

COVID-19 Reveals Vulnerabilities of the Food–Energy–Water Nexus to Viral Pandemics

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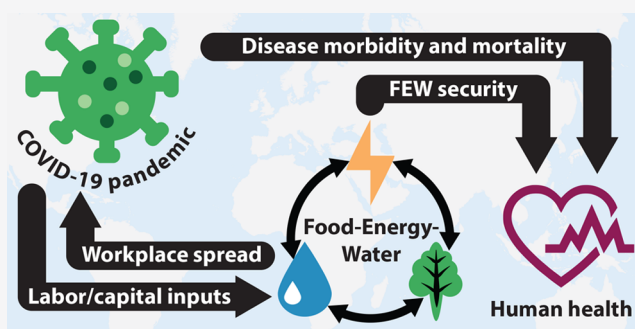


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ABSTRACT: Food, energy, and water (FEW) sectors are inextricably linked, making one sector vulnerable to disruptions in another. Interactions between FEW systems, viral pandemics, and human health have not been widely studied. We mined scientific and news/media articles for causal relations among FEW and COVID-19 variables and qualitatively characterized system dynamics. Food systems promoted the emergence and spread of COVID-19, leading to illness and death. Major supply-side breakdowns were avoided (likely due to low morbidity/mortality among working-age people). However, COVID-19 and physical distancing disrupted labor and capital inputs and stressed supply chains, while creating economic insecurity among the already vulnerable poor. This led to demand-side FEW insecurities, in turn increasing susceptibility to COVID-19 among people with many comorbidities. COVID-19 revealed trade-offs such as allocation of water to hygiene versus to food production and disease burden avoided by physical distancing versus disease burden from increased FEW insecurities. News/media articles suggest great public interest in FEW insecurities triggered by COVID-19 interventions among individuals with low COVID-19 case-fatality rates. There is virtually no quantitative analysis of any of these trade-offs or feedbacks. Enhanced quantitative FEW and health models are urgently needed as future pandemics are likely and may have greater morbidity and mortality than COVID-19.



INTRODUCTION

Modern viral pandemics such as the 2019 coronavirus disease (COVID-19, caused by the virus SARS-CoV-2) are predominantly caused by food systems that expose increasingly interconnected populations to reservoirs of viruses against which humans have little resistance.¹ As of July 2021, over 190 million cases of COVID-19 have been confirmed globally, resulting in over 4 million deaths.² Attempts to arrest the spread of the virus have meanwhile resulted in widespread economic and social disruption. For example, in the United States, gross domestic product (GDP) fell by an annualized rate of 32% between the first and second quarters of 2020 as physical distancing and travel restrictions constrained economic activity.^{3,4} COVID-19 demonstrates that modern food systems may disrupt global society by introducing novel pathogens, but interactions with tightly coupled water and energy systems have been underexplored. Characterizing how COVID-19 has influenced food–energy–water (FEW) systems is a first step toward building resilience to avoid catastrophic breakdowns in future pandemics.

Modern food systems promote pandemic zoonoses. Worldwide, animal supply chains create novel contacts between animal species and between animals and humans, promoting viral recombination, bacterial adaptation, and interspecies

infection.^{5–8} Low-latitude, less developed countries are biodiverse (with respect to fauna and pathogens) and are subject to social and ecological pressures that increase harvest and consumption of bushmeat, increasing risks of pathogen emergence.^{1,9–11} Virtually all major infectious diseases throughout history such as influenza, measles, and smallpox have been zoonotic and emerged alongside animal husbandry.^{12–14} The continual emergence of new diseases such as HIV/AIDS (1980 to present, >33 million deaths, likely chimpanzee origin),^{15,16} Ebola (1976 to present, >13 000 deaths over multiple outbreaks, likely bat origin),^{17–20} and SARS-CoV-2/COVID-19 (likely bat origin and pangolin intermediary)²¹ illustrate that emergent zoonotic disease continues to pose novel human health risks.

Current methods to forecast impacts of pandemics on social systems and to understand how policy responses mediate health and wellbeing are inadequate. State-of-the-science

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pandemic management and forecasting tools consider health as a single causal chain between infection, disease, and recovery or death.²² Yet policy responses instituted to slow disease spread have diverse consequences with impacts and trade-offs not anticipated at the start of the pandemic. For example, shocks to economic and social networks associated with responses to COVID-19 have caused a serious countervailing mental health risk. In a recent sample of the U.S. population, Czeisler et al.²³ found that symptoms of anxiety and depression in June 2020 were 3 and 4 times more prevalent, respectively, compared to June 2019, with >25% of respondents aged 18–24 reporting suicidal ideation.

Meanwhile, FEW research is oriented around unsustainable supply-side demand for overexploited resources (especially water) and its impacts on food, energy, and water availability. It is now widely understood that FEW sectors are inextricably linked given the strong dependence of each sector on the other (e.g., agriculture accounts for 71% of global water withdrawals) and that unsustainable practices in one sector can cause volatility and crises in another (e.g., water shortage-induced food price volatility in 2008–2010).^{24,25} COVID-19 however reveals that FEW interconnections are vulnerable not just to resource constraints but also to disruptions in human and financial capital on the supply and demand sides.²⁶ For instance, economic disruptions in the U.S. led to electric and gas arrears totaling roughly \$32 billion by the end of 2020.²⁷ Existing FEW modeling tools do not consider the human labor and financial capital required to sustain outputs and are therefore poorly suited to evaluating impacts of pandemics on FEW security.

While both pandemic zoonoses^{13,28} and FEW systems^{29,30} are major determinants of health globally, their combined effect on health is poorly understood. Pandemic research centers on biophysical processes, some of which have negligible if any impact on health. For example, several recent studies characterized wastewater as a vector of SARS-CoV-2 despite this pathway posing at most a negligible risk.^{31–36} Meanwhile, larger scale processes such as strains on infrastructure and the water insecurity caused by COVID-19-related economic precarity have been discussed often in the media but rarely in the scientific literature. Other topics of ongoing research on sector-specific impacts of COVID-19 include impacts on nutritional adequacy^{37,38} and the disproportionate risk of infection faced by workers in the water³⁹ and food^{40,41} sectors. While some studies recognize intrasector system dynamics (e.g., risk of an outbreak leading to labor and thus food system disruption in the United States⁴²), there has been a lack of analysis characterizing cross-sector trade-offs, feedbacks, and other system dynamics. This lack of integrated conceptual understanding hinders prediction and management of trade-offs and unintended consequences.

