Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Discussion

Recover the food-energy-water nexus from COVID-19 under Sustainable Development Goals acceleration actions

Caichun Yin\textsuperscript{a,b}, Paulo Pereira\textsuperscript{c,*}, Ting Hua\textsuperscript{a,b}, Yanxu Liu\textsuperscript{a,b}, Jing Zhu\textsuperscript{d,e}, Wenwu Zhao\textsuperscript{a,b}

\textsuperscript{a} State Key Laboratory of Earth Surface Processes and Resource Ecology, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China
\textsuperscript{b} Institute of Land Surface System and Sustainable Development, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China
\textsuperscript{c} Environmental Management Center, Mykolas Romeris University, Ateities g. 20, LT-08303 Vilnius, Lithuania
\textsuperscript{d} School of Humanities and Law, Northeastern University, Shenyang 110819, China
\textsuperscript{e} School of Economics, Northeastern University at Qinhuangdao, Qinhuangdao 066004, China

HIGHLIGHTS

\begin{itemize}
  \item COVID-19 and lockdown affected the food-energy-water (FEW) nexus.
  \item The pandemic posed challenges to FEW supply and demand, utilisation, and digitization.
  \item Recover the FEW nexus from COVID-19 under SDG Acceleration Actions.
  \item Nature’s contribution is essential to recover FEW nexus.
  \item Digital technologies and community production is key for FEW sustainability.
\end{itemize}

ABSTRACT

The interwoven relationship between food, energy, and water (FEW) is described as the FEW nexus. The COVID-19 pandemic has interrupted the FEW nexus and impeded the progress of FEW-related Sustainable Development Goals (SDGs) (SDG 2: Zero Hunger; 6: Clean Water and Sanitation; 7: Affordable and Clean Energy). We aim to find solutions to recover the FEW nexus from COVID-19. First, we discussed the challenges faced by FEW amid COVID-19. Second, we observed responses of the FEW nexus under COVID-19 interference. Finally, we proposed the solutions that guide the FEW nexus in recovery from the pandemic by mining 164 FEW-related SDG Acceleration Actions. The key solutions include 1) building or upgrading FEW facilities and infrastructure, 2) improving nature’s contribution to the FEW nexus, 3) developing digital technologies, 4) innovating the source and production of FEW, and 5) promoting community production and transforming the lifestyle. Our work highlights the importance of feasible and accelerated actions that recover the FEW nexus in the post-pandemic era.

ARTICLE INFO

Article history:
Received 29 October 2021
Received in revised form 3 January 2022
Accepted 5 January 2022
Available online 11 January 2022

Editor: Jay Gan

Keywords:
Food-energy-water nexus
The COVID-19 pandemic
SDG acceleration actions
Recovery

1. Introduction

Food, energy, and water (FEW) are the most critical resources that underpin human livelihoods and wellbeing (Endo et al., 2017). FEW are highly interdependent. For instance, the food sector is the largest consumer of freshwater. Also, more than one-quarter of the energy is consumed by the food sector.\textsuperscript{1} It indicates our increasing demand for 1) energy and water to develop agriculture and produce food, 2) water and crop biomass to produce energy, and 3) energy to supply water. Therefore, the FEW nexus acts as a holistic framework integrating the links between FEW (FAO, 2014). It helps reduce tradeoffs and promote synergies between FEW in the context of limited resources and increasing human demand (Bazilian et al., 2011).

FEW Sustainable Development Goals (SDGs) are: 2: Zero Hunger; 6: Clean Water and Sanitation and 7: Affordable and Clean Energy. Their nexus is key for achieving the United Nations (UN) SDGs (UN, 2015). The FEW-related SDG progress already lagged before 2020. Millions of people are estimated to live in areas lacking secure and stable FEW by 2050 (World Economic Forum, 2011). The COVID-19 pandemic, which began as a health emergency, has triggered an unprecedented socioeconomic...
crisis, stalling the SDG progress and interrupting their nexus. COVID-19 pushed 100 million people into poverty, doubling the number of starving populations in 2020 (Nature, 2021). Also, it led to the worst recession since World War II, threatening the global FEW security (Blake and Wadhwa, 2020).

