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Perspective

Food–Energy–Water Crises in the United States and China: Commonalities and Asynchronous Experiences Support Integration of Global Efforts

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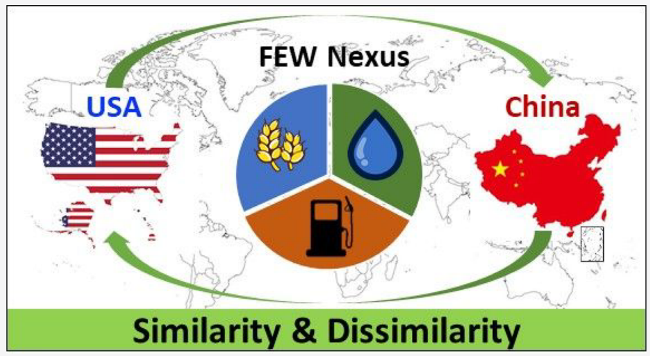
ABSTRACT: Food, energy, and water (FEW) systems have been recognized as an issue of critical global importance. Understanding the mechanisms that govern the FEW nexus is essential to develop solutions and avoid humanitarian crises of displacement, famine, and disease. The U.S. and China are the world's leading economies. Although the two nations are shaped by fundamentally different political and economic systems, they share FEW trajectories in several complementary ways. These realities place the U.S. and China in unique positions to engage in problem definition, dialogue, actions, and transdisciplinary convergence of research to achieve productive solutions addressing FEW challenges. By comparing the nexus and functions of the FEW systems in the two nations, this perspective aims to facilitate collaborative innovations that reduce disciplinary silos, mitigate FEW challenges, and enhance environmental sustainability. The review of experiences and challenges facing the U.S. and China also offers valuable insights for other nations seeking to achieve sustainable development goals.



■ INTRODUCTION

Humanity is poised on the precipice of global crises entailing growing needs for food, energy, and water (FEW) resources in the face of increasing climate change stress and dynamic demographic and socioeconomic transitions. A United Nations Environment Programme report[1] on achieving sustainable development goals highlights the lack of progress and even "negative change" for several indicators related to the availability and security of adequate FEW resources. Breakdowns in FEW systems can lead to human displacement, disease, and suffering. Understanding the dynamics of the evolution of the FEW nexus and the mechanisms that govern future FEW relationships is essential to mitigate potential humanitarian disasters associated with the lack of clean water, accessible energy, and nutritious food.[2]

China and the United States (U.S.) are the world's leading economies, with the highest levels of production and consumption of FEW resources and associated effects on the environment and society. These realities place China and the U.S. in unique positions to engage in problem definition, transdisciplinary convergence of research, and complementary actions to achieve productive solutions addressing FEW challenges on a global scale. Yet, geopolitical and ideological barriers are being raised that increasingly restrict U.S.–China research collaborations.[3,4] The aim of this perspective is to highlight differences and similarities between the two nations in FEW nexus challenges and opportunities and to identify steps that could facilitate collaborative solutions.

Developing solutions for FEW security and transitioning nexus knowledge to sustainable actions are facilitated by nurturing transdisciplinary collaborations that advance understanding of the multiscale impacts of FEW resource consumption.[5] FEW systems are characterized by complex intersystem interactions, socioeconomic impacts, and challenges of grand stressors (e.g., climate change and population growth).[6] The interactions (e.g., resource supply and demand) underlying FEW systems cut across all sectors of society and occur at scales ranging from garden plots and individual households, to regional and national production and consumption, and to international trade and supply chains.