In this paper, we characterize the interactions between FEW processes, COVID-19, and pre-vaccine mitigation measures such as physical distancing and hygiene protocols. We also identify processes that largely withstood the stresses of COVID-19 but may break down in the context of a pandemic disease with higher mortality and morbidity among the working-age population. We combine a review of the scientific literature with a review of news/media articles to characterize causal pathways and identify potential research gaps. Where possible, we identify processes that are unique to less developed countries and processes that interact with pre-existing social inequities in the United States. We conclude

with a summary of urgent needs for FEW-health modeling to improve decision-making for future viral pandemics.

METHODS

We conducted a scoping review of the peer-reviewed literature for articles addressing food–energy–water phenomena in the context of COVID-19. A scoping review aims to quantify the nature and extent of available research without critical appraisal of research quality.⁴³ Article abstracts of journals indexed in the Web of Science (WoS) Core Collection⁴⁴ were queried on October 15, 2020 using a syntax that allows for diverse words to qualify as food, energy, or water concepts. This syntax is summarized in [Supporting Information \(SI\) Table S1](#). The search was confined to publications in 2019 and 2020. We consider it very likely that virtually all articles that focused on food/energy/water interactions in any substantive way in the context of COVID-19 would have used one of the relevant terms in the abstract.

The search returned 179 articles, which were screened manually for relevance. A total of 98 articles were excluded without further review based on the conditions summarized in [SI Table S2](#). The remaining 81 articles were reviewed to extract causal associations asserted or evaluated by authors. [SI Table S3](#) lists all articles returned by the WoS search and excluded (sorted by exclusion reason). [SI Table S4](#) summarizes all articles retained from the WoS search.

Article abstracts were reviewed for assertions about causal relationships. These relationships were recorded by authors (M.J., R.C., and R.H.) and research assistants (G.B. and M.M.). Author R.C. reviewed all coding and consolidated similar concepts using consistent terminology. Causal associations were combined using general terminology to avoid exponential proliferation of causal relationships appearing in a graphical model. Author R.C. synthesized all articles using R.⁴⁵ This method was used successfully on a larger scale by Calder et al.⁴⁶

We note that the scientific literature is rapidly evolving, and so our mapping of literature coverage and gaps is subject to ongoing reevaluation. We also note that we have focused on cross-sector FEW nexus relationships rather than intrasector phenomena, where systems thinking is also needed.⁴⁷

We undertook a complementary review of news/media articles to evaluate which food–energy–water concepts are being addressed in connection with COVID-19 outside the peer-reviewed literature. This was done to identify possible gaps between issues of popular interest and the concepts addressed by existing research. This is particularly important due to the rapid nature of evolving COVID-19 and the less rapid pace of academic peer review and publishing.

Using the Nexis Uni database,⁴⁸ we extracted news/media articles including in their titles at least two of the three nexus concepts: food + energy (FE), food + water (FW), or energy + water (EW). Article types include press releases and newspaper articles. The distribution of article types is presented in [SI Figure S1](#). The words retained to describe each of the food, energy, and water concepts are the same as those summarized in the WoS search ([SI Table S1](#), rows 3–5). We confined our search to articles with these terms appearing in the title in order to generate a manageable number of results. Searching in article texts returns more than 1.4 million articles of which most are irrelevant (from a cursory screening). Final and rejected search syntaxes are described in [SI Table S5](#). News/media searches were performed on October 4, 2020 and

returned 572 total results, split between FW (184), EW (185), and FE (203). No articles included food, energy, and water together in their titles.

All authors and research assistant C.G. then coded causal relationships asserted in news/media articles as was done for the WoS search. Given the large number of news/media articles returned, we manually reviewed a subset of 25% each of FW, EW, and FE. The 25% reviewed for each category were the first 25% as sorted by Nexis Uni in decreasing order of relevance; cursory review of the remaining 75% of articles in each group coded revealed that the majority presented no discernible link to food–energy–water systems and/or included only a tangential reference to COVID-19. Duplicate articles (approximately 22%) were skipped. Roughly 52% of articles were market reports that mentioned COVID-19 that did not make any causal claims.

For all 572 news/media results, we evaluated the distribution of articles by industry and by article type and performed word frequency analysis for each nexus group (EW, FE, and FW). Word frequency analysis is often used as a screening method to identify concepts or associations of particular concern within a large body of literature.⁴⁹ This analysis was carried out using the WordCloud package⁵⁰ in Python.⁵¹

Finally, for all 572 news/media results, we investigated distributional similarity measures for a subset of high-frequency words to better understand their contextual significance in news/media articles. The distributional similarity measures the number of contexts shared by words in a given text under the assumption that words that occur in similar contexts have similar meanings.^{52,53} This analysis was carried out using the NLTK package for Python.⁵⁴

We note that our findings are based on articles written in English and therefore may not capture phenomena occurring only in non-English-speaking countries. However, we are not aware of FEW/COVID-19 phenomena unique to the non-English-speaking world.

RESULTS AND DISCUSSION

Supply-Side Stresses. The most frequently identified relationships correspond to risks associated with work in the food sector (notably meatpacking and processing); food sector workers are at high risk of SARS-CoV-2 infection, posing a risk of worker illness and mortality and necessitating physical distancing interventions, all of which have disrupted a food system dependent on labor inputs. This has resulted in localized food shortages with unclear impacts on nutrition and health.⁵⁵ All relationships identified in scientific and news/media articles relevant to supply-side disruptions in FEW sectors are displayed in Table 1. All causal relations identified are listed in SI Table S6 along with summary statistics and citation information.

In the United States, black, Hispanic, and Native American individuals face disproportionate COVID-19 risks, partly as a result of food, energy, and water systems. They are highly represented in workplaces with higher COVID-19 risks such as meatpacking^{56,57} and are also more likely to be food-insecure and hence vulnerable to disrupted food supply chains.⁵⁸ Meanwhile, food insecurity contributes to higher rates of pre-existing health conditions, which in turn increases susceptibility to COVID-19 morbidity and mortality.⁵⁹ These system dynamics are represented in Figure 1 and explored further below.

