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.

Science of the Total Environment 779 (2021) 146529

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The water-energy-food nexus and COVID-19: Towards a systematization of impacts and responses

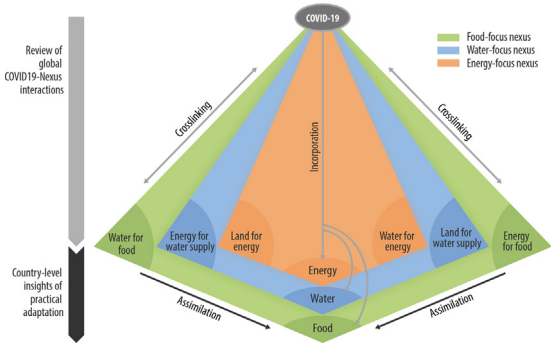
Mohammad Al-Saidi [a,*], Hussam Hussein [b]

[a] Center for Sustainable Development, College of Arts and Sciences, Qatar University, P.O. Box: 2713, Doha, Qatar
[b] Department of Politics and International Relations (DPIR), University of Oxford, Manor Road, OX1 3UQ Oxford, UK

HIGHLIGHTS

- A systematization of the impacts of COVID-19 on the WEF nexus is needed.
- Medicalization, demand fluctuations and production (re)localization are key impacts.
- Priority cross-links include water and energy for local food and energy-wastewater.
- The analysis shows varying adaptations and a re-valuation of water-food-trade link.
- COVID-19 reveals a lack of risk-based analyses and spatial aspects in the WEF nexus.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 November 2020
Received in revised form 7 March 2021
Accepted 11 March 2021
Available online 18 March 2021

Editor: Martin Drews

Keywords:
Environmental security
WEF nexus
Sustainable development
Basic supply infrastructure
Food security
Middle East

ABSTRACT

The COVID-19 pandemic offers an opportunity to examine the impacts of system-wide crises on key supply sectors such as water, energy and food. These sectors are becoming increasingly interlinked in environmental policy-making and with regard to achieving supply security. There is a pressing need for a systematization of impacts and responses beyond individual disruptions. This paper provides a holistic assessment of the implications of COVID-19 on the water–energy–food (WEF) nexus. First, it integrates the academic literature related to single cases and disruptions to provide a broader view of COVID-19 demand- and supply-side disruptions and immediate effects. Then, the major, long-term impact categories of medicalization/hygienization, (re)localization of production, and demand fluctuations are highlighted. These impacts result in priority cross-links such as irrigation, energy requirements for local food production, energy use for water and wastewater treatment, or water for energy use. Finally, sector-level insights on impacts and responses are provided, drawing from illustrative cases. The analysis of impacts of COVID-19 on the WEF nexus reflects heterogeneous experiences of short-term adaptations, and highlights the revaluation of the water–food–trade nexus. Revived debates on food sufficiency can benefit from green applications to minimize expected trade-offs. The current crisis also reveals some gaps in the WEF nexus debates with regard to the lack of risk-based perspectives and the need for a better consideration of spatial aspects in resource integration. Regarding resource-security issues in the WEF nexus, the COVID-19 stress test boosts debates concerning the adequacy of the production value chains (e.g., contingency and storage, diversification, and self-sufficiency) and the value of cross-border integration (e.g., trade, globalization, and aid).

* Corresponding author at: Qatar University, Center for Sustainable Development, P.O. Box: 2713, Doha, Qatar.
E-mail address: malsaidi@qu.edu.qa (M. Al-Saidi).

https://doi.org/10.1016/j.scitotenv.2021.146529
0048-9697/

1. Introduction

COVID-19 has had wide health and economic repercussions affecting the basic supply sectors and the environmental sector in general (Barbier and Burgess, 2020; Cohen, 2020; Naidoo and Fisher, 2020; O'Callaghan-Gordo and Antó, 2020). It has caused many tangible impacts such as the increase in medical waste and some improvements in air quality and carbon emissions (Ilyas et al., 2020; Saadat et al., 2020). In fact, COVID-19's environmental impacts have been conflictive. Major recent reviews cover a wide range of impacts that vary depending on the location, time, and the setting of COVID-19 responses (Cheval et al., 2020; Eufemia and Hussein, 2020; Hussein and Greco, 2020; Sarkar et al., 2021; Shakil et al., 2020). These reviews tend to contrast the human, health, and economic cost of the pandemic with positive aspects such as reduction in emissions, pollution, or noise. However, such positive observations are not specific to the pandemic; they can be caused in any case of downscaling of societal throughput, and besides, positive impacts do not always equate with positive news. COVID-19's environmental benefits are neither stable in the long term (once we "live with" or "defeat" the virus), nor possible nor desirable to induce again in the same manner (by arranging another pandemic).

Not unexpectedly, having fewer cars, planes and tourists translates into less environmental damage and smaller ecological footprints, but the repercussions of the COVID-19 crisis are both far-reaching and complex. We need to document immediate impacts, understand long-term implications, and unfold the interrelated aspects of the COVID-19 crisis. At the same time, investigating the significance of this crisis as a "stress test" for our sustainability targets, policies and management approaches can be quite a fruitful exercise. COVD-19 is shaping the environmental research agenda into the foreseeable future. It represents a unique experiment with long-term implications for environmental policies, climate regulations, and economics, as well as for our perception of globalization, equity and environmental responsibility (Deslatte et al., 2020; Helm, 2020). Several scholars have expressed how the current pandemic can reset, onset or delay key items of the global sustainability agenda such as the Sustainable Development Goals or the Paris Agreement (Barbier and Burgess, 2020; Cohen, 2020; Naidoo and Fisher, 2020; Rifai, 2020). In fact, our responses in terms of restarting economies, providing relief, and managing the adaptation of key environmental sectors can determine the final outcomes in terms of either causing more damage and inequalities or creating opportunities for a greener and more just transition.

Water, energy and food represent the main sectors for achieving basic supply and key environmental outcomes (Hoff, 2011; Simpson and Jewitt, 2019; World Economic Forum, 2011). Together, they form a water–energy–food (WEF) nexus of interlinked resource-use issues wherein decisions or pressures in one sector have multiple consequences for the other ones (Al-Saidi and Elagib, 2017; Hoff, 2011). The WEF nexus is a much-debated sustainability paradigm focusing on the increased integration between the water, energy and food sectors and the possible implications for resource security (Al-Saidi and Elagib, 2017; Hoff, 2011; World Economic Forum, 2011). COVID-19 represents a systematic and highly relevant stress on the WEF nexus, as this paper explains. Most research in the field has focused on analyzing how COVID-19 affects individual sectors (e.g., water, food and energy), but there have so far been few holistic analyses on the cascading or cross-sectoral impacts of pandemics on these vital sectors. So far, some nexus-related studies exist measuring COVID-19's impacts on access to water, food or energy in Africa (Durodola et al., 2020), and showcasing the relevance of COVID-19 for related nexus framings, e.g., the water–human health–environment–nutrition nexus (Nhamo and Ndlela, 2021).

There is a pressing need for greater systematization of the impacts of COVID-19, including practical insights into the reactions of basic supply sectors to the disease considering the increased integration among these sectors. The aim of this paper is to analyze the impacts, responses and practical adaptation strategies of the WEF sector to the COVID-19 crisis. The unique nature of the COVID-19 stress test is highlighted using a conceptual systematization, recent literature on pandemics, practical insights, and country-level examples from the Middle East as a focal region. This pandemic can inform us about the merits and limits of integrative approaches such as the WEF nexus. In view of this, the final section of this paper discusses the tangible impacts, critical factors and long-term perspectives related to the COVID-19 crisis and the WEF sectors. The main hypothesis of this paper is that COVID-19 has redefined the notion of resource security by increasing the importance of debates on risk-based assessments and cross-border integration and revaluing food-related aspects within the WEF nexus. Using the Middle East as a case study, the practical relevance of the COVID-19 crisis to the core WEF nexus objectives of resource security and improved well-being of communities is highlighted. Furthermore, by linking pandemics to the planning and management requirements of environmental sectors, this paper provides an initial examination of COVID-19 with the goal of informing environmental policymaking in situations characterized by crisis and sudden change.

2. Methods

2.1. The systematization approach using a three-layer nexus

This paper investigates COVID-19 and its impacts on the WEF nexus by providing a systematized or structured analysis of these impacts and illustrating their practical relevance. To this end, the paper has a two-part structure. Firstly, it maps global interactions using conceptualizations and recent literature (Sections 3.1 and 3.2). Secondly, it undertakes an analysis based on a case study (the Middle East) using country-level insights (Section 3.3). As a general approach for the systematization, we relied on the three understandings of the WEF nexus provided by Al-Saidi and Elagib (2017), namely incorporation, crosslinking, and assimilation. These three understanding together provide a coherent framework for examining the interactions in the WEF nexus from three different views: incorporation as a whole-system view (Section 3.1), cross-linking as a partial view of certain priority trade-offs and leverage points (Section 3.2), and assimilation as a practical view of sectoral management (the case-study portion of Section 3.3).

Fig. 1 explains the overall layout with the aim of providing a systematization of the analysis using the framework of the three-layer nexus put forward by Al-Saidi and Elagib (2017). The three views of the nexus under this framework can be explained as follows: Under incorporation, the analysis is carried out using a "bird's eye view" of the whole system and interlinkages; i.e., in our case, the totality of how COVID-19 affects the WEF sector. This perspective aims at providing an overview or a holistic picture of possible interactions without providing detailed sector-level or country-level details. In the cross-linking analysis, an "inside-out view" is used to highlight the priority linkages; i.e., which cross-sectoral issues are most affected by the consequences of COVID-19. The cross-linking perspective is a practical view that concentrates on the intersections (i.e., links or cross-cutting impacts) of at least two resources. In our analysis, we use both the incorporation and cross-linking analyses to provide a global view of the COVID-19 interactions. This is carried out through conceptualizing these interactions using recent evidence of the disruption caused by COVID-19. Finally, using country-level examples and issues raised in the discussion section, we deploy the assimilation perspective. This perspective represents the sectoral view of sectoral managers and decision-makers seeking to accommodate the concerns of other sectors into their strategies. Here, we highlight some preeminent management issues and provide recommendations for sectoral-level decision-making in order to better accommodate disruptions from COVID-19 while considering pressures from other sectors.