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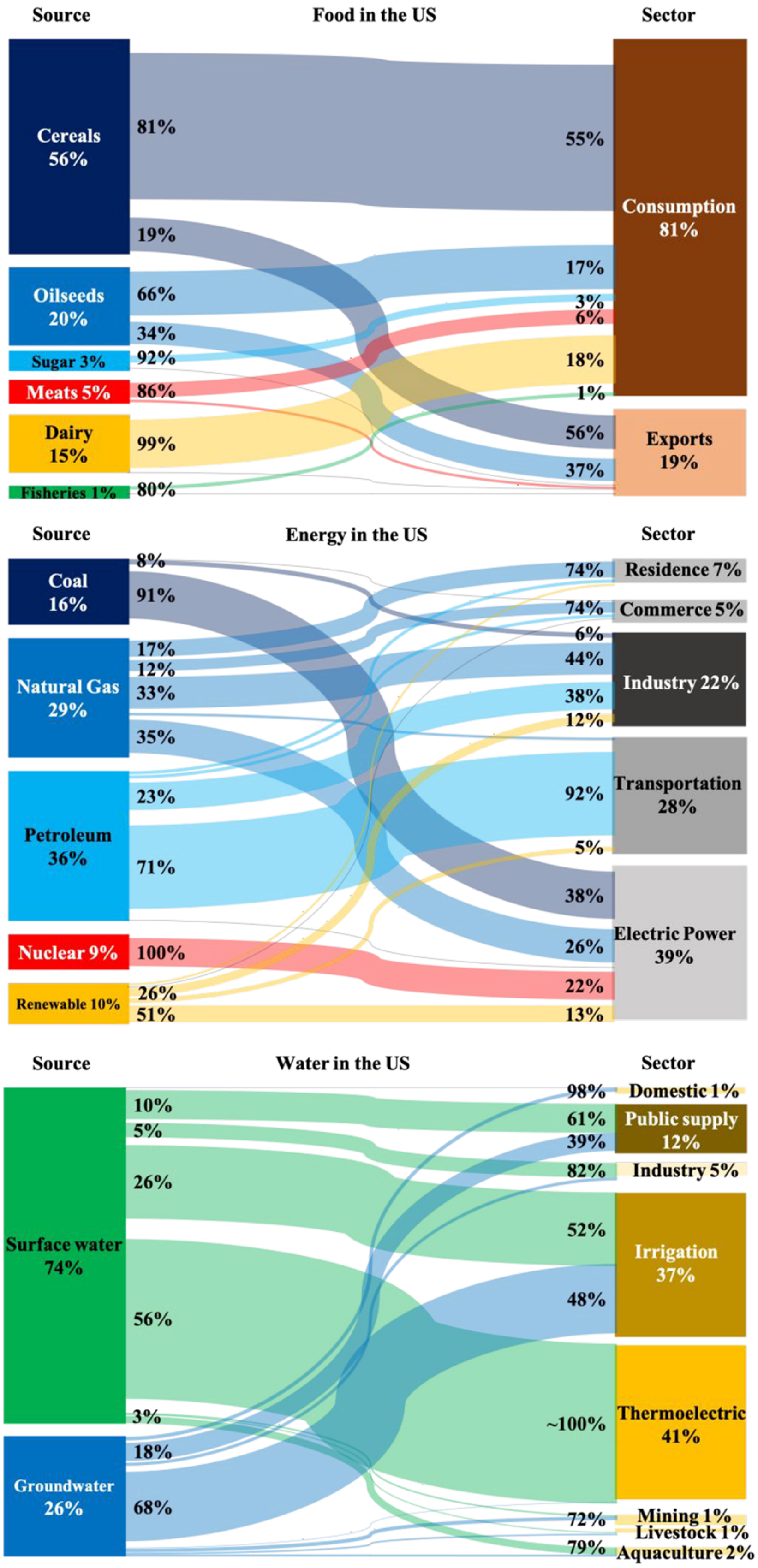

Figure 1. Sankey diagrams of food, energy, and water consumption flows in the U.S. in 2015. The width of flows reflects the proportion between the sources and sectors of consumption. Data sources: OECD-FAO Agricultural Outlook 2015−2024, U.S. Geological Survey (USGS), and U.S. Energy Information Administration (EIA).