Table 1. FEW Supply-Side Relationships Asserted in Scientific and News/Media Articles

relationship	percent reporting ^a	
	scientific articles	news/media articles
economic support → purchasing power (of producers)	22%	16%
food supply → food/nutritional security/choices	6%	20%
physical distancing → food supply ^b	9%	16%
food supply → SARS-CoV-2 transmission ^c	9%	9%
water availability → food supply	2%	9%
SARS-CoV-2 transmission → food supply ^d	4%	4%
physical distancing → water quality ^e	4%	0
employment/economic activity → water quality ^f	4%	0
water availability → water security	0	1%

^a“Percent reporting” reflects articles discussing supply-side and demand-side effects. ^bPhysical distancing measures instituted in meat processing and packing plants and elsewhere have resulted in food supply slowdowns. ^cMeat processing and packing plants are high-risk occupational settings for COVID-19, and there have been many outbreaks there. ^dCOVID-19 outbreaks in meat processing and packing plants and elsewhere lead to absenteeism, slowing down food production. ^eIncreased occupancy of residential buildings as a result of workplace distancing have changed volumes and quantities of wastewater produced worldwide. ^fDiminished industrial production at the start of the pandemic has changed volumes and quantities of wastewater produced worldwide.

The only cross-sector, supply-side stress identified was the potential impact of water availability on food production. This is consistent with recent observations that, generally, energy systems have weathered COVID-19 with no major disruptions, likely due to the overall suppressive effect the pandemic has had on energy demand (discussed in the Demand-Side Stresses section).²⁶

Economic support to agricultural producers was widely discussed, particularly in the U.S. media (between April 2020 and March 2021, roughly \$42 billion in public funds was appropriated to support the U.S. food sector).^{60–62} However, we did not identify any articles (news/media or scientific) evaluating whether enhanced producer purchasing power affects overall food supply or food security. Supply-side economic support has also generally not translated into support for food workers (e.g., paid sick leave) who are disproportionately susceptible to occupational SARS-CoV-2 exposure, which in turn destabilizes food supplies.^{63–65}

The news/media review identified 50 food–energy, 63 food–water, and 129 energy–water articles classified under “Energy & Utilities” (SI Figure S1). Word frequency analysis (SI Figure S2) also revealed a strong industry focus in EW articles (“market” and related words most represented) compared to the consumer focus among FE and FW articles (“COVID,” “people,” and related words most represented). This is also reflected in the results of semantic distribution analysis undertaken for the terms “government” (highly represented in FE and FW articles, SI Table S7) and “market” (highly represented in EW articles, SI Table S8). Many industry-related terms (e.g., “market,” “vendors,” “forecast,” “order”) appeared frequently in a similar context as the term “government,” supporting our finding that EW articles, more than FE and FW articles, focused on challenges, perceptions, and concerns of producers and industries. It was therefore

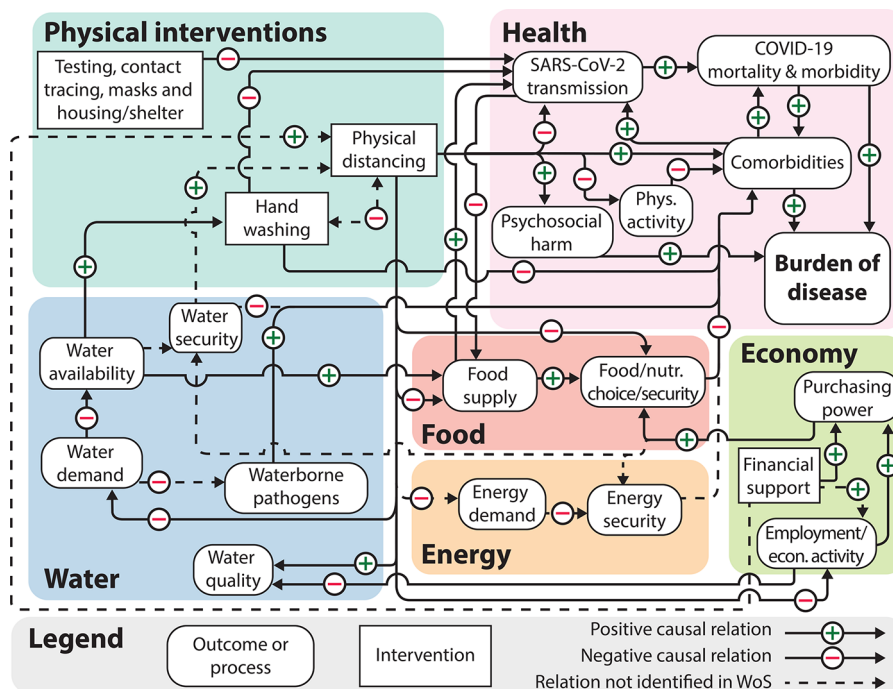


Figure 1. Relations among food, energy, water, health, and economic concepts in the context of COVID-19. Hatched lines are relations not corroborated in a Web of Science (WoS) search and correspond to possible research gaps. All hatched lines correspond to results of the news/media review except energy demand → energy security (limited media predictions not found by news/media review) and energy security → comorbidities (logical inference and media reports that emerged after our formal search). Non-FEW relations occurring only once in scientific articles are omitted for clarity. A complete list of relations with journal citation information and summary statistics for a news/media search included in SI Table S6. Positive/negative associations refer to expected numerical relationships rather than better/worse judgments.

surprising that no FE or EW cross-sector, supply-side relationships were identified from the news/media review.

Close inspection of the energy–water articles however reveals that virtually all are either market reports for cross-sector products (e.g., water heaters) or discuss industry concern about cross-sector trade-offs on the demand side. This includes water and power disconnections and disconnection bans introduced during the pandemic as described in the Demand-Side Stresses section. While supply-side terminology was heavily represented in news/media articles returned by the EW search, the underlying stresses fell virtually exclusively on the demand side.

After our structured searches were completed, in February 2021, a cold wave struck North America. This caused power failures in Texas where the electrical grid depends on poorly winterized generating assets and lacks regional interconnections.⁶⁶ This imperiled COVID-19 outpatients dependent on portable oxygen concentrators⁶⁷ and forced people in unheated homes to weigh risks of cold exposure against risks of contracting SARS-CoV-2 in congregate shelters.⁶⁸ This demonstrates a causal connection between energy security and COVID-19 morbidity and mortality not uncovered in our formal search.

Demand-Side Stresses. The most widely discussed demand-side stresses on FEW security relate to a collapse in purchasing power among lower-income individuals dependent on income from the retail, hospitality, and food services sectors. These sectors were severely affected by physical distancing interventions such as bar and restaurant closures. In the U.S., these disruptions disproportionately affected women and black, Hispanic, and Native American people.^{57,69}

Economic impacts from COVID-19 and related interventions have created FEW insecurities on the demand side (summarized in Table 2). In the United States, a patchwork of energy and water disconnection moratoria has so far reduced the number of utility disconnections thus representing a type of economic support by utilities to consumers.⁷⁰ With energy arrearages by the end of 2020 totaling roughly \$32 billion in the U.S. alone and disconnection moratoria now expiring,²⁷ a utilities access crisis may have been delayed rather than avoided.