After the COVID-19 outbreak, FEW security became a critical issue for researchers and policymakers, and the relevant publications proliferated. Many works focused on FEW separately, indicating the COVID-19s impacts on FEW security (Deaton and Deaton, 2020; Galanakis, 2020; Graff and Carley, 2020; La Rosa et al., 2020; Odh et al., 2020). Some studies also looked at COVID-19s effect on FEW from a nexus perspective. Calder et al. (2021) indicated causal relations among FEW and vulnerabilities of the FEW nexus under COVID-19 by reviewing scientific and news/media articles. Also, Al-Saidi and Hussein (2021) provided a holistic review of the COVID-19s implications on the FEW nexus. Mayer and Ryder (2021) studied COVID-19s effect on FEW security in Colorado, The United States. Karan and Agsari (2021) that a labour shortage during the pandemic impacted FEW resilience. Finally, Zhao and You (2021) suggested to optimise the FEW nexus by waste-to-energy technologies. In essence, COVID-19 threatened human wellbeing and sustainable development (i.e., SDGs), and the FEW insecurity is one of the manifestations. Therefore, after discussing COVID-19s impact on the FEW nexus, sustainable solutions to recover the FEW nexus from COVID-19 are strongly needed. This discussion paper aims to assess the challenges faced by FEW and their nexus amid the COVID-19 pandemic and find solutions to recover the FEW nexus from COVID-19 under SDG acceleration actions. Our work highlights the importance of feasible and accelerated action that recovers the FEW nexus in the post-pandemic era.

2. Common challenges faced by FEW amid the COVID-19 pandemic

FEW have faced issues such as limited access (quantity, quality, or both), growing demand, and coexisting benefits and risks produced by the international market (Bazilian et al., 2011). As the population increases to 9 billion and economic growth accelerate in 2050, it is predicted that global water demand will increase by 55% and energy and food production by 50% and 70%, respectively (UNEP, 2021). Also, it is estimated that in 2050 half of the world’s population will be affected by water stress.3 Finite land and water availability will increase the tradeoffs and competition between food and energy production (Hanes et al., 2018). Limited supplies amid expanding human needs threaten sustainable development. These issues have been amplified directly and indirectly by COVID-19. The direct impacts are a consequence of the virus spread (e.g., food and water contamination), while the indirect impacts due to lockdown measures produced cascading effects on social (e.g., social unrest; “stay at home” order; unemployment), economic (e.g., blocked supply-demand chain and international trade) and environmental (e.g., reduction of air, soil and water pollution; the increase of medical waste) (Dffenbaugh et al., 2020). Although COVID-19 effects on FEW are of global concern, underdeveloped regions are more vulnerable (e.g., inadequate FEW supplies, blocked access channels and low utilisation efficiency) (FAO and WFP, 2020).

2.1. The intensified contradiction between supply and demand of FEW

COVID-19 and lockdown disrupted the supply and demand of FEW, such as halting production and impeding logistics. The interdependence between FEW further intensified the cascade of COVID-19s disruption. The fluctuations of FEW prices increased the tension between the demand and supply. Global food prices have increased 38% since January 2020 due to the huge demand caused by COVID-19 on the supply chain (Bafles and Wu, 2021). Due to the strong demand for sanitation and clean water to prevent virus transmission, water-deficient regions suffered an additional pressure. In contrast, global energy demand in 2020 decreased on average 5%, COVID-19 reduced transport, trade and production (IEA, 2020b). Excess supply led to the oil market collapse with the benchmark price in April 2020 (Eroglu, 2021). The international market’s smooth operation is essential to regulate the FEW supply and demand. However, the lockdown and imposed restrictions and limitations imposed in international trade, disrupting the supply chain. The economic recession, coupled with a sharp decline in national GDP and unemployment rise, weakened the demand for FEW resources. Developed countries were more vulnerable to supply-side risks because of the high dependence on international supply chains. Developing countries were more vulnerable to demand-side risks due to the higher retail prices and income shocks during the pandemic (FAO et al., 2020).

2.2. Changes in resource usage profiles between workplaces and households

COVID-19 and preventive measures (e.g., lockdown and home isolation) affected socioeconomic functioning that required physical contact, altering the FEW usages. For instance, the FEW demands in public workplaces such as services and industry—FEW large consumers decreased. Increased residential FEW consumptions has partially offset this decline due to the “stay at home” requirement (Edomah and Ndulue, 2020). In America, the electricity sales in the industrial and commercial sectors in 2020 decreased 8.8% and 5.9%, respectively (EIA, 2020). In contrast, household energy consumption increased substantially. In the 2020 winter, natural gas expenditures increased 6%, electricity 7%, and propane 14%.4 The shift in socioeconomic activity from public places to households changed FEW uses pattern. Now the uses were later than usual. In New York, from 6 to 10 a.m., a time when FEW uses increase due to working period start, now there is a delay in the timing, and there was a reduction in energy usage (6% ~ 9%) compared to a pre-pandemic situation.5 These changes imposed new challenges for FEW resource management.