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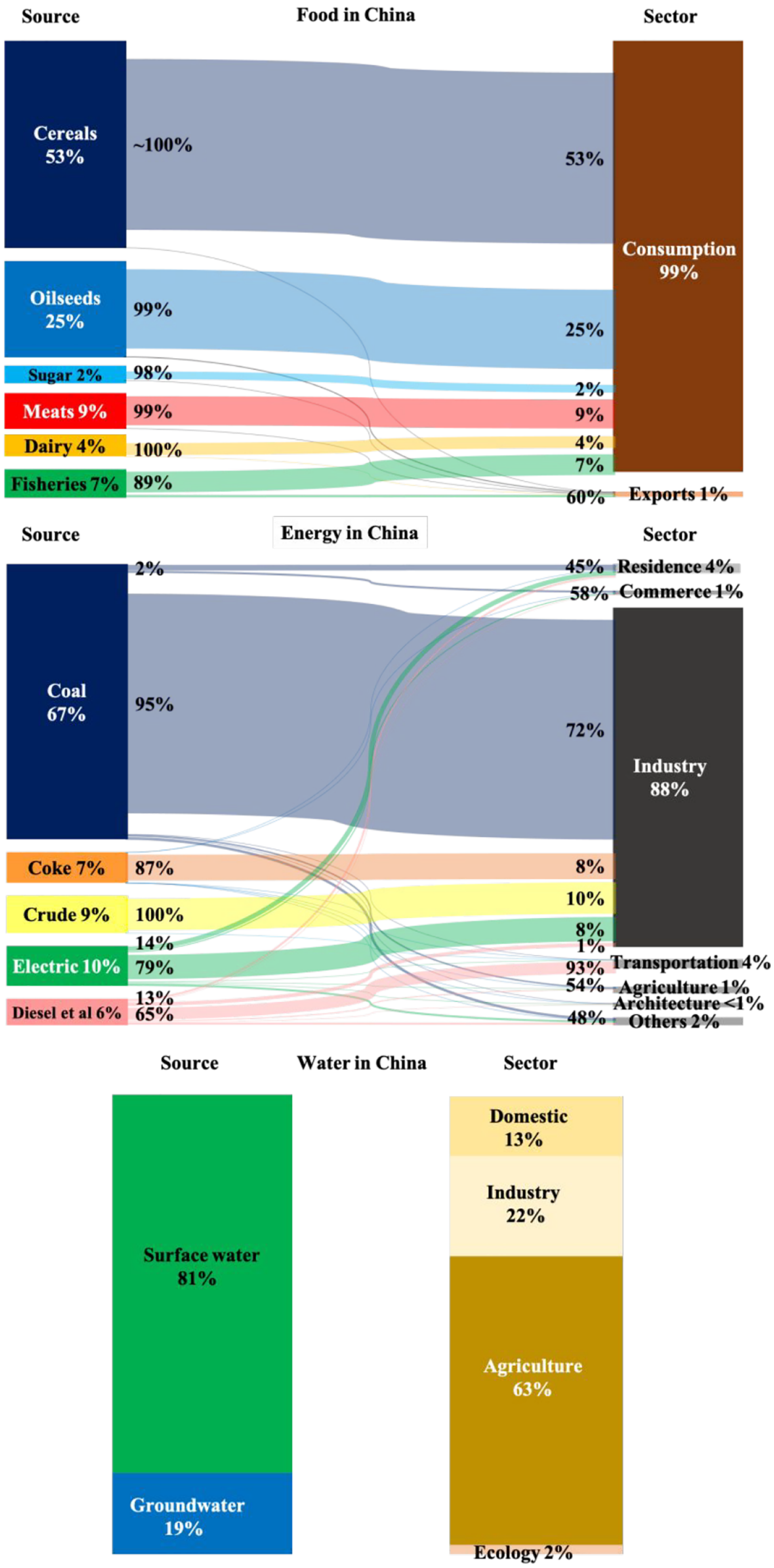

Figure 2. Sankey diagrams of food, energy, and water consumption flows in China in 2015. The width of flows reflects the proportion between the sources and sectors of consumption. The diesel et al. source in the energy includes diesel, petroleum, fuel oil, kerosene, and natural gas. Since the proportion data for the sources corresponding to the sectors of water consumption in China is not available, the flow relationship between the sources and sectors of water consumption is not shown. Data sources: OECD-FAO Agricultural Outlook 2015−2024 and China Statistical Yearbook by National Bureau of Statistics.

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The interconnectedness of production, transport, and consumption of various goods means that any solution toward the sustainable exploitation of FEW resources must consider their joint needs, opportunities, constraints, and feedbacks at local to global scales.

■ EXISTING DISSIMILARITY

The U.S. and China differ in their flows of FEW production, transport, and consumption (Figures 1 and 2). The FEW flows have led to significant differences in the nexus and impacts of FEW systems in the two nations. The most obvious difference is that the interdependences of FEW consumption are relatively imbalanced relative to those in the U.S. For instance, coal is the primary energy source for industry in China, whereas natural gas, petroleum, and renewable energy are widely used along with coal for industry development in the U.S. With regard to the energy−food nexus, modern agriculture is deeply dependent on energy, and energy determines the level of agricultural mechanization, farming intensification, and the use of fertilizers, pesticides, and plastic films.[7−9] Agriculture-related energy use in the U.S. is not illustrated in Figure 1; however, the U.S. Department of Agriculture (USDA) reported that the agricultural sector demanded 1.74% of total U.S. primary energy consumption in 2014.[10] In China, a lower amount of ∼1% of the total national energy consumption is directed toward the agricultural sector (Figure 2). Key differences between the two nations are the extent of mechanization and the rate of change in employing advanced agricultural technologies. While mechanized systems have dominated U.S. agriculture for decades, China is currently in a widespread and rapid transition phase, and the contributions of mechanized farming to agricultural output increased from about 44% in 2007 to over 70% in 2019.[11,12] The production of most staple crop (wheat, rice, and maize) now relies on mechanized systems, and the numbers of middle to large tractors has shown a 20% annual increase.[12] This mechanization has substantially accelerated energy consumption in the agricultural sector in China.[8,13] For example, the total power of agricultural machinery approximately doubled from 523 million kW in 2000 to 1,026 million kW in 2012.[14]

Focusing on the water-food nexus, agriculture is the second largest water consumer in the U.S. and the largest user in China. Agricultural irrigation accounts for 37% of U.S. total freshwater consumption, with about half the volume coming from surface water and half from groundwater resources (Figure 1). Irrigation has by far the largest demand on U.S. groundwater (68% of all groundwater withdrawals), with public water supply systems a distant second (18% of withdrawals). Agricultural water use in the U.S. is primarily dedicated to maize (*Zea mays* L.) and soybean (*Glycine max*) in the western plains, cotton (*Gossypium*) and rice (*Oryza sativa*) in the Mississippi valley, forage crops in western states, and specialty crops in California's Central Valley.[15]