Lower income and/or black, Hispanic, or Native American households are also at higher risks of illness and death from COVID-19. (The Supply-Side Stresses section discusses this in the setting of FEW.) However, we did not identify articles linking COVID-19 morbidity or mortality to FEW disruptions, apart from supply-side impacts on food workers described earlier.

Racial disparities in economic security translate to racial disparities in FEW security during the COVID-19 pandemic. For example, in the U.S., food insecurity increased from roughly 19% to 32% among white households and from 39% to 50% among black households.⁵⁸ Even controlling for economic security, racial disparities in FEW security persist. For example, in a nationally representative sample of households within 200% of the federal poverty line, black households had 3 times the odds of having been disconnected from power in the month to May 2020, while households under 100% of the poverty line had no increased odds compared to the study population as a whole.⁷¹

Physical distancing measures implemented in response to COVID-19 vastly increased person-hours spent in residential neighborhoods, changing food, energy, and water demand

Table 2. FEW Demand-Side Relationships Asserted in Scientific and News/Media Articles

relationship	percent reporting ^a	
	scientific articles	news/media articles
economic support → purchasing power (of consumers)	22%	16%
physical distancing → employment/economic activity ^b	10%	25%
purchasing power → food/nutrition security/choices	9%	25%
food supply → food/nutrition security/choices	6%	20%
physical distancing → food supply ^c	9%	16%
purchasing power → water security	0	17%
purchasing power → energy security	0	12%
employment/economic activity → purchasing power	5%	6%
economic support → physical distancing ^d	0	6%
physical distancing → water demand ^e	4%	4%
physical distancing → food/security nutrition/choices ^f	4%	0
water security → physical distancing ^g	0	4%
water demand → waterborne pathogens ^h	0	2%
physical distancing → energy demand ⁱ	0	1%
physical distancing → hand washing ^j	0	1%

^a“Percent reporting” reflects articles discussing supply-side and demand-side effects. ^bPhysical distancing measures heavily disrupted certain economic sectors such as hospitality and tourism leading to unemployment and economic precarity. ^cDecreased patronage of restaurants and other congregate dining settings (and increased at-home cooking) led to a mismatch in food packaging size supply vs demand. ^dEnhanced unemployment and other benefits make economically disruptive public health policies more feasible. ^eDecreased industrial/commercial building occupancy and increased residential building occupancy changes the volume and timing of water demand. ^fDecreased patronage of restaurants and other congregate dining settings (and increased at-home cooking) led to changes in food choices. ^gLack of household drinking water access (e.g., in less developed countries) requires congregation around community spigots and impeding physical distancing. ^hStanding water in the plumbing of commercial/industrial/institutional facilities with reduced occupancy can promote the proliferation of legionella. ⁱDecreased industrial/commercial building occupancy and increased residential building occupancy changes the volume and timing of energy demand. ^jPhysical distancing imperatives reduce the feasibility of hand washing in settings with community spigots (e.g., in less developed countries)

patterns. Electrical grid failures were widely prophesied for summer 2020 given the sharp increase in remote work during the COVID-19 pandemic,^{72,73} but we did not find evidence that this had occurred as of June 2021. In less developed countries where distributed drinking water access is not universal and water shortages are common, news/media articles suggested a trade-off between routine hand washing and physical distancing⁷⁴ and difficulty of following hand washing advice while leaving water available for other uses.⁷⁵ We did not identify scientific articles characterizing the physical distancing/hand-washing trade-off or evaluating competing demands for water use in the context of minimizing the burden of disease.

A smaller number of news/media and scientific articles addressed other demand-side disruptions to FEW systems not directly associated with purchasing power. This includes packaging size supply–demand mismatches (associated with

the collapse in retail dining), which has led to substantial waste of food as represented in Table 2 by physical distancing → food supply.⁷⁶ The second-order impacts of food waste on energy and water waste are increasingly appreciated, but papers returned by our review did not address this.⁷⁷ We are aware of reports of legionella proliferating in stagnant water in pipes and tanks of buildings shut down following physical distancing orders.⁷⁸ This is particularly concerning given the risks associated with SARS-CoV-2/legionella coinfection.⁷⁹ However, our review did not capture any scientific articles that addressed these phenomena.

FEW/COVID-19 System Dynamics. COVID-19 and associated policy interventions like physical distancing have had profound and uneven impacts on human health. Many of these impacts have been realized through intermediate effects on FEW systems as described above. Aggregating these causal relationships uncovers feedback loops and trade-offs that span traditional areas of research and practice. Below, we discuss these system dynamics. Figure 1 presents our integrated conceptual model of FEW/COVID-19 interactions. (All causal relations identified are listed in SI Table S6 along with summary statistics; FEW supply- and demand-side relations summarized in Tables 1 and 2 above.)

First, SARS-CoV-2 spreads throughout the population as a function of social and virological parameters. Morbidity and mortality are determined by many variables including nutritional status and food security.⁸⁰ The conditions of meatpacking and food processing plants promote disease spread, but these facilities are essential components of the food supply chain.⁸¹ Outbreaks there create disease burden among workers and among people who may suffer from supply chain disruptions resulting from worker absenteeism. Physical distancing (e.g., shift reductions) reduces the expected burden of disease among workers but may exacerbate food insecurities in the general population. This represents a direct burden of disease from malnutrition and indirect burden of disease from increased vulnerability to viral disease. There is currently no quantitative decision support for these interacting food–health–virus processes.

Second, economic disruption from COVID-19 (loss of wages among the sick) or policy responses (closure of industries such as retail dining) leads to the burden of disease via FEW insecurities and psychosocial impacts (described in the Demand-Side Stresses section). Physical distancing reduces disease burden, particularly among groups with high case-fatality rates. However, these groups are older and bear fewer of the countervailing economic impacts or second-order FEW insecurity risks. This raises equity issues that have been widely interrogated in the popular press but of which there has been virtually no quantitative analysis. Immediate and long-term impacts of simultaneous food, energy, and water affordability crises among low-income families are also unknown.