The three perspectives on integration in the nexus together provide a clear and holistic picture of COVID-19 and the WEF nexus.

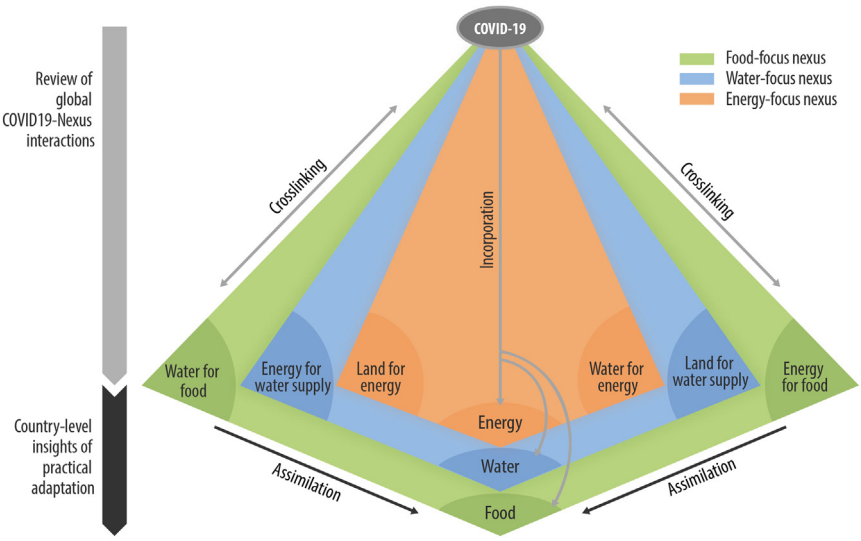


Fig. 1. Linking COVID-19 and the WEF nexus: overall outline and steps.

Incorporation, cross-linking, and assimilation are also useful for different levels of management, namely for planning, coordination or regulation, and operational management, respectively (Al-Saidi and Elagib, 2017; Hogeboom et al., 2021). With this multi-layered investigation (see Fig. 1), this paper can capture the impacts of COVID-19 as an additional external layer added to the complex interactions within the WEF nexus. Traditionally, these impacts (e.g., on energy supply changes, food and water demand changes, or waste management) have been treated as stand-alone disruptions. In practice, however, they are often cross-sectoral, with ramifications felt immediately by operational managers in other sectors. For example, an increase in food demand means more requirement for water, and thus more energy required for water pumping, delivery, and treatment. COVID-19 provides a stress scenario with simultaneous impacts across the WEF subsectors. It is also a test case for the resilience of basic supply systems as a highly important topic in WEF nexus research (Al-Saidi and Saliba, 2019), as well as for the viability of current (crisis) management responses and the level of integration in decisions affecting the WEF nexus.

2.2. Literature selection and case-study data

To carry out the analysis using the three nexus layers, we mainly relied on secondary academic literature on the impacts of COVID-19 in the WEF sectors. There have been a considerable number of publications on COVID-19 and the water, energy, and food sectors. A quick search of the scientific database Scopus resulted in more than 3000 publications having COVID-19 and at least one of these sectors in the title, keywords or abstracts. In our literature selection, we developed two databases (Appendix A), for the global analysis and the case-study focus. For the first part of the paper on the global interactions between COVID-19 and the WEF nexus (the incorporation and cross-linking views), we searched in Scopus for peer-reviewed papers for the period from December 2019 to February 2021 that include in the title, keywords, or abstract the keywords of COVID-19 and either water security, food security, or energy security. These resource securities comprise the major theme within debates on the WEF nexus (Al-Saidi and Elagib, 2017; Hoff, 2011; World Economic Forum, 2011). Since we aimed to provide a global overview of interactions, no particular geographies or cases were selected for this dataset. The resulting dataset of 274 publications was further processed to exclude irrelevant ones, namely publications that use the key terms (COVID-19 and water security, energy security, or food security) merely as buzzwords, mainly relate to larger impacts (e.g., economic or health impacts), or have a narrow focus (i.e., they do not seek to provide a holistic or sector-wide analysis of COVID-19 impacts). The resulting set had a predominant focus on food security. On the one hand, this apparent bias towards the food sector can reflect the relatively heavy impacts of COVID-19 on food security. On the other hand, it should be balanced out in our analysis in order to cover the impacts on and interlinkages with the other sectors. In order to overcome this bias, key papers linking energy and water securities with COVID-19 were searched for and added by the authors – who have a background in the WEF nexus and water and/or energy sectors – to the final dataset (43 papers). Furthermore, to provide more cross-sectoral insights, we also studied papers with a wider focus on the whole WEF nexus (Durodola et al., 2020; Nhamo and Ndlela, 2021), or on COVID-19's cross-sectoral environmental impacts (Cheval et al., 2020; Helm, 2020; Saadat et al., 2020; Shakil et al., 2020; Zambrano-Monserrate et al., 2020). Alongside the main dataset for the first part of the paper, other papers were used for the background and discussion of the larger context of COVID-19 and the WEF nexus.

Alongside the analysis of the global interaction between COVID-19 and the WEF nexus, there is an urgent need to break down COVID-19's impacts on critical supply sectors in order to provide practical insights and recommendations. Such a sectoral view is presented in the case study section of this paper.

The insights from regions characterized by scarcity of natural resources and significant anthropogenic pressures, are valuable for better assimilation of the integrated management mindset, and particularly when facing crises such as major health-related ones. Therefore, the case study section focuses on the Middle East, and particularly Jordan, Lebanon and the Gulf Cooperation Council (GCC) region. Lebanon is a particularly interesting case due to the compounded impacts of the ongoing economic crisis and COVID-19-related food security issues. Jordan is an exemplary case for severe water scarcity, which is exacerbated by COVID-19's impact on both the water and food sectors. The GCC region is usually listed among the highest-ranked countries for food security due to the wide availability of financial resources, but the region exhibits some of the world's largest energy and carbon footprints (due to energy requirements for cooling or desalination) (Al-Saidi and Elagib, 2018; Al-Saidi and Saliba, 2019). It is for this reason that the impacts on the energy sector were highlighted for this region. For the case-study section, a Scopus search was carried out for publications from December 2019 to February 2021 with the keywords COVID-19 and Middle East, Jordan, Lebanon, or GCC, that also include either water, energy or food. In the resulting dataset of 117 papers, the overall majority of entries were not specific to the regional focus, or were focused on other impacts of COVID-19 (mainly related to health). After sorting the data, the resulting reduced dataset (only nine papers) was supplemented

with media reports and publications from international organizations (an additional seven publications) providing country-level insights into the earlier-mentioned countries.

3. Results

3.1. Initial mapping using a bird's eye view of COVID-19 and the WEF sectors

COVID-19 affects the basic supply sectors through a range of disruptions, which we seek to systematize in this section as well as outlining the broad picture of interactions (the incorporation perspective). Fig. 2 summarizes this systematization. We have identified ten major disruptions relevant to the WEF sectors (Fig. 2). We also differentiate between whether a disruption is mainly transmitted through a change in demand patterns, or a supply problem/shortage. There are relationships among the disruptions but they can also occur independently. For example, increased hygiene habits usually lead to dangerous biomedical waste, although this is not necessarily the case; e.g., in the case of sound waste management or the use of biodegradable materials (Das et al., 2020). In fact, within demand-induced disruptions, the increased use of hygiene products and the increase in medical waste have often been highlighted in the COVID-19 literature. The two issues mainly affect the water sector, namely deteriorating water quality or higher demand for water, and in consequence, energy demand for water (Kalina and Tilley, 2020; Norouzi et al., 2020; Rhee, 2020; Vanapalli et al., 2021). Water is a key instrument in the global fight against COVID-19, even in low-income countries lacking chemical-based disinfectants (Amegah, 2020; Anim and Ofori-Asenso, 2020). Hand washing, disposal of materials used for COVID-19 control and treatment, handling of casualties of the virus, and disinfection of affected areas are expected to increase the demand for water and wastewater treatment, thus affecting water quality as well as quantity (Sivakumar, 2020). In the short term, the increase in water demand might be offset by the economic downturn, and, in the long term, tackled through improved efficiency, innovation or (digital) monitoring (Poch et al., 2020). Biomedical waste such as masks, gloves and other protective materials can greatly affect water-related ecosystems and thus threaten water supply sources, environmental health, and ultimately, human well-being (Kalina and Tilley, 2020; You et al., 2020). For example, disposable face masks have been reported to have reached oceans in Hong Kong, while microplastic pollution can threaten freshwater ecosystems (Fadare and Okoffo, 2020). Some authors point to similar problems from post-disaster responses; e.g., discarded water bottles in post-hurricane Haiti (Kalina and Tilley, 2020).

Demand effects such as the reduction in everyday mobility (e.g., for work or social events) can result in lower energy requirements, and hence some decreased demand for certain water types such as produced water. Other systematic (cross-sectoral and simultaneous) disruptions can lead to demand reductions across the WEF sectors. Decreased leisure activities (e.g., tourism, holidays, or irregular outdoor activities) will lead to lower demand for energy and food, and hence water. Significant energy-demand disruptions are expected as a result of lockdowns and restrictions (e.g., less primary energy consumption) (Sovacool et al., 2020), with significant reductions in electricity demand reported in some European countries during the first wave of COVID-19 (Bahmanyar et al., 2020). Dietary changes can have significant impacts, particularly on the water sector. Healthier diets that include less red meat are important for combatting COVID-19 (Abdulah and Hassan, 2020; Muscogiuri et al., 2020), and as a result, people might demand less meat (which exhibits a high water footprint in its production) in the long run. However, initial evidence from Italy, Spain and some Latin American countries has indicated no or only a slight increase in self-reported intake or purchase of processed and red meat in the short term (Batlle-Bayer et al., 2020; Ruiz-Roso et al., 2020). Other studies have reported an increased intake of processed meat with a decreased intake of low-fat meat (Górnicka et al., 2020). These changes might vary depending on culture, infection rate, and income level. In developing countries, for example, people might choose to spend less on meat due to economic hardship. At the same time, disruptions in eating habits (e.g., more food consumption at home) require more attention to the food losses in households and the relocations in consumption (Aldaco et al., 2020). Finally, increased requirements for digitalization can have an effect on energy demands in the long term, although the final impact is yet to be studied.