In comparison, food production systems are the primary sink for water in China, accounting for 63% of all water utilization (Figure 2). Increasing meat consumption and intensification of animal production systems will exacerbate the demand for freshwater.[16] Agriculture impacts water quality through both soil erosion and contamination as a consequence of increasing reliance on pesticides and chemical fertilizers.[17,18] Therefore, importing water-intensive food commodities (e.g., corn and soybean) from the U.S. not only is favorable for protecting the quality of limited water resources but also can save a significant volume of water for industrial and domestic needs in China. The role of "virtual water" via agricultural trade obviously provides opportunities for improving the supply of affordable food while conserving resources in water-scarce regions.[19,20]

The energy → water nexus is derived from energy consumption during the extraction and allocation of water, wastewater treatment, and water heating for domestic and industrial uses.[7,21−23] Moving water, including groundwater pumping and surface water transfers over long distances, is energy-intensive. Moreover, to ensure access to clean and potable water, additional energy-intensive processes, such as desalinization, filtration, and wastewater treatment, have been implemented.[21] The water → energy nexus is intensified by increasing water use in the energy sector.[24] For instance, water withdrawals for cooling thermal electric power plants represent the largest single demand sector in the U.S., or 41% of all water use (Figure 1). The total water use in the energy sector was estimated at 2.22×10^{11} m^3 of water withdrawals in 2015, mainly for fossil fuel extraction and processing. While 56% of surface freshwater withdrawals in the U.S. served cooling purposes in power plants, demand from this sector will decline as older coal and nuclear power plants are being retired and replaced with natural gas and renewable energy sources. In addition, increased energy efficiency will reduce the demand on energy and water resources.[25,26] In contrast, the water → energy nexus in China appears less favorable to conservation in the near term. The coal industry in China consumed 7.4×10^8 m^3 of water in 2015, which is 40% more than water required if natural gas would be the energy carrier.[27] Reduction of coal-based energy could thus lessen water scarcity in China.[28] While Figure 2 does not show water withdrawals for energy directly, one recent analysis found that water withdrawals for energy production in China have decreased from 4.34×10^{10} m^3 in 2002 to 1.56×10^{10} m^3 in 2015.[29] This decline is partly attributed to China's active participation in global energy trade, which allows more petroleum and natural gas to meet the country's energy needs and replace traditional coal to some extent. Of course, international cooperation and agreements are a prerequisite for international energy trade that can help to alleviate the water scarcity of import country (e.g., China).[27] However, energy trade might worsen the water scarcity in the energy export countries (e.g., Kazakhstan and Saudi Arabia).[30] A mutually favorable trade should thus be importing energy from water-abundant country. If a water-sustainable energy trade is impossible between two countries, the trade should involve a third country to balance the loss of "virtual" water. For instance, the energy export country that lacks water should trades in water-consuming foods (e.g., cereals) from another country that has no water scarcity problem. Overall, energy use for water currently dominates the energy-water nexus in China since China's food security heavily relies on exploration of water resources (Figure 2). In comparison, energy use for water and water use for energy are well balanced in the U.S. (Figure 1). This difference implies that a balance between energy and water consumptions is critical for sustainable development and that crop production in accordance with regional water availability might contribute to the mitigation of local energy−water conflict.[31−33]

■ ASYNCHRONOUS SIMILARITIES

Despite historical, cultural, and political differences, the U.S. and China share common objectives and challenges regarding FEW systems. Balancing demands for safe and nutritious food,