Third, food supply (and much else) depends on water and energy inputs, while food, energy, and water supply all depend on labor and capital inputs. COVID-19 morbidity and mortality has been concentrated among older people rather than working-age adults,⁸² and large-scale supply-side FEW system breakdowns have so far been avoided. In the context of COVID-19, decision makers have therefore not had to confront trade-offs that might be forced by a pandemic driven by a deadlier pathogen such as the 1918 H1N1 strain. A pandemic that kills or disables a substantial fraction of FEW workers would force decision makers to weigh provision of

Table 3. Pathways Longer than Two Relationships in Series Identified by Articles from WoS Search

pathway	narrative explanation	citations
food supply → SARS-CoV-2 transmission → food/nutrition choices/security → environment ⁴⁴	the perception of certain foods as vectors for SARS-CoV-2 may lead to more sustainable food choices	Yang ⁹⁰
physical distancing → employment → purchasing power	physical distancing can create economic precarity by reducing opportunities for certain types of work (e.g., food supply chain)	Orden ⁹¹
physical distancing → food supply → food/nutrition choices/security → comorbidities	physical distancing has second-order effects on health through reduced food security	Akseer et al. ⁹² , Lal ⁹³
water availability → food supply → food/nutrition choices/security → comorbidities → COVID-19 mortality and morbidity	water availability has second-order effects on health through reduced food security	Woertz ⁹⁴
SARS-CoV-2 transmission → COVID-19 mortality and morbidity → comorbidities → burden of disease	without intervention, COVID-19 will leave long-term impacts on maternal and general health	Kapur and Hod ⁹⁵
comorbidities → COVID-19 mortality and morbidity → burden of disease	comorbidities exacerbate COVID-19	Gasmi et al. ⁹⁶

⁴⁴Yang⁹⁰ quantified impacts on food choices in the context of broadly defined environmental “sustainability” but specific environmental end points were outside the scope of their study.

essential services against risks to workers, where risks to workers would also jeopardize the provision of essential services. Meanwhile, COVID-19 has revealed the lack of modeling tools available to predict the impact of capital or labor shortfalls on integrated FEW systems including risks of cascading FEW crises.

The current evidence base does not facilitate analysis of these feedbacks and trade-offs. Almost all articles coded considered one-way relationships between at most two concepts in series (i.e., $A \rightarrow B$ and $C \rightarrow D$ but not $B \rightarrow C$). Despite the complexity of coupled human–natural systems, most evidence in environmental and social sciences accounts only for such one-way interactions, limiting the ability of policymakers and others to quantify trade-offs and interactions across sectors.⁴⁶ This contrasts markedly to the biomedical sciences where careful statistical analysis is applied to determine the role of environmental exposures and prior disease status on mortality,^{83–87} the impact of COVID-19 on comorbidities, and the possible confounding role of treatment for comorbidities on COVID-19 outcomes.^{88,89}

While the study of complex causal structures in the FEW sciences has been limited, we did identify six pathways in the literature that reflect interest in second-order impacts, unintended consequences, and system dynamics (see Table 3 for narrative descriptions). Of 81 scientific articles reviewed, 18 evaluated or asserted multiple outcomes from a given intervention or variable (e.g., impacts of physical distancing on nutrition, physical activity, etc.) or, conversely, multiple predictors of a given outcome (e.g., impacts of hand washing and physical distancing on SARS-CoV-2 transmission). This framing allows for analysis of trade-offs and comparative efficacy of alternative interventions. However, no article that we identified explicitly undertook such an analysis.

Overall, COVID-19 has exposed trade-offs and feedbacks around FEW systems stressed by viral pandemics, but these dynamics have not yet been well characterized. Because most working-age people who contract SARS-CoV-2/COVID-19 recover, direct impacts on the supply-side FEW systems have been smaller than demand-side impacts of COVID-19 policy responses instituted to protect vulnerable populations (e.g., physical distancing). FEW systems have therefore withstood a number of stresses posed by COVID-19, such as the impact of virus morbidity and mortality on labor inputs, even as COVID-19 has highlighted these vulnerabilities.

Research Needs. The FEW nexus has amplified SARS-CoV-2/COVID-19 spread (e.g., initial outbreak and spread among food sector workers) and has been destabilized by the

loss of labor and capital inputs. While widespread food shortages, blackouts, and water shortages have largely been avoided, COVID-19 has demonstrated that FEW models have overlooked purchasing power and labor inputs as factors in assessing system resiliency. Similarly, tools to forecast viral spread across a population do not generally consider how illness and death from viruses contrast with (or interact with) burden of disease introduced by physical distancing measures, particularly among groups with low case-fatality rates. These impacts may be direct (psychosocial impacts) or triggered by FEW perturbations on the supply side (loss of labor inputs to ensure FEW system resiliency) or the demand side (loss of purchasing power to ensure FEW security).

Virtually all research we identified was retrospective, reporting on stresses that had already occurred. Overall, there is a lack of exploratory research including scenario analysis, risk analysis, and numerical simulation of FEW systems. Without these methods, insights into the potential for cascading failures will be limited. For example, as of July 2021, we have avoided large-scale supply-side breakdowns such as utility failures, despite the acknowledged potential of such events.^{72,73} We did not identify any research pointing to the conditions (virological or meteorological parameters, etc.) that would lead to such breakdowns, limiting the ability for resiliency planning.

Water stresses in less developed countries have been acknowledged as a constraint on the feasibility of widespread handwashing, potentially increasing COVID-19 risks.^{97,98} As of July 2021, inhalation of droplets and aerosols is now understood to drive SARS-CoV-2 transmission,^{99,100} reducing the urgency of this constraint. However, hands/fomite transmission may be more important in future pandemics, and we did not identify any quantitative framework to understand how pandemics may change optimal water allocation in densely populated, water-stressed areas.

Recent history has demonstrated that pandemics of greater severity than COVID-19 (e.g., the 1918–1920 H1N1 pandemic) are very possible.^{101,102} Major supply-side FEW disruptions were avoided during COVID-19, likely due to relatively low mortality among working-age adults. For example, in the United States, the case fatality rate of COVID-19 was roughly 130 times lower among 18-to-29-year-olds than among 65-to-74-year-olds prior to widespread vaccination.⁸² Across the three waves of the 1918–1920 H1N1 pandemic, this was almost exactly reversed with excess deaths among 15-to-44-year-olds 129 times higher than among ≥65-year-olds.¹⁰¹ Likewise, MERS-CoV and SARS-CoV-1 have case

fatality rates of roughly 34% and 9.5%, respectively, compared to ~1% with SARS-CoV-2.¹⁰³ Future risk and resilience simulations developed to enhance preparedness must account for such possibilities.

Quantitative risk trade-off frameworks can improve decision-making even when underlying processes are subject to large uncertainties.^{104,105} These approaches are increasingly appreciated as tools to structure complex policy questions¹⁰⁶ and would likely be a useful approach for FEW resiliency planning. It is essential that such characterizations leverage the existing simulation capacity of the supply side of food–energy–water systems.¹⁰⁷

■ ASSOCIATED CONTENT

SI Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.estlett.1c00291>.