2.3. Growing demand for remote work and digital management

Ensuring stable and adequate FEW supplies were essential during the COVID-19 crisis, which required staff in sectors that needed to work, despite the pandemic. Therefore, the demand for communication through digital platforms increased due to social distance (Poch et al., 2020). This increased the remote working development and the adoption of digital tools used to manage the FEW sectors (Zhou et al., 2020). Also, timely provision of high-quality data is key to improving policy responses in uncertain situations. However, data collection by statistical agencies during the lockdown. Crop, energy, and water-related data collected in the field were suspended (NASA, 2020). These circumstances boosted the development of FEW data collection through remote sensing. Satellite images facilitated understanding regional-to-global environmental, economic, and societal impacts of COVID-19 and how lockdown measures affected food security, water quality, and energy consumption (NASA, 2020). Using remote sensing data and advanced statistical methods (e.g., machine learning) to map where and which crops are growing allowed to monitor the COVID-19 effects on food security (Mishra et al., 2021). These techniques are key to understanding the pandemic’s impact on FEW and optimising the production activities without increasing the transmission risk.

3. The FEW nexus under the interference of COVID-19

The FEW nexus was not changed with COVID-19, viz. food and agriculture require energy and water as a resource, energy needs water and crop biomass, and water needs energy as power (Hellegers et al., 2008; Khan and Hanjra, 2009). Nevertheless, FEW nexus stability and security were strongly affected by COVID-19. In the absence of secure and stable international trade, many countries/regions strengthen their domestic capacity to

---

3 https://www.water-energy-food.org/.
4 https://www.eia.gov/outlooks/steo/.
5 https://www.eia.gov/todayinenergy/detail.php?id=43295.
safeguard the demand and the supply for food, energy and water (Hellegers et al., 2008). FEW are interdependent. 90% of the world’s power depends on water, and agriculture consumes 70% of the global water. If the food and energy sectors seek to promote local self-sufficiency, the expanded food and energy production will increase the water supply competition. This may create some conflicts since the resource is limited (Hanes et al., 2018). Moreover, food and energy supply changes the water consumption timing and spatial distribution, imposing challenges to water management (Redmon et al., 2020).

In addition, COVID-19 transmission and socioeconomic stagnation posed multiple challenges to food-energy, food-water, energy-water, and the FEW nexus during the pandemic (Fig. 1). COVID-19 interfered with the FEW life cycles (e.g., input, processing, marketing, production, transportation and consumption). The lockdown also reduced the human pressure on the environment, contributing to short-term improvements in the FEW services (Yin et al., 2021). The details of the nexus between food, energy, and water during COVID-19 are presented in the following sections.

3.1. Food-energy

Food depends more on energy since energy is essential in producing, transporting and distributing food. It is estimated that food production consumes approximately 30% of the world’s energy (FAO, 2012; FAO, 2014). Food is also key to energy production, such as crops and residues (e.g., biomass). To curb the COVID-19 spread, several governments imposed strict controls on manufacturing activities, leading to the shutdown of many small-scale food processing plants. During quarantine, most catering demand shifts from the service sector to the home, reducing energy consumption and high residential energy demand (Edomah and Ndulue, 2020). In this situation, the poor are the most vulnerable to energy shortages and hunger. Nearly one billion of the world’s poor had little access to energy. During the pandemic, this situation was exacerbated, and households that depended on firewood were seriously affected in gathering energy for basic needs (e.g., preparing food). Also, oscillations in the energy market affected food prices dramatically (Bazilian et al., 2011). The pandemic strongly disrupted energy demand. It is estimated that COVID-19 impact on energy was seven times greater than the 2008 financial crisis (IEA, 2020a). For instance, the reduced demand for ethanol for transportation dropped corn prices (NASA, 2020). The “negative oil price” event and the instability of international energy markets devaluated the Russian ruble, affecting local crop prices and food and energy security (Torero, 2020).