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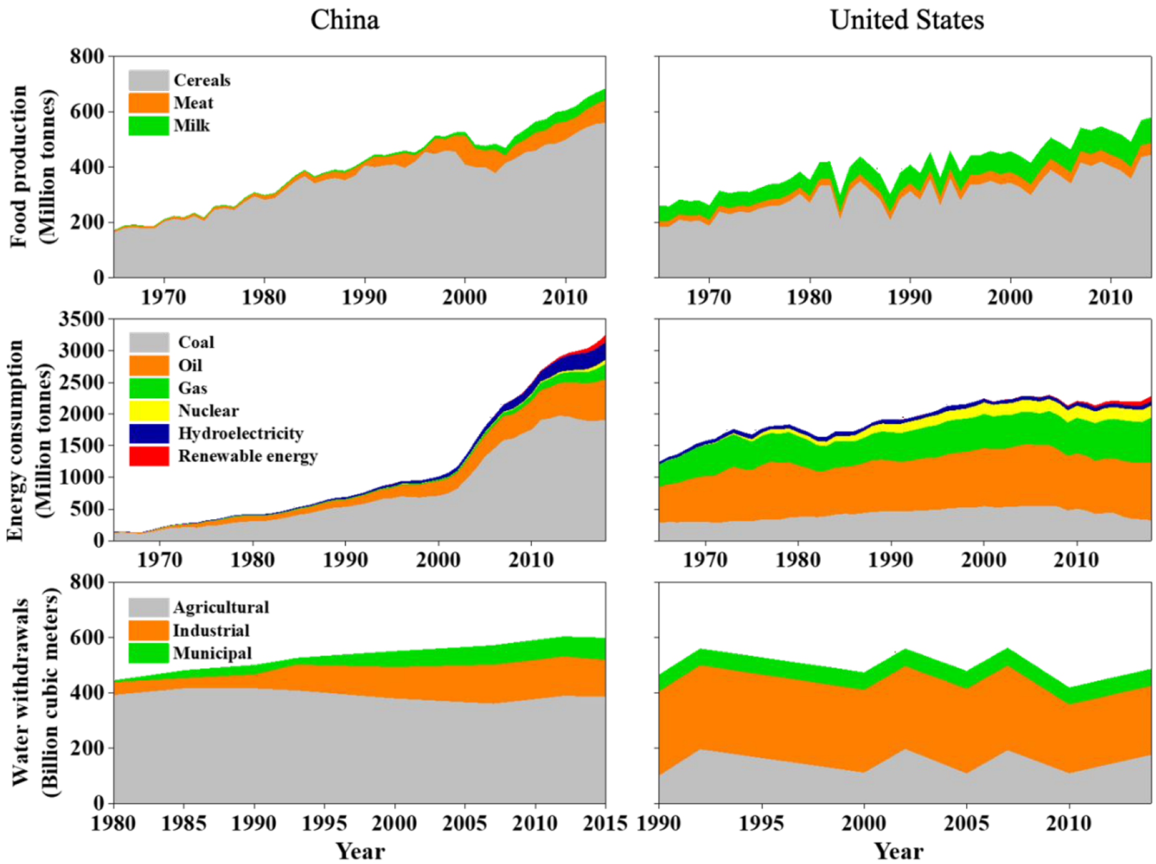

Figure 3. Food production, energy consumption, and water withdrawals in China (left column) and the U.S. (right column). The *x*-axes for water differ from those for energy and food due to the limitation of data. The distribution of water withdrawals in China was based on the database in 1980, 1985, 1990, 1993, 2000, 2007, 2012, and 2015. The withdrawals in the U.S. was based on the database in 1990, 1992, 2000, 2002, 2005, 2007, 2010, and 2014. Data sources of food production, water withdrawals, and energy consumption of both countries are United Nations Food and Agriculture Organization (UNFAO) in 2016 and 2017, Our World in Data (https://ourworldindata.org/water-use-stress) and AQUASTAT of UNFAO, and BP Statistical Review of World Energy in 2016, respectively.

secure, and sufficient energy, and clean water among people and sectors, while also confronting the uncertainties surrounding climate change, is a shared challenge. Furthermore, while the timing is distinct, the two nations have similar patterns of production and consumption of FEW resources. While ramping up food production, both China and the U.S. are attempting to increase water-use efficiency and to improve water quality by adopting advanced irrigation systems in fields and developing rainwater-harvesting and wastewater reuse technologies. Sustenance of high living standards and thriving rural communities while embracing more sustainable yet cost-competitive agricultural production systems are a common core goal.[34,35] Cereals and oilseeds are the top two food classes produced in both nations (Figures 1−3). The total food production in the U.S and in China was similar (8.45×10^8 versus 9.70×10^8 tonnes in 2015, respectively) (Figures 1 and 2). While China consumed 99% of the food domestically, the U.S. exported 19%.

China has a thousand-year history of feeding the world's largest population through labor-intensive agriculture.[34] China's rapid movement toward a developed economy has overturned the peasant farming model and threatens to hollow out China's rural areas following a pattern similar to what was observed in rural America, where big businesses and confined animal feeding operations (CAFOs) replaced small family farms.[36] In addition, increasing affluence and rapid urbanization have substantially affected food consumption patterns in China.[37] The growing urban population is shifting toward higher levels of consumption of meats and dairy products.[37,38] This new domestic market has resulted in a rapid, often uneven, expansion of animal production in China since the 1990s (Figure 3).

In the U.S., animal and food production systems have matured over decades, with persistent improvements in yields and efficiency. Agricultural technologies (e.g., GPS-assisted vehicle guidance systems, yield and soil mapping, and advanced equipment) and agricultural policies through farm subsidy program have driven increases in both quantity and quality, leading to consolidation of farmland and the growth of corporate farming.[39,40] Meanwhile, increased food consumption in the U.S. is mainly driven by the population growth.[34] The structure of food production in recent decades has been relatively stable with a 1% average annual increase in quantity since 1999, in part due to relatively stable but higher levels of income and food consumption. The U.S. enjoys an abundance of food products provisioned by domestic and imported sources.