Web of Science search syntax and annotated results for scientific literature review, NexisUni search syntaxes, summary statistics and summary figures for news/media review (PDF)

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Supporting Information

COVID-19 reveals vulnerabilities of the food-energy-water nexus to viral pandemics

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Supporting tables

Table S1: Web of Science (WoS) search syntax	2
Table S2: Number of articles excluded from results of WoS search for each exclusion reason	3
Table S3: Articles returned from WoS and excluded sorted by exclusion reason.....	4
Table S4: Articles returned from WoS and reviewed for causal relations	13
Table S5: Summary of NexisUni search syntaxes.....	21
Table S6: Summary of causal relations with articles invoking each	23
Table S7: Terms by semantic similarity to “government” for groups of popular press articles...	28
Table S8: Terms by semantic similarity to “market” for groups of popular press articles.....	29

Supporting figures

Figure S1: Distribution of news/media articles by article type and industry.....	20
Figure S2: Word frequency in news/media articles returned from NexisUni	27

Table S1: Web of Science search syntax for articles addressing the interaction between COVID-19 and the food-energy-water nexus. Syntax expressed with symbolic representations of strings for search terms associated with COVID-19 (S_{Covid}), food (S_{Food}), energy (S_{Energy}) and water (S_{Water}) which are each is defined below. AB = abstract; PY = publication year. * is a wildcard.

$AB = S_{COVID} AND$

$\left((S_{Food} AND S_{Water}) OR (S_{Food} AND S_{Energy}) OR (S_{Energy} AND S_{Water}) \right) AND$

$PY = (2019 OR 2020)$

$S_{COVID} = covid* OR coronavirus OR sars-cov-2$

$S_{Food} = food OR nutrition* OR hunger* OR crop* OR agricultur*$

$S_{Energy} = energy OR electri* OR heat* OR conditioning OR conditioner$

$S_{Water} = irrigat* OR water$

Table S2: Total number of articles excluded from results of WoS search for each exclusion reason (refer to SI Table S3 for a list of all papers excluded by reason)

Exclusion condition	Number excluded
Biomedical research	49
Technology design	15
No connection (or tangential connection) to COVID-19	14
Case reports and clinical care research and advice	8
Healthcare occupational safety	7
Transmission scenarios research	5
Total	98

Table S3: Articles returned from Web of Science (WoS) and excluded sorted by exclusion reason

No.	Title	First author	Journal	DOI
<i>Biomedical research</i>				
1	A comparative study of the laboratory features of COVID-19 and other viral pneumonias in the recovery stage	Zhao, GL	J Clin Lab Anal	10.1002/jcla.23483
2	A recombinant Lactobacillus plantarum strain expressing the spike protein of SARS-CoV-2	Wang, MP	Int J Biol Macromol	10.1016/j.ijbiomac.2020.05.239
3	A review of properties, nutritional and pharmaceutical applications of Moringa oleifera: integrative approach on conventional and traditional Asian medicine	Meireles, D	Adv Tradit Med	10.1007/s13596-020-00468-0
4	Amantadine disrupts lysosomal gene expression: A hypothesis for COVID19 treatment	Smieszek, SP	Int J Antimicrob Agents	10.1016/j.ijantimicag.2020.106004
5	Body composition findings by computed tomography in SARS-CoV-2 patients: increased risk of muscle wasting in obesity	Gualtieri, P	Int J Mol Sci	10.3390/ijms21134670
6	C-phycoerythrin of spirulina plantesis inhibits NSP12 required for replication of SARS-CoV-2: a novel finding in-silico	Raj, TK	Int J Pharm Sci Res	10.13040/IJPSR.0975-8232.11(9).4271-78
7	Conformational transition of SARS-CoV-2 spike glycoprotein between its closed and open states	Gur, M	J Chem Phys	10.1063/5.0011141
8	COVID-19 and cardiovascular risk: susceptibility to infection to SARS-CoV-2, severity and prognosis of COVID-19 and blockade of the renin-angiotensin-aldosterone system. An evidence-based viewpoint	Cappuccio, FP	Nutr Metab Cardiovasc Dis	10.1016/j.nuamec.2020.05.013
9	COVID-19 and comorbidities: a role for dipeptidyl peptidase 4 (DPP4) in disease severity?	Bassendine, MF	J Diabetes	10.1111/1753-0407.13052
10	Debunking cannabidiol as a treatment for COVID-19: time for the FDA to adopt a focused deterrence model?	Shover, CL	Cureus	10.7759/cureus.8671
11	Drug repurposing against SARS-CoV-2 using E-pharmacophore based virtual screening, molecular docking and molecular dynamics with main protease as the target	Arun, KG	J Biomol Struct Dyn	10.1080/07391102.2020.1779819

Table S3: Articles returned from WoS and excluded sorted by exclusion reason (cont'd)

No.	Title	First author	Journal	DOI
<i>Biomedical research (cont'd)</i>				
12	Epidemiological Determinants of Acute Respiratory Syndrome Coronavirus-2 Disease Pandemic and The Role of the Bacille-Calmette-Guerin Vaccine in Reducing Morbidity and Mortality	Singh, BR	J Pure Appl Microbiol	10.22207/JPA M.14.SPL1.39
13	Hesperidin and SARS-CoV-2: New Light on the Healthy Function of Citrus Fruits	Bellavite, P	Antiox–idants	10.3390/antiox 9080742
14	High affinity interaction of Solanum tuberosum and Brassica juncea residue smoke water compounds with proteins involved in coronavirus infection	Dave, GS	Phyther Res	10.1002/ptr.67 96
15	Hydroxychloroquine alternatives for chronic disease: response to a growing shortage amid the global COVID-19 pandemic	Husayn, SS	J Pharm Pract	10.1177/08971 90020942658
16	Hypermetabolism and coronavirus disease 2019	Yu, PJ	J Parenter Enter Nutr	10.1002/jpen.1 948
17	Immunomodulatory effects of zinc as a supportive strategies for COVID-19	Tayyib, NA	J Pharm Res Int	10.9734/JPRI/ 2020/v32i1330 577
18	Impact of botanical fermented foods on metabolic biomarkers and gut microbiota in adults with metabolic syndrome and type 2 diabetes: a systematic review protocol	Chan, M	BMJ Open	10.1136/bmjop en-2019- 029242
19	In silico identification of widely used and well-tolerated drugs as potential SARS-CoV-2 3C-like protease and viral RNA-dependent RNA polymerase inhibitors for direct use in clinical trials	Gul, S	J Biomol Struct Dyn	10.1080/07391 102.2020.1802 346
20	In silico investigation of spice molecules as potent inhibitor of SARS-CoV-2	Rout, J	J Biomol Struct Dyn	10.1080/07391 102.2020.1819 879
21	In silico screening of potential spike glycoprotein inhibitors of SARS-CoV-2 with drug repurposing strategy	Wei, TZ	Chin J Integr Med	10.1007/s1165 5-020-3427-6
22	Influence of different inactivation methods on severe acute respiratory syndrome coronavirus 2 RNA copy number	Chen, HL	J Clin Microbiol	10.1128/JCM. 00958-20

