. Dorling, T. Krueger, W. Landman, B. Lankford, K, Lebek, T. Osborn, C. Ringler, J. Thurlow, T. J. Zhu, and C. Dalin, "Climate and southern Africa's water-energy-food nexus," Nature Climate Change, vol. 5, pp. 837-846, 2015.
34. A. Endo, I. Tsurita, K. Burnett, and P. M. Orencio, "A review of the current state of research on the water, energy, and food nexus," Journal of Hydrology: Regional Studies, vol. 11, pp. 20-30, 2017.
35. F. M. Mukuve, and R. A. Fenner, "The influence of water, land, energy and soil-nutrient resource interactions on the food system in Uganda," Food Policy, vol. 51, pp. 24-37, 2015.
36. I. Ozturk, "Sustainability in the food-energy-water nexus: evidence from BRICS (Brazil, the Russian Federation, India, China, and South Africa) countries," Energy, vol. 9, pp. 999-1010, 2015.
37. C. I-Chun, W. Yi-Hsin, L. Wei, and M. Hwong-wen, "Assessing the risk of the food-energy-water nexus of urban metabolism: A case study of Kinmen Island, Taiwan," Ecological Indicators, vol. 110, 105861, 2020.
38. E. Ayşen, "Transformation of the water-energy nexus in Turkey: Re-imagining hydroelectricity infrastructure," Energy Research & Social Science, vol. 41, pp. 22-31, 2018.
39. L. William, and F. Amro, "Quantitative engineering systems modeling and analysis of the energy-water nexus," Applied Energy, vol. 135, pp. 142-157, 2014.
40. S. Apoorva, F. Amro, and Y. Kamal, "Real-time economic dispatch for

the supply side of the energy-water nexus," Applied Energy, vol. 122, pp. 42-52, 2014.
41. S. Apoorva, F. Amro, and Y. Kamal, "The impact of storage facility capacity and ramping capabilities on the supply side economic dispatch of the energy-water nexus," Energy, vol. 66, pp. 363-377, 2014.
42. J. Liu, H. Mooney, V. Hull, S. J. Davis, J. Gaskell, T. Hertel, J. Lubchenco, K. C. Seto, P. Gleick, C. Kremen, and S. Li, "Systems integration for global sustainability," Science, vol. 347, 1258832, 2015.
43. Y. Liu, M. Hejazi, P. Kyle, S. H. Kim, E. Davies, D. G. Miralles, A. J. Teuling, Y. He, and D. Niyogi, "Global and regional evaluation of energy for water," Environmental Science & Technology, vol. 50, pp. 9736-9745, 2016.
44. T. Avellán, M. Roidt, A. Emmer, J. von Koerber, P. Schneider, and W. Raber, "Making the Water-Soil-Waste Nexus Work: Framing the Boundaries of Resource Flows," Sustainability, vol. 9, pp. 1-17, 2017.
45. S. Chen, and B. Chen, "Coupling of carbon and energy flows in cities A meta-analysis and nexus modelling," Applied Energy, vol. 194, pp. 774-783, 2017.
46. K. M. Ernst, and B. L. Preston, "Adaptation opportunities and constraints in coupled systems: Evidence from the U.S. energy-water nexus," Environmental Science & Policy, vol. 70, pp. 38-45, 2017.
47. A. Berardy, and M. V. Chester, "Climate change vulnerability in the food, energy, and water nexus: concerns for agricultural production in Arizona and its urban export supply," Environmental Research Letters, vol. 12, pp. 1-13, 2017.
48. B. W. Abegaz, T. Datta, and S. M. Mahajan, "Sensor technologies for the energy-water nexus-A review," Applied Energy, vol. 210, pp. 451-466, 2018.
49. B. R. Scanlon, B. L. Ruddell, P. M. Reed, R. I. Hook, C. Zheng, V. C. Tidwell, and S. Siebert, "The food-energy-water nexus: Transforming science for society," Water Resources Research, vol. 53, pp. 3550-3556, 2017.
50. M. F. McCabe, M. Rodell, D. E. Alsdorf, D. G. Miralles, R. Uijlenhoet, W. Wagner, A. Lucieer, R. Houborg, N. E. C. Verhoest, T. E. Franz, J. Shi, H. Gao, and E. F. Wood, "The future of Earth observation in hydrology," Hydrology and Earth System Sciences, vol. 21, pp. 3879-3914, 2017.
51. N. Bashir, R. Saeed, M. Afzaal, A. Ahmad, N. Muhammad, J. Iqbal, A. Khan, Y. Maqbool, and S. Hameed, "Water quality assessment of lower Jhelum canal in Pakistan by using geographic information system (GIS)," Groundwater for Sustainable Development, vol. 10, 100357, 2020.
52. T. R. Albrecht, A. Crootof and C.A. Scott, "The Water-Energy-Food Nexus: A systematic review of methods for nexus assessment," Environmental Research Letters, vol. 13, pp. 1-26, 2018.
53. S. Hosseini, K. Barker, and J. E. Ramirez-Marquez, "A review of definitions and measures of system resilience," Reliability Engineering & System Safety, vol. 145, pp. 47-61, 2016.
54. A. L. Mayer, R. P. Donovan, and C. W. Pawlowski, "Information and entropy theory for the sustainability of coupled human and natural systems," Ecology & Society, vol. 19, pp. 1-9, 2014.