Finally, some of the supply-induced impacts represent systemic disruptions. Mortality and morbidity affect the labor supply across industries (del Rio-Chanona et al., 2020), and particularly in critical ones such as the food industry (Mardones et al., 2020; Parks et al., 2020; Savary et al., 2020). The economic downturn caused by decreased or delayed consumption, trade disturbances and reduced mobility can cause supply disruptions affecting, for example, the food trade or the production of other basic supplies (Laborde et al., 2020). Restrictions on mobility have resulted in the lack of farm labor, livelihood losses for farmers, and other constraints on the food supply chains (Adamchick and Perez, 2020; Bochtis et al., 2020; Inegbedion, 2020; Mor et al., 2020; Niles et al.,

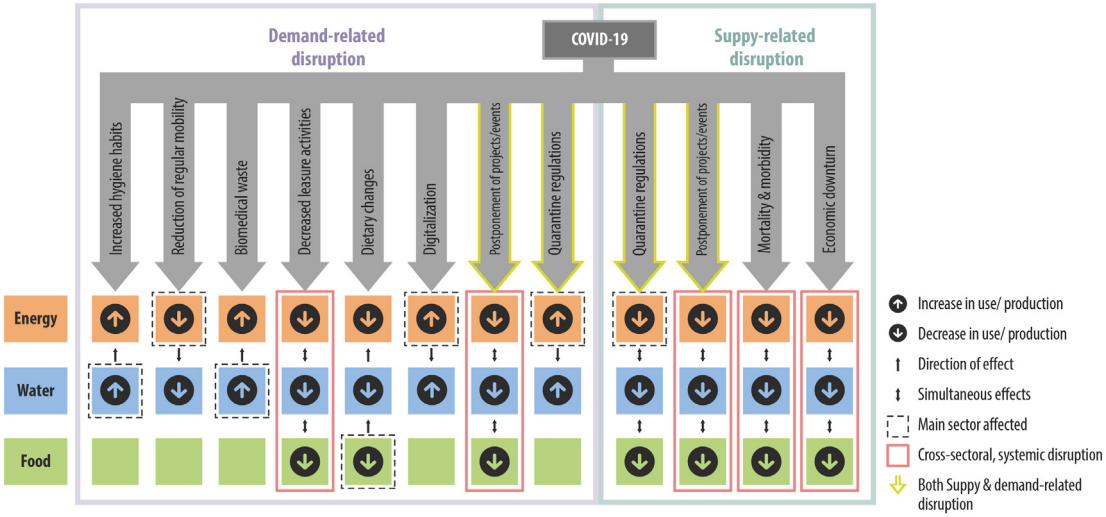


Fig. 2. A global overview (incorporation) of initial disruptions from COVID-19 in the WEF sectors.

2020). Furthermore, several disruptions have been reported to the global food trade, e.g., affecting agricultural exports from China (Cao et al., 2020) and those developing countries highly integrated in the global food markets (Erokhin and Gao, 2020). At the same time, the postponements of major events, e.g., major sporting events or mega-projects, can decrease the pressure on basic supply but also affect related infrastructure development. In some parts of the world, e.g., the Arab states of the Gulf, or some parts of Africa, megaprojects are driving much of the newer infrastructure development and rehabilitation (Al-Saidi and Elagib, 2018). Similarly, quarantine regulations can lead to a combined disruption of both supply and demand. Confinement and travel restrictions can result in labor shortages in basic supply, especially in the agricultural sector and among seasonal workers. Developing countries exhibit the highest vulnerability to food insecurity as a result of the COVID-19 crisis (Udmale et al., 2020). In Africa, for example, food security is greatly threatened by the COVID-19 pandemic due to the lack of social protection and health insurance (Lawson-Lartego and Cohen, 2020). As a result, food insecurities induced by the COVID-19 pandemic can jeopardize not only human health and well-being but also key developmental goals (e.g., the Sustainable Development Goals (SDGs)) on the African continent (Ezirigwe et al., 2021; Nhamo and Ndlela, 2021). At the same time, household consumption of energy (e.g., for cooling purposes) increased in homes (e.g., around 6% to 8% in the US) (Saadat et al., 2020), thus affecting other sectors such as water (e.g., requirements for produced water or cooling water).

3.2. An inside-out look at key pandemic crosslinks

The inside-out view (cross-linking perspective) on COVID-19 and the WEF nexus seeks to highlight priority crosslinks and provide an informed focus. Such a focus is required to reduce the high complexity in terms of possible disruptions and impact directions. In order to do this, we summarized the COVID-19 disruption categories and linked them to WEF sub-nexuses (Fig. 3). From the disruptions highlighted earlier, we synthesized three main impacts (i.e., categories of disruptions oriented towards the longer term) of the COVID-19 crisis on the three basic supply sectors (Fig. 3).

Firstly, the increased medicalization and hygienization of society is mainly affecting two sub-nexuses. This category affects the food/land–water nexus through the pollution of (arable) land, and therefore water sources, as well as the energy–water nexus through increased requirements for water and energy for wastewater treatment or water production. There have been several studies highlighting the environmental interactions between COVID-19 and water use, wastewater, soil and water pollution, and energy use for wastewater treatment (Klemeš et al., 2020; Poch et al., 2020; Sivakumar, 2020; The Lancet Global Health, 2020; Zambrano-Monserrate et al., 2020). We have already pointed out some of the issues within this category of COVID-19 impacts; for example, water pollution through biomedical waste (Kalina and Tilley, 2020; Rhee, 2020; Vanapalli et al., 2021; You et al., 2020), energy requirements for wastewater treatment and monitoring (Adelodun et al., 2020; Street et al., 2020), and increased need for water for disinfection and hygiene (Chiluba et al., 2020; The Lancet Global Health, 2020). However, the long-term impacts of this impact category of medicalization and hygienization are yet to unfold, and will arguably linger for a long while. In considering these impacts, both the environmental health and human livelihoods of communities living in the impacted ecosystems should be analyzed (Nhamo and Ndlela, 2021).

Secondly, several disruptions related to mobility, sickness, quarantine and changing diets translate into (re)localizations of the production of basic supplies (Benton, 2020; Espitia et al., 2020; Pu and Zhong, 2020). In some countries, COVID-19 will result in rising demands for local food production, and national governments may choose to reinstate food-security and self-sufficiency policies (Fontan Sers and Mughal, 2020; Keulertz et al., 2020; Woertz, 2020). This impact is forcing revaluation of the crosslinks between COVID-19 and the food–water and energy–food sub-nexuses, mainly through energy and water requirements for enhanced food self-sufficiency or local food policies. In practical terms, if labor and energy should decrease for major food exporters, this may negatively impact the availability of food products on the international market (Adamchick and Perez, 2020; Cao et al., 2020; Erokhin and Gao, 2020). At the same time, a decrease in labor in the agricultural sector in importing countries – due, for instance, to travel restrictions, quarantine, and sickness – would result in increased food demand from the international market to cover the decrease in their national production (Hussein and Greco, 2020; Woertz, 2020). In the long term, responses to the COVID-19 crisis might strengthen agri-food and green innovations using local or regional partnerships (e.g., the European Green Deal initiative with the new EU Farm to Fork Strategy) (Rowan and Galanakis, 2020). They also revalue the role of food science in improving local food systems and enhancing food-related entitlements and transfers (Devereux et al., 2020), particularly in the context of humanitarian food aid policies in vulnerable regions such as the African Sahel (Bounie et al., 2020). For this, resilient food-supply chains are important and they should be dealt with comprehensively by including equity considerations at the levels of individuals, households, and communities (Gillespie, 2020). Furthermore, for Small Island Developing States, enhancing local food security has become an even bigger priority in view of the triple burden of climate change, COVID-19, and malnutrition (Hickey and Unwin, 2020).

Thirdly and finally, some COVID-19-related disruptions will result in short-term fluctuations in demand or capacity to produce water or energy resources. However, these might be relatively uncertain and site-

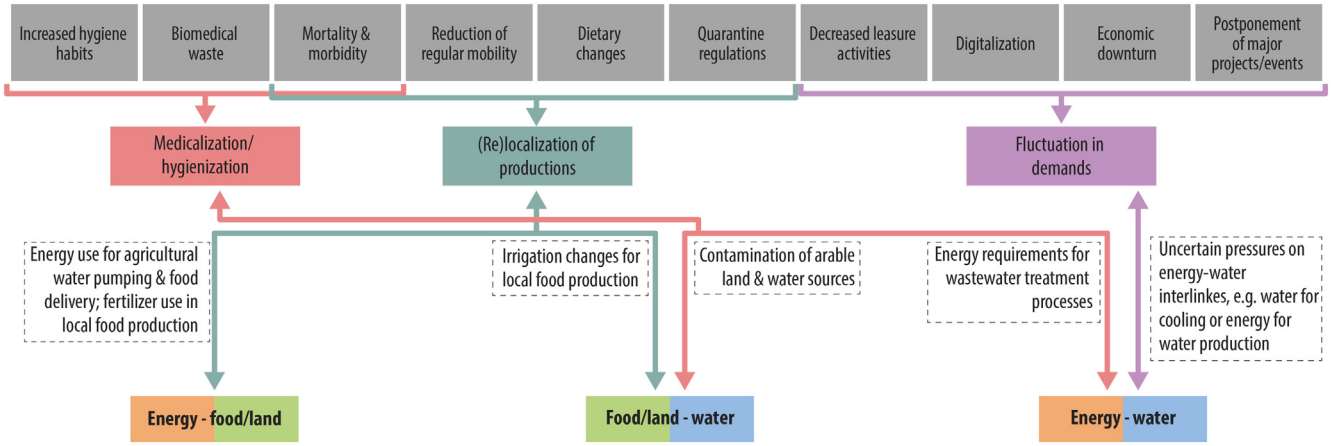


Fig. 3. Crosslinks between COVID-19 and WEF subsectors.

specific. For example, stay-at-home COVID-19 strategies increase the demand for cooling in some regions (and heating in others), resulting in higher electricity and water demands (Hospers et al., 2020). While the energy demands (and electricity bills) might increase, the consumption load profile can fluctuate, and the willingness to conserve energy or invest in energy management systems can increase (Chen et al., 2020). These COVID-19-related changes might compensate each other, e.g., increased electricity use at home and decreased energy use elsewhere. In fact, the type of COVID-19 containment measures influences the overall consumption profile (Bahmanyar et al., 2020). Due to this instability of insights, there is so far little knowledge on COVID-19-related changes in water use for electricity supply. Similarly, disruptions due to COVID-19 can lead to short-term fluctuations in industrial and household demand for water, thus affecting the required energy input. Generally, these fluctuations are expected to be less stable than those related to the other two impact categories of local food policies and COVID-19 prevention and treatment.