In both the U.S. and China, food abundance is unequally distributed within society.[41] For instance, about 11% of U.S. households were food-insecure in 2019, meaning access to enough food for an active, healthy life for all household members was not assured.[42] Relatively wealthy and diverse

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consumers drive increasing agricultural imports to the U.S. (e.g., a 6% increase in 2018).[43] Agricultural imports in China (which rose by 3% in 2018) are increasing to secure basic food needs of its 1.4 billion people and for animal feed to meet growing demands of urban consumers.[41]

In terms of energy, both nations rely asynchronously on fossil fuels, with coal and oil supplying ~70% of the energy needs (Figures 1−3). Figure 1 shows that total energy consumption in the U.S. was 2.25×10^9 tonnes (8.92×10^{16} Btu) in 2015 and relied heavily on petroleum and natural gas. The U.S. energy supply was used primarily for electric power production, transportation, and industry. Approximately 51%, 26%, and 14% of renewable energy were consumed by electric power plant, industry, and transportation, respectively. Petroleum was mainly used for transportation, and natural gas was consumed primarily by electric power plants and industry. Similarly, Figure 2 shows the total energy consumption in China was 4.30×10^9 tonnes in 2015 with heavy reliance on coal. This energy was consumed primarily by industry. Specifically, all of the crude oil and most of the coal and renewable electric energy were used for industry (Figure 2). Overall, Figure 3 shows that China surpassed the U.S. in energy consumption in 2010. The sources of consumed energy in China lacked diversity prior to 2000. Coal was the dominant fossil fuel (contributing more than 80% of energy needs) followed by oil fuel. The source diversity of energy consumption increased after 2000 and accelerated after 2010. For instance, the consumption of natural gas, nuclear power, and renewable energy (e.g., hydropower) increased, though coal and oil fuels still occupied large proportions.

The differences in consumption and structure of energy between the two nations are closely linked to their levels of urbanization and industrialization.[37,44,45] The urban population of China increased from 172 million in 1978 to 771 million in 2015, with an average annual increase of 16 million. As a result, the urbanization rate (i.e., percentage of urban population in total population) increased from 18% to 56%, with an average annual absolute increase by 1%.[46] The pace of China's urbanization has significantly accelerated since 1996, with the average annual increase maintained at a rate of over 1.3% during the period from 1996 to 2015. This urbanization rate was 4.5 times higher than that during 1949−1978 and 1.9 times higher than that during 1978−1996.[46] This demographic change has substantially increased the energy consumption in the urban areas. In addition, China has been experiencing an industrial transition from primary industry toward secondary and tertiary industries. This transition since 2000 has led to a rapid increase in energy consumption and facilitated the diversification of energy composition.[45] In contrast, during the same period, the energy consumption in the U.S. remained relatively stable. Urbanization in the U.S. increased from 79.6% in 2000 to 81.7% in 2015, with an average annual absolute increase of 0.14%.[47] This very slow increase in urbanization, along with an upgrade of economic structure toward higher value activities in production (e.g., advanced engineering and pharmaceutical development), flattened the energy consumption.[45] Currently, similar trajectories of energy consumption and urbanization as occurred in China and the U.S. are occurring in other developing (e.g., Indonesia) and developed countries (e.g., Germany), respectively.[48] Predictions based on the Food Demand Model (FDM), total energy use is expected to increase by 78% in developing countries and by ~1% in developed countries during the period from 2015 to 2050.[49]

Total water withdrawals are very similar between the two nations and range from 400 to 620 billion m^3/year (Figure 3). Water consumption illustrates that water use in both nations relies on surface water by ~80% and groundwater by ~20%. Figure 1 shows that the total water consumption in the U.S. was 4.44×10^{11} m^3 in 2015, with most coming from fresh surface water. Fresh surface water accounted for almost all of the water used in thermoelectric energy production and most of the water used in industrial production and aquaculture. Figure 2 shows that the total water consumption in China was 6.10×10^{11} m^3 in 2015, with most being fresh surface water. Most of the water was used for agriculture (Figure 2). Use of water for agriculture in China has slowly declined since 1992.[50] Specifically, the increase in agricultural water use slowed down from an acceleration rate of +8.33 km^3/y^2 in 1965−1975 to +3.09 km^3/y^2 in 1975−1992 to −1.99 km^3/y^2 afterward.[50] The responses of farmers to the changes in local climate, market condition, and irrigation subsidies are key drivers of increases in irrigation efficiency. Urbanization also played a role in increasing water consumption by domestic sectors as a result of water-intensive lifestyle of urban people.[51] In the U.S., agricultural production mainly relies on large-scale farming systems, which are mostly coupled with advanced water-conserving technologies for high efficient irrigation. As a result, the U.S. used less water for agriculture than China. Water resources have thus been saved to support industrial needs, such as raw materials extraction and conversion processes and energy generation (e.g., thermoelectric, hydropower, and nuclear power). Afterward, the wastewater is reclaimed and returned to river systems.[30,52]