3.2. Energy-water

Energy is essential to water extraction, treatment, distribution, and disposal. On the other hand, water input is also key for energy processing such as hydropower, thermoelectric cooling and fossil fuels extraction (Siddiqi and Anadon, 2011). Due to the socioeconomic activity stagnation during the pandemic, energy and water demand decreased substantially (e.g., breweries) (Redmon et al., 2020). Restrictions and reduced consumer demand imposed a decrease in production and a close in energy-intensive factories. The global demand for oil, coal, and electricity in 2020 decreased 9%, 8%, and 5%, respectively (IEA, 2020a). This reduced the pressure on water demand as well. The decrease in consumption and emission of fossil fuels reduced the pressure on water resources and alleviated the pressures on the environment (Yunus et al., 2020). Nevertheless, energy is under pressure to support wastewater treatment due to increased medical waste (Bel and Marengo, 2021).

3.3. Water-food

Without water, agriculture and food chains cannot be sustained (FAO, 2014). This is especially evident in arid developing countries, where 90% of water is used for irrigation (Bazilian et al., 2011). Most countries that lack water resources are food importers and rely on the international food trade. As an “anti-globalisation virus”, COVID-19 disrupted international trade and resource supply chains, forcing net food importers and water
scarcely countries to ensure food self-sufficiency (Keulertz et al., 2020; Redmon et al., 2020). However, increasing domestic agriculture will increase water exploitation in countries with reduced water resources, such as Saudi Arabia, Jordan or Lebanon (Keulertz et al., 2020).

Also, COVID-19 transmission can compromise water and food safety. Despite the progress, 2.2 billion and 4.2 billion people worldwide do not have access to clean drinking water and sanitation, respectively (Sivakumar, 2021; UN, 2020). The lack of food and hand washing may exacerbate COVID-19 transmission. In addition, COVID-19-carrying effluent from hospitals, quarantine centres and households continue to be treated and discharged without improvements in wastewater technology (Blowmink et al., 2020). This wastewater will contaminate irrigation water and food crops if not adequately treated, especially in rural households with poor sanitation. Imported aquatic products may also be at risk of COVID-19 transmission (e.g., traces on frozen seafood packaging).

4. Recover the FEW nexus from COVID-19 under SDG acceleration actions

Since FEW resources underpin human wellbeing and sustainability, progress on the FEW-related SDGs (SDG 2, 6, 7) is central to the SDG implementation. Moving ahead on the Decade of Action (2020–2030), SDG Acceleration Actions are global initiatives promoting linkages among goals and accelerating the coherent SDG implementation. FEW-related SDG Acceleration Actions, therefore, can guide the way towards FEW sustainability. We read in detail and mined 164 FEW-related SDG Acceleration Actions, respectively (Fig. 2), can improve nature’s contribution to the FEW nexus. Therefore, actions to protect nature, such as the UN Decade on Ecosystem Restoration (2021–2030), should be integrated into the FEW nexus’s recovery in the post-pandemic era.

4.3. Develop digital technologies

Digital technologies develop rapidly under lockdown and physical isolation (Ting et al., 2020). Satellites and drones can monitor FEW change remotely. Internet of Things (IoT) and big data provide farmers access to market and weather information. Digitisation, therefore, contributes to better FEW allocations and increases supply-demand efficiency. SDG Acceleration Actions also highlighted the technology’s role in recovering FEW sectors from COVID-19 (11%) (Fig. 2). The Digital Farmer Community project10 for instance, it provides localised agriculture information and crop-specific advice for farmers leveraging IoT and satellite technology. Also, BrightTap project11 deploys IoT water meter sensors, which are attached to water tap or pipe, to monitor real-time water consumption and send the records to users. Therefore, instead of reserving production or laying off workers to address the financial risk, FEW sectors need to improve productivity and efficiency by technology advances. Also, workers and farmers should improve or be trained in digital skills.

4.4. Innovate FEW resources

Actions that innovate FEW resources, e.g., clean energy and atmospheric water generation, account for 6% of the FEW-related SDG Acceleration Actions. The green investment provides a financing base for innovative action (3%) (Fig. 2). Energy sustainability requires the transition from fossil fuels to renewable energy such as photo-voltaic, solar thermal, wind and tidal energy. Furthermore, the energy transition can optimise the FEW nexus. For instance, although many regions use seawater to alleviate water shortage, desalination is expensive and fossil fuel-intensive (e.g., Panagopoulos, 2021). Therefore, solar-desalination solutions can produce a smaller carbon footprint and more affordable water supplies (e.g., Abd Elbar and Hassan, 2020). For the food sector, water-friendly solutions, agricultural practices that save water (e.g. mulching) can alleviate local water pressure and improve the environment (Rahma et al., 2019).