3.3. Assimilating initial impacts on resource securities: the Middle East as a case study

In this section, we highlight some sectoral or management-level perspectives on COVID-19 impacts focusing on resource-supply security and day-to-day challenges as well as actions in the water, energy and food sectors. These sectoral practices and impacts (Fig. 4) provide further details and country-level examples of the earlier-explained disruptions, impact categories and priority crosslinks.

In the water sector, the main direct impacts of the pandemic are the increased use of water and the resultant contamination, and some of the effects are translated through source-water contamination (land for water) and increased energy use for wastewater treatment and water supply. A recent study by Gerard (2020) analyzed the impacts of the pandemic on water uses in Jordan and found that COVID-19 is indeed impacting current domestic water-use patterns by increasing demand by 40% and forcing residents to embrace a water conservation mindset. This was generally seen as being due to hygiene requirements related to the pandemic, increased water use due to being at home rather than at school or work, and some newly adopted household activities, such as gardening. Nevertheless, interviewees also emphasized that while in lockdown, they were more inclined to conserve water as a result of the pandemic. This shows that in Jordan, the second most water-scarce country worldwide, the issue was the increased demand for water at the domestic level, which resulted in increased energy use for wastewater treatment. Jordan has been receiving international support throughout this pandemic to ensure water security for its population. For instance, the German cooperation effort has been working closely with the water utilities to identify additional water sources and aquifers in order to meet the increased water demand (MENAFN, 2020).

As regards *the food sector*, in Jordan the government took measures in March and April of 2020 to ensure food security, maintaining the food supply chain and facilitating it through digitalization of payment transfers and movement licenses (Fathallah, 2020). However, the initial challenges due to the curfew were barriers to the farmers in accessing their land, and ensuring continuity of labor on the land. A recent study on Jordan (Gerard, 2020) that focused on the first months of the pandemic found that in the short term, the lockdown meant that countries such as Jordan that are heavily reliant on food imports, saw the border closures in neighboring countries and in the rest of the world as a challenge for the import and export of food products. In fact, Jordan has taken measures to restrict food exports, a measure to enhance local food security in the face of the COVID-19 pandemic (Nsour, 2020). Exporting the locally produced crops was difficult and led to a crisis in which farmers were attempting to sell their excess crops for extremely low prices. The pandemic pushed farmers and practitioners in Jordan to reflect on the possibility of switching to less water-intensive crops: "Hopefully, if COVID impacts longer into the next growing season, they will think about it" (ibid.). According to Gerard (2020), the pandemic is impacting the agricultural sector primarily through the disruption of exports. Because COVID-19 is disrupting the food supply chain, it has the potential to change future agricultural water use by decreasing the amount of crops grown by farmers. However, it is unclear whether COVID-19 is changing agricultural water use at the present time. Because most farmers had already grown most of their yearly crops by the time of the pandemic, COVID-19 has likely had little effect on agricultural water use up until this point. Assuming the effects of the pandemic last at least until the upcoming planting season, however, it seems likely that COVID-19 will influence agricultural water use, either through decreases in planting or through crop switching. According to Nsour (2020), though, "Nevertheless, overall, the Jordanian case

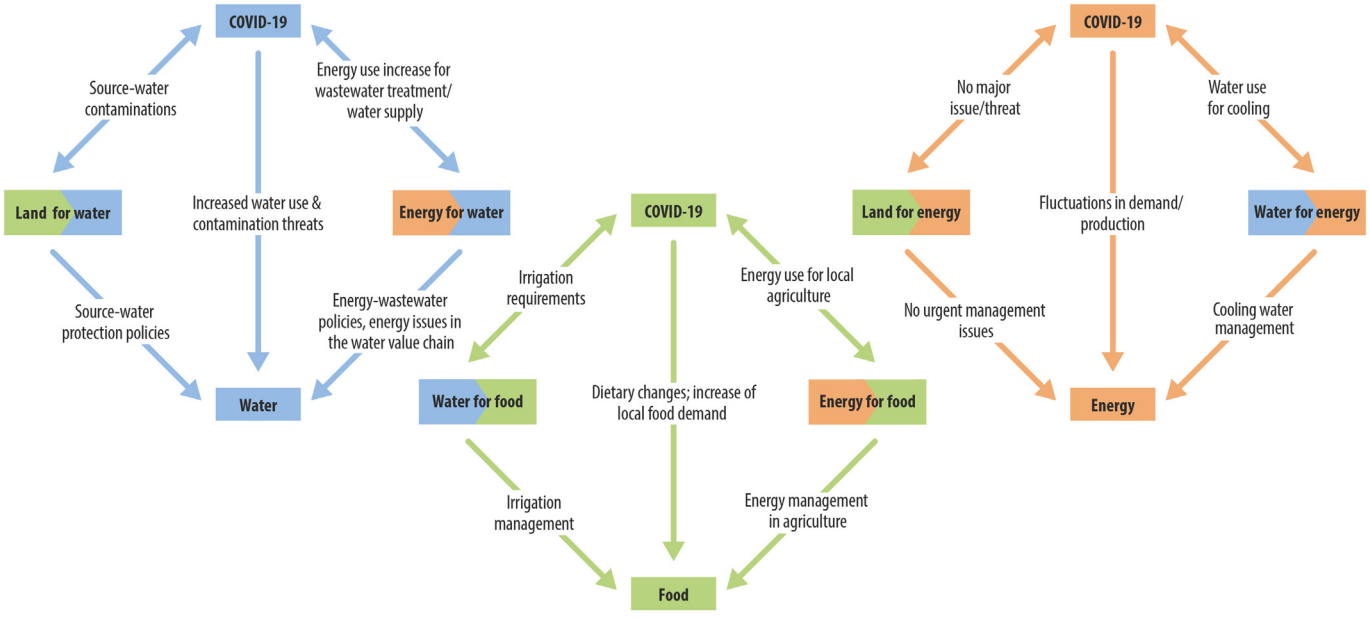


Fig. 4. Overview of some sector-level interactions and impacts of COVID-19.

shows how managers and policies contributed to maintaining internal trade and food trade, and access to it" (ibid.). Moreover, the pandemic also impacted the Jordanian food sector by pushing farmers to increase self-production, which, in turn, increased the demand for manpower and water resources.

In the case of Lebanon, the pandemic has worsened food security, building on an ongoing economic and financial crisis. In fact, since autumn 2019, Lebanon has been facing the largest economic and financial fallout in history, worsened by the COVID-19 outbreak. COVID-19 forced lockdowns in April, May, and August of 2020, which severely exacerbated the economic and financial crisis, and consequently, the food security status reached an alarming level. International media, including the Telegraph, and the Guardian (Cheeseman, 2020; Chulov and Zavallis, 2020), highlighted in June 2020 that Lebanon was experiencing a food crisis, that "People will die within months," and that "The Lebanese are at risk of famine." These alarms regarding a heightened state of food insecurity have been expressed for other developing countries (Erokhin and Gao, 2020; Lawson-Lartego and Cohen, 2020), but Lebanon has proven particularly vulnerable due to the underlying economic problems. In Lebanon, people living in poverty are no longer able to buy all their needs, as prices of commodities and foodstuffs, even fruits and vegetables, increased by 58.43% since September 2019 when the tumbling of the Lebanese pound, pegged to the US dollar, initiated chaos. A recent report carried out by the World Food Program (2020) in June 2020, assessing the impact of the economic and COVID-19 crises in Lebanon, showed that the price of the Survival Minimum Expenditure Basket (SMEB) has been steadily increasing over time with cumulative inflation of 109% compared to the prices in September 2019. Amid this economic crisis, further exacerbated by the pandemic, in August 2020 – following the massive explosion at Beirut port – some of the grain reserves of the country were destroyed, and the naval food trade interrupted, pushing Lebanon further towards a food crisis. In this context, Lebanon is experiencing a food crisis in terms of affordability of food, as extensive segments of society who are living in poverty are not able to access food. Rural communities are therefore increasing the self-production of agricultural goods, and in turn increasing the demand for water resources. Moreover, recent research also confirms that the situation is particularly challenging in the Syrian refugee camps in Lebanon, where the quality of water was already an issue (Kassem and Jaafar, 2020). In this context,

> It is evident that sufficient access to clean water and sustainable treatment of wastewater are critical for the health of the refugees and the hosting communities, especially during the unfolding COVID-19 pandemic. Failure to address these issues promptly might lead to severe disease and outbreaks in these populations.
>
> [(Kassem and Jaafar, 2020)]

A recent study on Jordan by Elsahoryi et al. (2020) suggests that the pandemic and the quarantine and other measures taken in response had an impact on food security. They recommend identifying appropriate strategies in order to support individuals at higher risk, including factors such as "the number of persons in the family, younger adults (18–30 years old), and those who do not own their houses" (Elsahoryi et al., 2020). Woertz (2020) highlights that especially in the GCC, it is necessary to ensure accessibility to food for the most vulnerable and marginalized members of the society (such as migrant labor) and considers also introducing policy measures for their support, such as a potentially "politically controversial" safety net.