In past decades, both nations have emphasized investments in massive-scale infrastructure projects for securing water and energy resources. For instance, China South-North Water Transfer Project (SNWTP) consists of three routes to move vast volumes of water from regions in the south to support municipalities and agriculture in the dry north and central regions.[53,54] The project's East Route and Middle Route have been in operation since 2013 and 2014, respectively, while the West Route is still in planning.[55] The East Route transports nearly 9 km^3 of water per year from the Yangtze River Basin to the Yellow River Basin over distances of up to 2000 km. The water transfer via this route could rise to as much as 14.8 km^3 per year by 2030. The East Route pumps water uphill over 65 m through a large-scale system of pumping stations from the Yangtze River to its destinations. The system of pumping stations consumed electricity at a rate of 0.15 kWh/m^3,[56] which means a total of 2.35 billion kWh of energy was consumed to transfer 15.5 billion m^3 water during the period from November 2013 to May 2017. This energy production embodied consumption of 7.4 million m^3 of virtual water during the operation period, which indicates transferring 100 m^3 of water consumes 0.05 m^3 of water due to the electricity consumption. Hence the East Route of SNWTP will consume 1.35 billion kWh of energy and 4.6 million m^3 of virtual water in order to transfer 7.3 billion m^3 water by 2030. The Middle Route can carry up to 9.5 km^3/year of water over 1246 km from the Danjiangkou Reservoir on the Han River (a tributary to the Yangtze) and cross Henan and Hebei provinces before reaching its destination in Beijing and Tianjin for residential, agriculture, and industrial uses. A future plan for the Middle Route is to eventually transfer 14 km^3 of water per year. The West Route crosses the Qinghai-Tibetan Plateau, transferring 17 km^3 of water per year from the headwaters of the Yangtze

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River Basin to the headwater of the Yellow River Basin.[54] Similar public works projects in the U.S. were implemented to move water from the Rocky Mountains to California and arid southwestern states.[57] The inception of California State Water Project (CSWP) was in 1960, and carries up to 5 km^3 of water per year over 1126 km from northern to southern regions in California.[58] This mega-project supplies water to more than 27 million people ranging from the San Francisco Bay Area through the San Joaquin Valley, to the Central Coast and southern California. The transferred water irrigates 3035 km^2 of farmland, mainly in the San Joaquin Valley and generates an average of 6500 GWh of hydroelectricity annually.

■ DISCONNECTED EFFORTS

Despite sharing similar objectives and challenges related to the FEW nexus, major barriers exist in interdisciplinary research as well as international research efforts between China and the U.S. Historically siloed subsystems, which focus solely on specific missions while ignoring system connectivity, stymie development of approaches involving international, transdisciplinary teams. Recent policies and trade disputes have further complicated efforts to develop scientific research collaborations.[3,4] Neither the U.S. nor Chinese societies have yet produced a skilled workforce capable of effectively addressing complex sustainability issues. Awareness of the FEW nexus is generally low, which limits the political will to invest in research. Useful engineering solutions in the peer-reviewed literature may be overlooked because of lackluster support from stakeholders.[59] This problem is mainly caused by a lack of collaboration between researcher and stakeholder. As a result, some scientific investigations are not open to stakeholders, and some research findings are not actionable at stakeholder level. Failure to incorporate human behaviors and cultural differences among various interest groups creates disparity between the FEW research community and stakeholders, including farmers and consumers, corporations, nongovernmental organizations, and policymakers.[60]

An additional challenge is the need to collect consistent and comparable data and effectively coordinate and synthesize data sets generated in different FEW disciplines. Although creation and analyses of large data sets are making great progress in both countries, those advances have not often been applied to FEW systems.[61,62] Also, while the complexity of FEW-system interactions requires extensive collaborations and big data science approaches, the perceived or actual inequity of credit sharing can discourage researchers from engaging in the process.[63] The reward and assessment systems that credit scholarly accomplishments (e.g., publications) in both countries are discipline-specific and differ for researchers in engineering, business, natural science, and social science disciplines.[64,65] Disparities also exist among tenure-track faculty, research faculty, extension faculty, government scientists, and private sector researchers and consultants.[65,66] At many academic institutions, performance measures rely on outdated metrics and rarely embrace collaborative efforts outside the home discipline.[66] The traditional thinking is counter-productive for enticing researchers to engage in FEW nexus investigations.