4.5. Promote community production and transform the lifestyle

The population ultimately consumes FEW. Therefore, actions starting at the grassroots, such as promoting community production (2%) and efficient use (2%), are key to FEW sustainability (Fig. 2). Community-based food production can reduce water stress and carbon emissions by reducing rainwater, recycling greywater and reducing energy consumption (UNEP, 2021). Urban Green Gardens project,12 for instance, is developing community agriculture and urban agroecology to improve food security and foster environmental education. Reinventing lifestyles, especially diet, can also benefit the FEW nexus. For instance, meat production is the most water-intensive and has the highest carbon footprint. Producing 1 kg of tomatoes just needs 214 l of water, while 1 kg of beef needs 15,400 l of water. The livestock and fisheries industry is responsible for 31% of food greenhouse gases emissions (Poore and Nemecek, 2018). Therefore, a diet with less meat consumption and more plant-based food is friendly to the environment and the FEW nexus (UNEP, 2021). To improve lifestyle, it is also essential to choose sustainability-certified green commodities, improve FEW utilisation efficiency and reduce waste (Light, 2020; UNEP, 2021).

In addition to the above specific solutions, systematic deployments, such as the FEW nexus demonstration pilots and the overall SDG

---

10 https://sustainabledevelopment.un.org/partnership/?p=38025.
11 https://climatelaunchpad.org_FINALISTS/brighttap/
12 https://www.urbangreengardens.com/.
Acceleration Actions, also contribute to the FEW nexus’s recovery from COVID-19 (Wang et al., 2020). Accelerating the implementation of FEW-related SDGs, UN, multilateral bodies, and organizations (e.g., FAO, International Energy Agency, International Water Association) should strengthen their leadership and coordination (73%) (Fig. 2). They are the major bodies to recover the FEW nexus from the “anti-globalisation” pandemic by developing strategies for FEW security, building platforms for bilateral and multilateral investment and trade cooperation, and coordinating market rules for FEW under the global lockdown (Fu et al., 2020; Zhao et al., 2020).

5. Conclusions

FEW and their nexus underpin human wellbeing and the SDG implementation. The COVID-19 pandemic, however, posed challenges on the FEW nexus, such as the increased contradiction between supply and demand and the need to reform FEW utilisation and management amid the global lockdown and economic recession. The pandemic is still spreading in 2022. Finding and moving towards recovery from COVID-19 is a global priority. Moving ahead on the 2030 Agenda, FEW-related SDG Acceleration Actions guide the way towards FEW sustainability. By examining COVID-19’s impact on the FEW nexus, this work put forward solutions to recover the FEW nexus based on acceleration actions of SDG 2, 6, 7. Future work could focus on the links between the FEW nexus and SDGs under changing environments such as the pandemic and promote FEW sustainability in the post-pandemic era.

CRediT authorship contribution statement

Caichun Yin: Conceptualization, Visualization, Writing - original draft, Paulo Pereira: Investigation, Formal analysis, Writing - review & editing, Ting Hua: Writing - review & editing, Yanxu Liu: Writing - review & editing, Jing Zhu: Writing - review & editing, Wenwu Zhao: Conceptualization, Investigation, Writing - review & editing.

Declaration of competing interest

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

Acknowledgements

This work was supported by the National Natural Science Foundation of China (41861134038), the Alliance of International Science Organizations (No. ANSO-SBA-2020-01), the State Key Laboratory of Earth Surface Processes and Resource Ecology (No. 2020-KF-10), and the Fundamental Research Funds for the Central Universities of China.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.153013.

References

Abd Elbar, A.R., Hassan, H., 2020. Enhancement of hybrid solar desalination system composed of solar panel and solar still by using porous material and saline water preheating. Solar Sci. 204, 382–394.
Al-Saidi, M., Hussein, H., 2021. The water-energy-food nexus and COVID-19: towards a systematization of impacts and responses. Sci. Total Environ. 779.
Baffes, J., Wu, J., 2021. Food commodity markets: Prices spike amid supply shortfalls and strong demand. World Bank. https://blogs.worldbank.org/opendata/food-commodity-markets-prices-spike-amid-supply-shortfalls-and-strong-demand. (Accessed 25 October 2021).
Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Mueller, A., Komor, P., Tol, R.S.J., Yumkella, K.K., 2011. Considering the energy, water and food nexus: towards an integrated modelling approach. Energy Policy 39, 7896–7906.
Bel, J.-B., Marengo, P., 2021. The impact of the COVID-19 on municipal waste management systems. Brussels. https://acplus.org/images/technical-reports/2021_ACR_Impact_COVID-19_pandemic_on_municipal_waste_management_systems.pdf.