Table S3: Articles returned from WoS and excluded sorted by exclusion reason (cont'd)

No.	Title	First author	Journal	DOI
<i>Biomedical research (cont'd)</i>				
23	Lead molecule prediction and characterization for designing MERS-CoV 3C-like protease inhibitors: an in silico approach	Rahman, MM	Curr Comput - Aided Drug Des J Pediatric	10.2174/1573409914666180629151906
24	Lung microbiota in the acute respiratory disease: from coronavirus to metabolomics	Fanos, V	Neonatal Individ Med	10.7363/090139
25	Microbiota modulating nutritional approaches to countering the effects of viral respiratory infections including SARS-CoV-2 through promoting metabolic and immune fitness with probiotics and plant bioactives	Shinde, T	Microorganisms	10.3390/microorganisms8060921
26	Molecular docking, validation, dynamics simulations, and pharmacokinetic prediction of natural compounds against the SARS-CoV-2 main-protease	Shiva-nika, C	J Biomol Struct Dyn	10.1080/07391102.2020.1815584
27	Natural derivatives with dual binding potential against SARS-CoV-2 main protease and human ACE2 possess low oral bioavailability: a brief computational analysis	Sharma, P	J Biomol Struct Dyn	10.1080/07391102.2020.1794970
28	Potential anti-viral activity of approved repurposed drug against main protease of SARS-CoV-2: an in silico based approach	Mahan-ta, S	J Biomol Struct Dyn	10.1080/07391102.2020.1768902
29	preliminary data related to the effect of climacostol produced by the freshwater ciliate <i>Climacostomum virens</i> on human adenovirus	Verani, M	Viruses-Basel	10.3390/v12060658
30	Protein reliability analysis and virtual screening of natural inhibitors for SARS-CoV-2 main protease (M-pro) through docking, molecular mechanic & dynamic, and ADMET profiling	Kapusta, K	J Biomol Struct Dyn	10.1080/07391102.2020.1806930
31	Relation of dietary factors with infection and mortality rates of COVID-19 across the world	Abdu-lah, DM	J Nutr Health Aging	10.1007/s12603-020-1434-0
32	Repurposing approved drugs as inhibitors of SARS-CoV-2 S-protein from molecular modeling and virtual screening	de Oliveira, OV	J Biomol Struct Dyn	10.1080/07391102.2020.1772885
33	Role of immune dysregulation in increased mortality among a specific subset of COVID-19 patients and immune-enhancement strategies for combatting through nutritional supplements	Rao, KS	Front Immunol	10.3389/fimmu.2020.01548

Table S3: Articles returned from WoS and excluded sorted by exclusion reason (cont'd)

No.	Title	First author	Journal	DOI
<i>Biomedical research (cont'd)</i>				
34	SARS-CoV-2 infection and some controversies concerning therapy with chloroquine and hydroxychloroquine: case report and selected literature review	Cieplucha, H	Postepy Hig Med Dosw	10.5604/01.3001.0014.3589
35	Selenium biofortification in the 21 st century: status and challenges for healthy human nutrition	Schiavon, M	Plant Soil	10.1007/s11104-020-04635-9
36	Several coumarin derivatives and their Pd(ii) complexes as potential inhibitors of the main protease of SARS-CoV-2, an in silico approach	Milenkovic, DA	RSC Adv	10.1039/d0ra07062a
37	Six decades of lateral flow immunoassay: from determining metabolic markers to diagnosing COVID-19	Andryukov, BG	AIMS Microbiol	10.3934/microbiol.2020018
38	State-of-the-art tools to identify druggable protein ligand of SARS-CoV-2	Azeez, SA	Arch Med Sci	10.5114/aoms.2020.94046
39	Structural basis of the potential binding mechanism of remdesivir to SARS-CoV-2 RNA-dependent RNA polymerase	Zhang, LL	J Phys Chem B	10.1021/acs.jpcc.0c04198
40	Structure-based drug repurposing for targeting Nsp9 replicase and spike proteins of severe acute respiratory syndrome coronavirus 2	Chandel, V	J Biomol Struct Dyn	10.1080/07391102.2020.1811773
41	Structure-based virtual screening of phytochemicals and repurposing of FDA approved antiviral drugs unravels lead molecules as potential inhibitors of coronavirus 3C-like protease enzyme	Gurung, AB	J King Saud Univ Sci	10.1016/j.jksus.2020.07.007
42	The impact of nutrition on COVID-19 susceptibility and long-term consequences	Butler, MJ	Brain Behav Immun	10.1016/j.bbi.2020.04.040
43	The inhibitory effect of some natural bioactive compounds against SARS-CoV-2 main protease: insights from molecular docking analysis and molecular dynamic simulation	Abdelrheem, DA	J Environ Sci Health A	10.1080/10934529.2020.1826192
44	The role of environmental factors to transmission of SARS-CoV-2 (COVID-19)	Eslami, H	AMB Express	10.1186/s13568-020-01028-0

Table S3: Articles returned from WoS and excluded sorted by exclusion reason (cont'd)