As noted by Ma et al. (2021), food security is also strongly affected in fragile states and those facing conflicts and political instability. They confirm that Yemen, Sudan and Syria are among the most vulnerable states when it comes to food security. The pandemic is, in fact, further exacerbating an already vulnerable situation:

> Prior to the pandemic, over 80% of Yemen's population are dependent on food aid and facing acute food insecurity. In Syria, 9.3 million people are food insecure due to record-high food price inflation. Sudan currently facing strict curfew while the food price inflated to 82% in April compared to the previous month.
>
> [(Plecher cited in Ma et al., 2021)]

Sen (2020) notes that the impacts of the pandemic are also very visible in countries already facing political or economic embargos, blockades, and restrictions, such as in the case of Gaza. Smith and Wesselbaum (2020) point out that COVID-19-related food insecurity can act as a multiplier of the pandemic's impacts on health and human well-being, and as a result, it can also lead to increased rural–urban and international migrations.

In the energy sector, the immediate impacts of the COVID-19 pandemic are reflected in fluctuating energy demands. Overall, the lockdowns and commercial restrictions seem to have lowered the overall demand for primary energy and electricity (Bahmanyar et al., 2020; Sovacool et al., 2020), although such reductions seem not to apply to the residential sectors. In New York during the lockdowns, for example, most households surveyed reported increased electricity usage and no morning or evening peaks during weekdays, with the lockdowns seeming to make weekday consumption curves similar to pre-COVID-19 weekend curves (Chen et al., 2020). Such a change in the electricity consumption profile indicates the revaluation of the water–energy link for management of the energy sector. This is more evident with regard to water requirements for cooling, particularly in hot and arid regions such as the GCC region. In Kuwait, for example, during the COVID-19-related lockdowns in 2020, there were noticeable reductions in energy consumption in governmental, industrial and commercial sectors, but an increase in power consumption and peak load in the residential sector (although less than the decreased load in other sectors), which accounted for over 80% of power consumption during the lockdown (Alhajeri et al., 2020). In the context of the hot and dry (and thus water-scarce) region of the Gulf Cooperation Council (GCC), most electricity consumption is used for space-cooling (up to 50% of total and 70% of peak electricity consumption in the GCC) (Eveloy and Ayou, 2019). This comes with a water footprint depending on the type of cooling system used (e.g., water usage in water-cooled chillers for large buildings or in district cooling for whole neighborhoods). The energy issue is especially important for GCC countries in terms of meeting the high domestic energy demands, but it should also be contextualized within the global fluctuations in oil prices that also impacted the GCC oil-producing countries (Jaffe, 2020). In response to this, GCC governments have in the past adopted measures to mitigate production fluctuations and ensure energy security in general. They have invested in the use of energy-efficient (and thus more climate-friendly) cooling technologies such as district cooling, which has 18–55% lower energy consumption, and 20–30% lower life-cycle cost than current cooling alternatives (Alajmi and Zedan, 2020). District cooling in the GCC region is mostly used for residential areas, the water source for which can theoretically stem from freshwater, desalinated water or treated wastewater (Alajmi and Zedan, 2020; Eveloy and Ayou, 2019). However, the supply of water is the main concern for district cooling companies in the region (10% of the plants' operational costs), and has been largely covered through desalinated water due to past concerns of these companies regarding corrosion and fouling associated with the use of seawater or treated wastewater (Rajan, 2009). In this context, managing any fluctuations in energy and cooling demands in the context of the COVID-19 crisis is linked to several water-related concerns.

4. Discussion and the way forward

The current COVID-19 crisis is argued to be representative of the notion of modern risks associated with global change (e.g., in the climate or the earth's biodiversity) and increased integration between economies (i.e., globalization and increased mobility) in an era shaped by human alterations (the Anthropocene) (Manzanedo and Manning,

2020; McNamara and Newman, 2020; Norouzi et al., 2020; O'Callaghan-Gordo and Antó, 2020). It is also revealing of the limits and interdependence of today's environmental policy-making related to natural resource management and supply security. In this context, in this section, we discuss the short- and long-term implications of COVID-19 for management responses in the WEF sectors, and draw lessons for the nexus paradigm. Firstly, with regard to *short-term implications*, the COVID-19 crisis has translated itself broadly into immediate disruptions and persistent fluctuations in demands. We highlighted the nature and interrelations of these impacts, while the management responses are still underway. These responses can be characterized as coping mechanisms that vary from one case to another and that can result in trade-offs with long-term policy objectives; e.g., ad hoc or unplanned responses can affect the long-term, planned development or the resilience of a certain sector. More developed countries (particularly those prone to disasters or disruptions) might be economically more resilient and have better anticipation and adaptation strategies in place, while the picture is more heterogeneous in developing ones. In Australia, for example, disruptions in the water systems are not new due to recurrent extreme events (e.g., drought or fires), and thus knowledge, monitoring systems, danger signals, and regulations already exist to some extent (Daniell, 2020). In the energy sector, short-term fluctuations seem to be well handled, arguably due to the overall energy-decreasing effect of COVID-19, for example, in India where no noticeable power interruptions were observed (Madurai Elavarasan et al., 2020). As noted earlier, the food-related disruptions have been significant in some developing countries, while the efficacy of responses often depends on the quality of ad hoc decisions and international aid (Bounie et al., 2020; Lewin, 2020). Importantly, the ability to deal with sectoral supply disruptions is a function of the overall management of the COVID-19 health crisis, as well as the level of success in managing the associated panic, installing trust, and improving the quality of communication and information (Mocatta and Hawley, 2020).

In the long term, the COVID-19 crisis is expected to lead to revaluation of some issues and links in the WEF nexus. From our previous analysis, the water–food–trade sub-nexus seems to stand out. National food-security priorities might be revisited in light of the debates reignited by the current crisis regarding self-sufficiency, trade risks, resilient value chains and production relocations. Here, negative long-term impacts on national water and energy footprints are not necessarily pre-programmed. Several options have been put forward for enhancing local and sustainable (i.e., low-carbon and water-efficient) food production in a post-COVID-19 world; e.g., using smart agriculture, traditional irrigation, or integrated greenhouses (Awjah Almehmadi et al., 2020; Chazarra-Zapata et al., 2020). It is important also to incorporate food-security approaches linking human health and well-being to environment health (Nhamo and Ndlela, 2021), and to reflect the important issues of equity, food access for vulnerable groups, and fair food prices (Clapp and Moseley, 2020; Gillespie, 2020; O'Hara and Toussaint, 2021). These suggestions on the way forward go hand in hand with long-term recommendations for the energy sectors to accelerate the energy transition in a holistic way (including commercial availability, planning institutions, and public participation) (Vanegas Cantarero, 2020), and to advance renewables on different regional scales (i.e., also for rural areas or residential uses) (D'Adamo et al., 2020; Madurai Elavarasan et al., 2020). Such recommendations are in line with the current debate about the "green recovery" from COVID-19; e.g., pro-environment fiscal stimulus, comprehensive sustainability spending (Green New Deal), and support for green investments (Mukanjari and Sterner, 2020; Rosenbloom and Markard, 2020; Sovacool et al., 2020).

Finally, there are some implications of the COVID-19 crisis related to the merits and current limits of the integrative approach of the WEF nexus. In this paper, the analysis of impacts, responses and new debates reiterates the importance of integrated perspectives and the notion of change in analyzing the three resources. Such a change, which drives integration within the nexus, has been attributed to endogenous (e.g., socio-economic change in infrastructure, policies or lifestyles) or exogenous (e.g., climate, technological and market-related changes) factors (Abulibdeh et al., 2019). This core focus of the WEF nexus on change, integration and securities has been enriched by debates on the importance of sustainable livelihoods and environmental considerations (Biggs et al., 2015; Hellegers et al., 2008).

The COVID-19 pandemic particularly highlights two gaps in the current debates. Firstly, the impact of pandemics on resource integration has not featured highly in previous WEF nexus debates, but the expected impacts (e.g., disruptions, or revaluation of food-security links to water and trade) might not necessarily result in new interlinkages. Moreover, COVID-19's impacts are reminders of the broader point with regard to redefining the security debate within the WEF nexus. So far, the bulk of resource-security debates have focused on aspects related to stability (regulating the integrated resource-supply systems through policies, rights or incentives) and reliability (improving performance, efficiency, or coverage) (Al-Saidi and Saliba, 2019). COVID-19 highlights the need for security assessments and risk perspectives focusing on the highly integrated resource-supply systems, such as issues related to risk management, resilience assessments, or storage and contingencies. The resilience perspective is a highly demanded but rather underrepresented theme within the WEF nexus debates (Al-Saidi and Saliba, 2019; Hogeboom et al., 2021). Secondly, spatial aspects need to be reexamined and better analyzed in the WEF nexus. This includes a deeper consideration of cross-regional interdependences or trade issues, globalization, relocations of production, or international collaboration (e.g., for aid or short-term supply compensation).

In summary, we highlight the following points regarding the way forward for integrating insights from the COVID-19 crisis into the current research and debates within the WEF nexus:

- Security-based assessments within the WEF nexus should better incorporate risk- and shock-related aspects, while the focus should not only be on the nature of short-term disruptions. The post-pandemic research can capitalize on long-term lessons learnt in order to re-examine the issues of resource security and integration within the WEF nexus. Related to this, resilience-enhancing strategies that consider integration among the WEF sectors are essential, and they should be prepared in advance in order to avoid ad hoc or suboptimal reactions to sudden shocks.
- During the COVID-19 pandemic, food security has emerged as the primer for understanding resilience and vulnerability within the WEF nexus. Particularly in developing countries, it is important that food-related aspects are addressed within the nexus. They can be approached through a re-thinking and re-optimizing of the use of resources (land, water, and energy) towards more sustainable (i.e., a green agri-food industry) local food production.
- COVID-19 has highlighted the temporal aspects of resource-supply security within the WEF nexus since negative impacts on the food, water and energy sectors are transmitted at different speeds. While it can be possible to provide short-term and local alternatives to water and energy supplies, food-supply shortages are immediately felt and difficult to compensate for. Water- and energy-related disruptions can also be unstable or temporary, or, if sustained in the long term, lead to exacerbated food crises. Here, it is important to address the temporality of the WEF nexus interlinkages in a way that can enhance resource supply security; e.g., through a better understanding of contingency planning or the nature of adaptations within the nexus.
- Cross-boundary spatial aspects have been pushed to the forefront by the COVID-19 pandemic, although they have not featured highly within the traditional WEF nexus debates on integration and security. Future WEF nexus analyses should relate more to international aspects highlighted by global shocks; e.g., food–water and trade (aspects of optimal integration, dependence, and responsibility) as well as food–energy–health and international cooperation (e.g. state-based

cooperation/geopolitics, international aid, access, or justice).
- Beyond the immediate environmental impacts of health-related crises, the COVID-19 crisis has spawned new, cross-sectoral issues. For example, the medicalization and digitalization of societies as well as the relocation of production might be sustained for some time to come, thus leading to profound impacts on the use and integration of water, energy and land resources. These emerging or accelerating issues need to be monitored and probably integrated within future WEF nexus debates.