■ STEPS TOWARD SOLUTIONS

Successful implementation of innovative solutions requires inclusion of scientists, engineers, and other stakeholders in the entire process of coproducing knowledge to enhance the sustainability of FEW systems. These stakeholders need to be engaged from the start, with identification of the problem, through the process to identify and test solutions, and to implement selected innovations and technologies.[67] Thus, a first step toward constructive collaborations on FEW nexus issues is to link people from traditionally disconnected disciplines and places through a common vision and specific goals. Teaching curricula, organizational structures, and rewards for advancement need to be revised to give researchers deserved credit for contributions to large, transdisciplinary team efforts and to ensure that outcomes are understood, agreed upon, and communicated. Better understanding of the benefits derived from such research partnerships could help catalyze U.S. participation.[5]

The second step is to develop universal metrics that can effectively monitor progress in terms of human welfare and sustainable outcomes. Well-defined measures of success can help guide both implementation and future FEW research agendas.[59] The United Nations' Sustainable Development Goals (SDGs) include indicators and targets designed to address global goals such as eradicating poverty and hunger by 2030.[1,68] The interconnectedness of these goals means that all countries must cooperate in implementing and monitoring global goals, sharing knowledge, and sharing technology. SDGs to eliminate poverty and hunger and provide clean water and sufficient energy to all require transformation in food production and delivery systems that focus on efficiency, nutritional quality, and sustainable production systems.

The third step toward more sustainable FEW systems is to provide decision makers with clear, balanced choices based on technical, economic, and life cycle analyses of integrated systems. Since international relations and disturbances affect supply and demand of FEW resources, system models should incorporate sociopolitical influences, global trade considerations, demographics, and changes in disturbance regimes. For example, growers around the globe are learning the value of timely market information and careful planning so that harvests can retain a competitive advantage within global markets and respond to supply disruptions caused by extreme weather or other calamities around the world. Therefore, development of smart data-based prediction system for regional and global trade of FEW resources is critical to buffer temporary shortfalls, respond to natural disasters, and enhance resilience.[69] A shared vision developed from data analysis could identify win-win goals while acknowledging disparate national or local needs. For instance, while some nations may emphasize economic growth and/or sociopolitical stability (e.g., the U.S. and China), other nations (e.g., Switzerland, Sweden, and Norway) pay more attention to environmental sustainability while ensuring energy security and equity.[70]

The fourth step is to create effective mechanisms for integrating different approaches and to validate the adaptively optimized schemes. To date, no single theoretical or empirical model exists that satisfies the needs of FEW nexus researchers and stakeholders. This gap is because each FEW system has different boundary conditions, stakeholders, and socioeconomic and environmental settings. However, comparison and infusion of different approaches can help accelerate demonstrations, learning, and development of a FEW research agenda. The agenda should evolve in response to changing needs and conditions, while contributing to demonstrations of how science applied to human−environmental systems can

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reduce FEW crises and enhance benefits in a complex world. To achieve these goals, integrated efforts that engage many stakeholders should incorporate cultural differences in order to be able to address local and global threats and to implement changes that might avert disasters.[67]

The fifth step is to develop shared standards and communication platforms that ensure implementation of sustainable FEW solutions among different countries. For instance, artificial intelligence systems could be employed to more quickly and effectively share data and knowledge. Reliable interfaces are required to transfer and transform information so that it can be used to meet the diverse needs of different communities. A virtual platform can be established that allows different stakeholders to proactively collaborate on common tasks related to specific FEW nexus solutions. Technological developments in the U.S. and China are already interconnected. Many electronic devices designed in the U.S. are assembled in China, and most Chinese technology firms rely on foreign suppliers. Thus, instead of thinking of the U.S. and China as competitors, FEW goals are better achieved if the two countries work in partnership.[71] Such cooperation has implications for making progress toward sustainable development goals for food security, affordable renewable energy, and access to clean water.

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Notes

The authors declare no competing financial interest.

Biography

Dr. Jie Zhuang is a professor in the Department of Biosystems Engineering and Soil Science and Center for Environmental Biotechnology at the University of Tennessee, Knoxville, Tennessee, United States. As one of founders, he has served as the deputy director of the China–U.S. Joint Research Center for Ecosystem and Environmental Change since 2007. He created a U.S.–China 100-PhD Program in the areas of Environment, Energy, and Food in 2014 and has recruited more than 40 students for PhD study in the United States. Currently, with the financial support of National Science Foundation of the United States, Dr. Zhuang leads a project aiming to develop a global research network of food–energy–water nexus for supporting urban sustainability. This transdisciplinary project involves researchers, students, stakeholders, and policymakers of many countries of the world. Over the past three decades, Dr. Zhuang has worked on many challenging research projects in the United States, Japan, and China. His specific research focuses on the fate and transport of contaminants (pathogens, radionuclides, colloids, organic chemicals, and munitions constituents), soil carbon management, soil hydrology, and plant–water relations.

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