5. Conclusions

So far, research related to COVID-19's environmental impacts has focused on describing individual disruptions, analyzing short-term drawbacks and benefits, and stating long-term perspectives for the sustainability agenda. However, this pandemic represents a unique and systematic stress test that goes beyond single natural-resources sectors and requires analysis beyond immediate or temporary symptoms. It is, therefore, important to provide a systematization of impact, current responses and long-term perspectives of COVID-19 with regard to the three increasingly interlinked sectors of water, energy and food. The cross-cutting ramifications of the pandemic provide an additional layer of complexity and urgency in studying integration within the WEF nexus, and the potential consequences on our understanding of environmental or resource-supply security. This paper carries out this systematic analysis in three steps: i) a global or "bird's eye" view of disruptions, ii) an "inside-out view" of preeminent linkages and priorities, and iii) a "managerial view" of country-level responses in assimilating COVID-19 cross-sectoral impacts. In the broad or global picture, we highlighted how supply and demand disruptions associated with COVID-19 can result in multidirectional effects that can last for years to come. Some of these disruptions (e.g., decreased leisure activities, restrictions on mobility, economic downturn, and postponement of activities) cut across the WEF sectors, while many of the predicted production and demand fluctuations might be unstable and dependent on the localized nature of disruptions.

On the priority crosslinks, we synthesized three main impact categories of COVID-19 and discussed the priorities and cross-sectoral issues. Firstly, the increased medicalization and hygienization are associated with increased requirements for wastewater treatment (hence more energy use) and the protection of water sources and arable land from pollution and contamination. Secondly, the (re)localization of production seems to increase tendencies for local food production, thus increasing pressure on water for irrigation and energy use in local agriculture. Thirdly, fluctuations in demand can bring uncertain pressures on the water–energy interlinks; e.g., water for cooling requirements, or energy for water production. Regarding the managerial responses, we highlighted several sectoral experiences from case studies, particularly from the Middle East, showing largely overwhelmed institutions and ad hoc reactions, particularly with regard to food-security impacts. These sectoral responses also confirm the identified trends such as the localization of food production, increased pressures on water resources, and fluctuations in energy demands.

Finally, the COVID-19 crisis offers an opportunity for reflection on management responses across the WEF nexus sectors. In the short term, these responses seem to be variable and largely dependent on the overall quality of pandemic management, but also on the existing local capacities in the WEF nexus to withstand the COVID-19 storm. With regard to resource-supply security, the developed and disaster-prone countries might be well prepared, whereas developing countries' experiences are heterogeneous, with factors such as trade dependences, aid flow, and adequate communication proving important. In the long term, the COVID-19 crisis forces revaluation of the water–food–trade nexus as it revives debates about self-sufficiency, supply security, and local food production. These debates should also be linked to broader issues of livelihoods, environmental protection and sustainable development as overarching objectives. Here, incorporating green or sustainable resource-production systems can help in minimizing trade-offs of production relocations; e.g., sustainable agriculture, use of renewables, recycling, and smart and efficient systems. At the same time, this crisis reveals some gaps in previous integration and security debates within the WEF nexus. These gaps relate to the need for a more risk-based perspective on integration and resource security as well as better incorporation of spatial aspects (beyond the local) in analyzing interdependences and linkages among the vital resources of water, energy and food.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.146529.

CRediT authorship contribution statement

Mohammad Al-Saidi: Conceptualization, Investigation, Formal analysis, Validation, Writing – original draft, Writing – review & editing. **Hussam Hussein:** Investigation, Formal analysis, Validation, Writing – original draft, 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.

References

Abdulah, D.M., Hassan, A.B., 2020. Relation of dietary factors with infection and mortality rates of COVID-19 across the world. J. Nutr. Health Aging https://doi.org/10.1007/s12603-020-1434-0.

Abulibdeh, A., Zaidan, E., Al-Saidi, M., 2019. Development drivers of the water-energy-food nexus in the Gulf Cooperation Council region. Dev. Pract. 29 (5), 582–593.

Adamchick, J., Perez, A.M., 2020. Choosing awareness over fear: risk analysis and free trade support global food security. Global Food Security 26, 100445. https://www.sciencedirect.com/science/article/pii/S2211912420300997.

Adelodun, B., Ajibade, F.O., Ibrahim, R.G., Bakare, H.O., Choi, K.-S., 2020. Snowballing transmission of COVID-19 (SARS-CoV-2) through wastewater: any sustainable preventive measures to curtail the scourge in low-income countries? Sci. Total Environ. 742, 140680. http://www.sciencedirect.com/science/article/pii/S0048969720342029.

Alajmi, A., Zedan, M., 2020. Energy, cost, and environmental analysis of individuals and district cooling systems for a new residential city. Sustain. Cities Soc. 54, 101976. http://www.sciencedirect.com/science/article/pii/S2210670719314040.

Aldaco, R., Hoehn, D., Laso, J., Margallo, M., Ruiz-Salmón, J., Cristobal, J., et al., 2020. Food waste management during the COVID-19 outbreak: a holistic climate, economic and nutritional approach. Sci. Total Environ. 742, 140524. http://www.sciencedirect.com/science/article/pii/S0048969720340468.

Alhajeri, H.M., Almutairi, A., Alenezi, A., Alshammari, F., 2020. Energy demand in the state of Kuwait during the Covid-19 pandemic: technical, economic, and environmental perspectives. Energies 13, 4370. https://doi.org/10.3390/en13174370.

Al-Saidi, M., Elagib, N.A., 2017. Towards understanding the integrative approach of the water, energy and food nexus. Sci. Total Environ. 574, 1131–1139. http://www.sciencedirect.com/science/article/pii/S0048969716319581.

Al-Saidi, M., Elagib, N.A., 2018. Ecological modernization and responses for a low-carbon future in the Gulf Cooperation Council countries. WIREs Clim Change 9 (4), e528.

Al-Saidi, M., Saliba, S., 2019. Water, energy and food supply security in the Gulf Cooperation Council (GCC) countries—a risk perspective. Water 11 (3), 455.

Amegah, A.K., 2020. Improving handwashing habits and household air quality in Africa after COVID-19. Lancet Glob. Health 8 (9), e1110–e1111. http://www.sciencedirect.com/science/article/pii/S2214109X20303533.

Anim, D.O., Ofori-Asenso, R., 2020. Water scarcity and COVID-19 in sub-Saharan Africa. J. Infect. 81 (2), e108–e109. http://www.sciencedirect.com/science/article/pii/S0163445320303121.

Awjah Almehmadi, F., Hallinan, K.P., Mulford, R.B., Alqaed, S.A., 2020. Technology to address food deserts: low energy corner store groceries with integrated agriculture greenhouse. Sustainability 12 (18), 7565.

Bahmanyar, A., Estebsari, A., Ernst, D., 2020. The impact of different COVID-19 containment measures on electricity consumption in Europe. Energy Res. Soc. Sci. 68, 101683. http://www.sciencedirect.com/science/article/pii/S2214629620302589.

Barbier, E.B., Burgess, J.C., 2020. Sustainability and development after COVID-19. World Dev. 135, 105082. http://www.sciencedirect.com/science/article/pii/S0305750X20302084.

Batlle-Bayer, L., Aldaco, R., Bala, A., Puig, R., Laso, J., Margallo, M., et al., 2020. Environmental and nutritional impacts of dietary changes in Spain during the COVID-19 lockdown. Sci. Total Environ. 748, 141410. http://www.sciencedirect.com/science/article/pii/S0048969720349391.

Benton, T.G., 2020. COVID-19 and disruptions to food systems. Agric. Hum. Values 37 (3), 577–578. https://doi.org/10.1007/s10460-020-10081-1.

Biggs, E.M., Bruce, E., Boruff, B., Duncan, J.M.A., Horsley, J., Pauli, N., et al., 2015. Sustainable development and the water–energy–food nexus: a perspective on livelihoods.

Environ. Sci. Pol. 54, 389–397. https://www.sciencedirect.com/science/article/pii/S1462901115300563.
Bochtis, D., Benos, L., Lampridi, M., Marinoudi, V., Pearson, S., Sørensen, C.G., 2020. Agricultural workforce crisis in light of the COVID-19 pandemic. Sustainability 12(19).
Bounie, D., Arcot, J., Cole, M., Egal, F., Juliano, P., Mejia, C., et al., 2020. The role of food science and technology in humanitarian response. Trends Food Sci. Technol. 103, 367–375. http://www.sciencedirect.com/science/article/pii/S0924224420305070.
Cao, L., Li, T., Wang, R., Zhu, J., 2020. Impact of COVID-19 on China's agricultural trade. China Agricultural Economic Review 13 (1), 1–21. https://EconPapers.repec.org/RePEc:eme:caerpp:caer-05-2020-0079.
Chazarra-Zapata, J., Parras-Burgos, D., Arteaga, C., Ruiz-Canales, A., Molina-Martínez, J.M., 2020. Adaptation of a traditional irrigation system of micro-plots to smart agri development: a case study in Murcia (Spain). Agronomy 10 (9), 1365.
Cheeseman, A., 2020. 'People Will Die within Months': Lebanon Heads for Famine as Pandemic Accelerates Hunger. The Telegraph https://www.telegraph.co.uk/global-health/science-and-disease/people-will-die-within-months-lebanon-heads-famine-pandemic/. (Accessed 24 October 2020) (Jun 30).
Chen, C.-f., Zarazua de Rubens, G., Xu, X., Li, J., 2020. Coronavirus comes home? Energy use, home energy management, and the social-psychological factors of COVID-19. Energy Res. Soc. Sci. 68, 101688. http://www.sciencedirect.com/science/article/pii/S2214629620302632.
Cheval, S., Mihai Adamescu, C., Georgiadis, T., Herrnegger, M., Piticar, A., Legates, D.R., 2020. Observed and potential impacts of the COVID-19 pandemic on the environment. Int. J. Environ. Res. Public Health 17(11).
Chiluba, B., Chitangala, F., Dube, G., 2020. Will the current coronavirus disease 2019 affect progress in the attainment of sustainable development goals in Africa? Biomedical and Biotechnology Research Journal 4 (5), 60–64. https://www.bmbtrj.org/article.asp?issn=2588-9834;year=2020;volume=4;issue=5;spage=60;epage=64;aulast=Chiluba.
Chulov, M., Zavallis, A., 2020. 'I Can See the Despair on their Faces': Lebanon's Economy Unravels. The Guardian https://www.theguardian.com/world/2020/jul/30/i-can-see-the-despair-on-their-faces-lebanons-economy-unravels. (Accessed 24 October 2020) (Jul 30).
Clapp, J., Moseley, W.G., 2020. This food crisis is different: COVID-19 and the fragility of the neoliberal food security order. J. Peasant Stud. 47 (7), 1393–1417.
Cohen, M.J., 2020. Does the COVID-19 outbreak mark the onset of a sustainable consumption transition? Sustainability: Science, Practice and Policy 16 (1), 1–3.
D'Adamo, I., Gastaldi, M., Morone, P., 2020. The post COVID-19 green recovery in practice: assessing the profitability of a policy proposal on residential photovoltaic plants. Energy Policy 147, 111910. http://www.sciencedirect.com/science/article/pii/S0301421520306212.
Daniell, K.A., 2020. Water systems and disruptions: the 'old abnormal'? Australasian Journal of Water Resources 24 (1), 1–8.
Das, O., Neisiany, R.E., Capezza, A.J., Hedenqvist, M.S., Försth, M., Xu, Q., et al., 2020. The need for fully bio-based facemasks to counter coronavirus outbreaks: a perspective. Sci. Total Environ. 736, 139611. http://www.sciencedirect.com/science/article/pii/S0048969720331314.
del Rio-Chanona, R.M., Mealy, P., Pichler, A., Lafond, F., Farmer, J.D., 2020. Supply and demand shocks in the COVID-19 pandemic: an industry and occupation perspective. Oxf. Rev. Econ. Policy 36 (Supplement_1), 94–137.
Deslatte, A., Hatch, M.E., Stokan, E., 2020. How can local governments address pandemic inequities? Public Adm. Rev. n/a (n/a).
Devereux, S., Béné, C., Hoddinott, J., 2020. Conceptualising COVID-19's impacts on household food security. Food Security 12 (4), 769–772. https://doi.org/10.1007/s12571-020-01085-0.
Durodola, O.S., Nabunya, V., Kironde, M.S., Nevo, C.M., Bwambale, J., 2020. COVID-19 and the water–energy–food nexus in Africa: evidence from Nigeria, Uganda, and Tanzania. World Water Policy 6 (2), 176–201.
Elsahoryi, N., Al-Sayyed, H., Odeh, M., McGrattan, A., Hammad, F., 2020. Effect of Covid-19 on food security: a cross-sectional survey. Clinical Nutrition ESPEN 40, 171–178. https://www.sciencedirect.com/science/article/pii/S2405457720302138.
Erokhin, V., Gao, T., 2020. Impacts of COVID-19 on trade and economic aspects of food security: evidence from 45 developing countries. Int. J. Environ. Res. Public Health 17 (16).
Espitia, A., Rocha, N., Ruta, M., 2020. Covid-19 and Food protectionism: the impact of the pandemic and export restrictions on world food markets: world bank. Policy Research Working Paper 9253.
Eufemia, L., Hussein, H., 2020. How did the COVID-19 crisis relate to meeting global climate targets for 2020? FOFJ 1 (1). https://www.thefutureoffoodjournal.com/index.php/FOFJ/article/view/367.
Eveloy, V., Ayou, D.S., 2019. Sustainable district cooling systems: status, challenges, and future opportunities, with emphasis on cooling-dominated regions. Energies 12, 235. https://doi.org/10.3390/en12020235.
Ezirigwe, J., Ojike, C., Amechi, E., Adewopo, A., 2021. 'COVID-19/food insecurity syndemic': navigating the realities of food security imperatives of sustainable development goals in Africa. Law and Development Review 14 (1), 129–162.
Fadare, O.O., Okoffo, E.D., 2020. Covid-19 face masks: a potential source of microplastic fibers in the environment. Sci. Total Environ. 737, 140279. http://www.sciencedirect.com/science/article/pii/S0048969720338006.
Fathallah, H., 2020. How Jordan Managed Food Security Risks During the First COVID-19 Wave. IFPRI, Cairo, Egypt.
Fontan Sers, C., Mughal, M., 2020. Covid-19 outbreak and the need for rice self-sufficiency in West Africa. World Dev. 135, 105071. http://www.sciencedirect.com/science/article/pii/S0305750X20301972.
Gerard, W., 2020. COVID-19 as a Catalyst of Change in the Jordanian Water Sector. (Oxford, UK).
Gillespie, S., 2020. Epidemics and food systems: what gets framed, gets done. Food Security 12 (4), 895–898. https://doi.org/10.1007/s12571-020-01072-5.
Górnicka, M., Drywień, M.E., Zielinska, M.A., Hamułka, J., 2020. Dietary and lifestyle changes during COVID-19 and the subsequent lockdowns among Polish adults: a cross-sectional online survey PLifeCOVID-19 study. Nutrients 12(8).
Hellegers, P., Zilberman, D., Steduto, P., McCornick, P., 2008. Interactions between water, energy, food and environment: evolving perspectives and policy issues. Water Policy 10 (S1), 1–10.
Helm, D., 2020. The environmental impacts of the coronavirus. Environ. Resour. Econ. 76 (1), 21–38. https://doi.org/10.1007/s10640-020-00426-z.
Hickey, G.M., Unwin, N., 2020. Addressing the triple burden of malnutrition in the time of COVID-19 and climate change in Small Island Developing States: what role for improved local food production? Food Security 12 (4), 831–835. https://doi.org/10.1007/s12571-020-01066-3.
Hoff, H., 2011. Understanding the Nexus: Background Paper for the Bonn 2011 Nexus Conference: Stockholm Environment Institute.
Hogeboom, R.J., Borsje, B.W., Deribe, M.M., Van Der Meer, Freek D., Mehvar, S.S., Meyer, M.A., et al., 2021. Resilience meets the water-energy-food nexus: mapping the research landscape. Front. Environ. Sci. 9, 630395. https://doi.org/10.3389/fenvs.2021.630395.
Hospers, L., Smallcombe, J.W., Morris, N.B., Capon, A., Jay, O., 2020. Electric fans: a potential stay-at-home cooling strategy during the COVID-19 pandemic this summer? Sci. Total Environ. 747, 141180. http://www.sciencedirect.com/science/article/pii/S0048969720347094.
Hussein, H., Greco, F., 2020. How will the COVID-19 pandemic impact food security and virtual water "trade"? FOFJ 1 (1). https://www.thefutureoffoodjournal.com/index.php/FOFJ/article/view/346.
Ilyas, S., Srivastava, R.R., Kim, H., 2020. Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management. Sci. Total Environ. 749, 141652. http://www.sciencedirect.com/science/article/pii/S0048969720351810.
Inegbedion, H.E., 2020. COVID-19 lockdown: implication for food security. Journal of Agribusiness in Developing and Emerging Economies https://doi.org/10.1108/JADEE-06-2020-0130.
Jaffe, A.M., 2020. Geopolitics and the oil price cycle - an introduction. EEEP 9 (2).
Kalina, M., Tilley, E., 2020. "This is our next problem": cleaning up from the COVID-19 response. Waste Manag. 108, 202–205. http://www.sciencedirect.com/science/article/pii/S0956053X20302324.
Kassem, I.I., Jaafar, H., 2020. The potential impact of water quality on the spread and control of COVID-19 in Syrian refugee camps in Lebanon. Water Int. 45 (5), 423–429.
Keulertz, M., Mulligan, M., Allan, J.A., 2020. The impact of COVID-19 on water and food systems: flattening the much bigger curve ahead. Water Int. 45 (5), 430–434.
Klemeš, J.J., van Fan, Y., Jiang, P., 2020. The energy and environmental footprints of COVID-19 fighting measures – PPE, disinfection, supply chains. Energy 211, 118701. http://www.sciencedirect.com/science/article/pii/S0360544220318090.
Laborde, D., Martin, W., Swinnen, J., Vos, R., 2020. COVID-19 risks to global food security. Science (New York, N.Y.) 369 (6503), 500.
The Lancet Global Health, 2020. Water and sanitation in a post-COVID world. Lancet Glob. Health 8 (9), e1101. http://www.sciencedirect.com/science/article/pii/S2214109X20303685.
Lawson-Lartego, L., Cohen, M.J., 2020. 10 recommendations for African governments to ensure food security for poor and vulnerable populations during COVID-19. Food Security 12 (4), 899–902. https://doi.org/10.1007/s12571-020-01062-7.
Lewin, K.M., 2020. Beyond business as usual: aid and financing education in Sub Saharan Africa. Int. J. Educ. Dev. 78, 102247. http://www.sciencedirect.com/science/article/pii/S0738059320304065.
Ma, N.L., Peng, W., Soon, C.F., Noor Hassim, M.F., Misbah, S., Rahmat, Z., et al., 2021. Covid-19 pandemic in the lens of food safety and security. Environ. Res. 193, 110405. https://www.sciencedirect.com/science/article/pii/S0013935120313025.
Madurai Elavarasan, R., Shafiullah, G.M., Raju, K., Mudgal, V., Arif, M.T., Jamal, T., et al., 2020. COVID-19: impact analysis and recommendations for power sector operation. Appl. Energy 279, 115739. http://www.sciencedirect.com/science/article/pii/S0306261920312290.
Manzanedo, R.D., Manning, P., 2020. COVID-19: lessons for the climate change emergency. Sci. Total Environ. 742, 140563. http://www.sciencedirect.com/science/article/pii/S0048969720340857.
Mardones, F.O., Rich, K.M., Boden, L.A., Moreno-Switt, A.I., Caipo, M.L., Zimin-Veselkoff, N., et al., 2020. The COVID-19 pandemic and global food security. Frontiers in Veterinary Science 7, 928. https://www.frontiersin.org/article/10.3389/fvets.2020.578508.
McNamara, K.R., Newman, A.L., 2020. The big reveal: COVID-19 and globalization's great transformations. Int. Organ. 1–19.
MENAFN, 2020. Germany Supports Jordan's Water Suppliers During COVID-19 Crisis With 7m Euros in Emergency Funding. MENAFN https://menafn.com/1100154382/Germany-supports-Jordans-water-suppliers-during-COVID-19-crisis-with-7m-euros-in-emergency-funding. (Accessed 24 October 2020) (May 12).
Mocatta, G., Hawley, E., 2020. The coronavirus crisis as tipping point: communicating the environment in a time of pandemic. Media International Australia 177 (1), 119–124.
Mor, R.S., Srivastava, P.P., Jain, R., Varshney, S., Goyal, V., 2020. Managing food supply chains post COVID-19: a perspective. IJSOM 7 (3), 295–298. http://www.ijsom.com/article_2822.html.
Mukanjari, S., Sterner, T., 2020. Charting a "green path" for recovery from COVID-19. Environ. Resour. Econ. 76 (4), 825–853. https://doi.org/10.1007/s10640-020-00479-0.
Muscogiuri, G., Barrea, L., Savastano, S., Colao, A., 2020. Nutritional recommendations for CoVID-19 quarantine. Eur. J. Clin. Nutr. 74 (6), 850–851. https://doi.org/10.1038/s41430-020-0635-2.
Naidoo, R., Fisher, B., 2020. Reset sustainable development goals for a pandemic world. Nature 583 (7815), 198–201.

Nhamo, L., Ndlela, B., 2021. Nexus planning as a pathway towards sustainable environmental and human health post Covid-19. Environ. Res. 192, 110376. https://www.sciencedirect.com/science/article/pii/S0013935120312731.

Niles, M.T., Bertmann, F., Belarmino, E.H., Wentworth, T., Biehl, E., Neff, R., 2020. The early food insecurity impacts of COVID-19. Nutrients 12(7).

Norouzi, N., Zarazua de Rubens, G., Choupanpiesheh, S., Enevoldsen, P., 2020. When pandemics impact economies and climate change: exploring the impacts of COVID-19 on oil and electricity demand in China. Energy Res. Soc. Sci. 68, 101654. http://www.sciencedirect.com/science/article/pii/S2214629620302292.

Nsour, M.F.A., 2020. Internal trade law and food exports during Covid-19 pandemic: the case of Jordan. European Food and Feed Law Review 15 (5), 438–448. https://effl.lexxion.eu/article/EFFL/2020/5/6?utm_source=fb&utm_medium=fb&utm_campaign=fb_post_organic&utm_content=effl_5_20_A3&fbclid=IwAR24vDW0c95zbcAUWJSqHxGtawIWFFteQldghp-NN9ahsnwcbjebJOhcXM4.

O'Callaghan-Gordo, C., Antó, J.M., 2020. COVID-19: the disease of the anthropocene. Environ. Res. 187, 109683. http://www.sciencedirect.com/science/article/pii/S0013935120305764.

O'Hara, S., Toussaint, E.C., 2021. Food access in crisis: food security and COVID-19. Ecol. Econ. 180, 106859. https://www.sciencedirect.com/science/article/pii/S0921800920312179.

Parks, C.A., Nugent, N.B., Fleischhacker, S.E., Yaroch, A.L., 2020. Food system workers are the unexpected but under protected COVID heroes. J. Nutr. 150 (8), 2006–2008.

Poch, M., Garrido-Baserba, M., Corominas, L., Perelló-Moragues, A., Monclús, H., Cermerón-Romero, M., et al., 2020. When the fourth water and digital revolution encountered COVID-19. Sci. Total Environ. 744, 140980. http://www.sciencedirect.com/science/article/pii/S0048969720345095.

Pu, M., Zhong, Y., 2020. Rising concerns over agricultural production as COVID-19 spreads: lessons from China. Global Food Security 26, 100409. http://www.sciencedirect.com/science/article/pii/S2211912420300638.

Rajan, S., 2009. District Cooling in the GCC: An Insight into District Coolings Massive Potential in the Middle East. Utilities. https://www.utilities-me.com/article-1-district-cooling-in-the-gcc. (Accessed 2 November 2020).

Rhee, S.-W., 2020. Management of used personal protective equipment and wastes related to COVID-19 in South Korea. Waste Manag. Res. 38 (8), 820–824.

Rifai, H.S., 2020. The sustainable development goals in a bioremediation journal context: what a difference a year makes in a post COVID-19 world! Bioremediation Journal 24 (2–3), 91–94.

Rosenbloom, D., Markard, J., 2020. A COVID-19 recovery for climate. Science (New York, N.Y.) 368 (6490), 447.

Rowan, N.J., Galanakis, C.M., 2020. Unlocking challenges and opportunities presented by COVID-19 pandemic for cross-cutting disruption in agri-food and green deal innovations: Quo Vadis? Sci. Total Environ. 748, 141362. http://www.sciencedirect.com/science/article/pii/S0048969720348919.

Ruiz-Roso, M.B., de Carvalho Padilha, P., Mantilla-Escalante, D.C., Ulloa, N., Brun, P., Acevedo-Correa, D., et al., 2020. Covid-19 confinement and changes of adolescent's dietary trends in Italy, Spain, Chile, Colombia and Brazil. Nutrients 12(6).

Saadat, S., Rawtani, D., Hussain, C.M., 2020. Environmental perspective of COVID-19. Sci. Total Environ. 728, 138870. http://www.sciencedirect.com/science/article/pii/S0048969720323871.

Sarkar, P., Debnath, N., Reang, D., 2021. Coupled human-environment system amid COVID-19 crisis: a conceptual model to understand the nexus. Sci. Total Environ. 753, 141757. http://www.sciencedirect.com/science/article/pii/S0048969720352864.

Savary, S., Akter, S., Almekinders, C., Harris, J., Korsten, L., Rötter, R., et al., 2020. Mapping disruption and resilience mechanisms in food systems. Food Security 12 (4), 695–717. https://doi.org/10.1007/s12571-020-01093-0.

Sen, S., 2020. The pandemic under siege: a view from the Gaza Strip. World Dev. 135, 105063. https://www.sciencedirect.com/science/article/pii/S0305750X20301893.

Shakil, M.H., Munim, Z.H., Tasnia, M., Sarowar, S., 2020. COVID-19 and the environment: a critical review and research agenda. Sci. Total Environ. 745, 141022. http://www.sciencedirect.com/science/article/pii/S0048969720345514.

Simpson, G.B., Jewitt, G.P.W., 2019. The development of the water-energy-food nexus as a framework for achieving resource security: a review. Frontiers in Environmental Science 7, 8. https://www.frontiersin.org/article/10.3389/fenvs.2019.00008.

Sivakumar, B., 2020. COVID-19 and water. Stoch. Env. Res. Risk A. https://doi.org/10.1007/s00477-020-01837-6.

Smith, M.D., Wesselbaum, D., 2020. COVID-19, food insecurity, and migration. J. Nutr. 150 (11), 2855–2858.

Sovacool, B.K., Furszyfer Del Rio, D., Griffiths, S., 2020. Contextualizing the Covid-19 pandemic for a carbon-constrained world: insights for sustainability transitions, energy justice, and research methodology. Energy Res. Soc. Sci. 68, 101701. http://www.sciencedirect.com/science/article/pii/S2214629620302760.

Street, R., Malema, S., Mahlangeni, N., Mathee, A., 2020. Wastewater surveillance for Covid-19: an African perspective. Sci. Total Environ. 743, 140719. http://www.sciencedirect.com/science/article/pii/S0048969720342418.

Udmale, P., Pal, I., Szabo, S., Pramanik, M., Large, A., 2020. Global food security in the context of COVID-19: a scenario-based exploratory analysis. Progress in Disaster Science 7, 100120. https://www.sciencedirect.com/science/article/pii/S2590061720300570.

Vanapalli, K.R., Sharma, H.B., Ranjan, V.P., Samal, B., Bhattacharya, J., Dubey, B.K., et al., 2021. Challenges and strategies for effective plastic waste management during and post COVID-19 pandemic. Sci. Total Environ. 750, 141514. http://www.sciencedirect.com/science/article/pii/S0048969720350439.

Vanegas Cantarero, M.M., 2020. Of renewable energy, energy democracy, and sustainable development: a roadmap to accelerate the energy transition in developing countries. Energy Res. Soc. Sci. 70, 101716. http://www.sciencedirect.com/science/article/pii/S2214629620302917.

Woertz, E., 2020. Wither the self-sufficiency illusion? Food security in Arab Gulf States and the impact of COVID-19. Food Security 12 (4), 757–760. https://doi.org/10.1007/s12571-020-01081-4.

World Economic Forum, 2011. Water Security: The Water-Food-Energy-Climate Nexus. World Economic Forum, Washington, DC.

World Food Programme (WFP), 2020. Assessing the Impact of the Economic and COVID-19 Crises in Lebanon. World Food Programme (WFP), Rome, Italy.

You, S., Sonne, C., Ok, Y.S., 2020. COVID-19's unsustainable waste management. Science (New York, N.Y.) 368 (6498), 1438.

Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 on the environment. Sci. Total Environ. 728, 138813. http://www.sciencedirect.com/science/article/pii/S0048969720323305.