No.	Title	First author	Journal	DOI
<i>Biomedical research (cont'd)</i>				
45	Virtual screening, molecular dynamics and structure-activity relationship studies to identify potent approved drugs for Covid-19 treatment	Rahman, MM	J Biomol Struct Dyn	10.1080/07391102.2020.1794974
46	Vitamin B12 may inhibit RNA-dependent-RNA polymerase activity of nsp12 from the SARS-CoV-2 virus	Narayanan, N	IUBMB Life	10.1002/iub.2359
47	Why are lopinavir and ritonavir effective against the newly emerged coronavirus 2019? Atomistic insights into the inhibitory mechanisms	Nutho, B	Biochemistry	10.1021/acs.biochem.0c00160
48	Prevention of community-acquired pneumonia in children: South African Thoracic Society guidelines (part 4)	Zar, HJ	S Afr Med J	10.7196/SAMJ.2020.v110i8.15024
49	Nicotinamide riboside-the current state of research and therapeutic uses	Mehmel, M	Nutrients	10.3390/nu12061616
<i>Case reports and clinical care</i>				
50	Acute acalculous cholecystitis on a COVID-19 patient: a case report	Mattone, E	Ann Med Surg	10.1016/j.amsu.2020.08.027
51	Is naso-pharyngeal swab always safe for SARS-CoV-2 testing? An unusual, accidental foreign body swallowing	De Luca, L	J Clin Gastroenterol	10.1007/s12328-020-01236-y
52	Early nutritional supplementation in non-critically ill patients hospitalized for the 2019 novel coronavirus disease (COVID-19): rationale and feasibility of a shared pragmatic protocol	Caccialanza, R	Nutrition	10.1016/j.nut.2020.110835
53	Easy-to-prescribe nutrition support in the intensive care in the era of COVID-19	de Watteville, A	Clin Nutr ESPEN	10.1016/j.clnesp.2020.07.015
54	Normothermia is best achieved by warming above and below with pre-warming adjunct: a comparison of conductive fabric versus forced-air and water	Ohki, K	Surg Technol Int	
55	Nutritional Support in Coronavirus 2019 Disease	Stachowska, E	Medicina-Lithuania	10.3390/medicina56060289
56	Position paper of the Italian association of medical specialists in dietetics and clinical nutrition (ANSISA) on nutritional management of patients with COVID-19 disease	Cena, H	Mediterr J Nutr Metab	10.3233/MNM-200425

Table S3: Articles returned from WoS and excluded sorted by exclusion reason (cont'd)

No.	Title	First author	Journal	DOI
<i>Case reports and clinical care (cont'd)</i>				
57	Postintubation Dysphagia During COVID-19 Outbreak-Contemporary Review	Frajkova, Z	Dysphagia	10.1007/s00455-020-10139-6
<i>Economics – No connection (or tangential connection) to COVID-19</i>				
58	Regional specialization and agglomeration effects in the Russian economy	Rastvortseva, SN	Econ Soc Changes-Facts Trends Forecast	10.15838/esc.2020.3.69.4
59	The Discounted money value of human lives lost due to COVID-19 in Spain	Kirigia, JM	J Health Res	10.1108/JHR-04-2020-0116
60	The effectiveness of self-sufficiency policy: international price transmissions in beef markets	Guo, J	Sustainability	10.3390/su12156073
61	Transformation of the strategy of state economic policy in modern conditions	Petrunen, I	Balt J Econ Stud	10.30525/2256-0742/2020-6-3-107-113
<i>Education – No connection (or tangential connection) to COVID-19</i>				
62	Development and use of kitchen chemistry home practical activities during unanticipated campus closures	Schultz, M	J Chem Educ	10.1021/acs.jchemed.0c00620
63	Visualizing the invisible: class excursions to ignite children's enthusiasm for microbes	McGenity, TJ	Microb Biotechnol	10.1111/1751-7915.13576
<i>Governance – No connection (or tangential connection) to COVID-19</i>				
64	From Four-Way Linking to a One Health Platform in Egypt: institutionalisation of a multidisciplinary and multisectoral One Health system	Allal, L	Rev Sci Tech	10.20506/rst.38.1.2958
65	Political intrusions into the international health regulations treaty and its impact on management of rapidly emerging zoonotic pandemics: what history tells us	Burkle, FM	Prehosp Disaster Med	10.1017/S1049023X20000515
<i>Healthcare occupational safety</i>				
66	Coronavirus contamination in dental clinics. New systems and operating devices	Gandolfi, MG	Dent Cadmos	10.19256/d.cadmos.06.2020.06
67	COVID-19 in Africa: care and protection for frontline healthcare workers	Chersich, MF	Glob Health	10.1186/s12992-020-00574-3

Table S3: Articles returned from WoS and excluded sorted by exclusion reason (cont'd)

No.	Title	First author	Journal	DOI
<i>Healthcare occupational safety (cont'd)</i>				
68	Health issues among healthcare workers during COVID-19 pandemic: a psychosomatic approach	Widjaja, FF	Acta Med Indones	
69	Nutritional recommendations for healthcare and essential personnel exposed to COVID-19 in Latin America	Palacios, C	Arch Latinoam Nutr	10.37527.2019.69.4.005
70	Pediatric endoscopy in the era of Coronavirus Disease 2019: a North American Society for Pediatric Gastroenterology, Hepatology, and Nutrition position paper	Walsh, CM	J Pediatr Gastro–enterol Nutr	10.1097/MPG.00000000000002750
71	Safe surgery during the coronavirus disease 2019 crisis	Tivey, DR	ANZ J Surg	10.1111/ans.16089
72	Strategic implementation of dental infection control in resource-poor jurisdictions during COVID-19 pandemic: a perspective from South Africa	Blignaut, E	Acta Odontol Scand	10.1080/00016357.2020.1804073
<i>Information technology – No connection (or tangential connection) to COVID-19</i>				
73	An Infoveillance system for detecting and tracking relevant topics from Italian tweets during the COVID-19 event	De Santis, E	IEEE Access	10.1109/ACCESS.2020.3010033
74	We all deserve broadband	Higginbotham, S	IEEE Spectr	10.1109/MSPEC.2020.9078451
<i>Marketing – No connection (or tangential connection) to COVID-19</i>				
75	Impact of the perceived threat of COVID-19 on variety-seeking	Kim, J	Australas Mark J	10.1016/j.ausmj.2020.07.001
<i>Nutrition – No connection (or tangential connection) to COVID-19</i>				
76	Food choices of young adults in the United States of America: a scoping review	Powell, PK	Adv Nutr	10.1093/advances/nmy116
<i>Political science – No connection (or tangential connection) to COVID-19</i>				
77	The Middle East at a time of negative certainty	Zvyagel'skaya, ID	Mirovaya Ekon Mezhdunar Otnos	10.20542/0131-2227-2020-64-6-94-103
<i>Technology design</i>				
78	A laboratory-based study examining the properties of silk fabric to evaluate its potential as a protective barrier for personal protective equipment and as a functional material for face coverings during the COVID-19 pandemic	Parlin, AF	PLoS One	10.1371/journal.pone.0239531

Table S3: Articles returned from WoS and excluded sorted by exclusion reason (cont'd)

No.	Title	First author	Journal	DOI
<i>Technology design (cont'd)</i>				
79	A novel and stable way for energy harvesting from Bi ₂ Te ₃ Se alloy based semitransparent photo-thermoelectric module	Fatima, N	J Alloys Compd	10.1016/j.jalcom.2020.156702
80	Charged PVDF multilayer nanofiber filter in filtering simulated airborne novel coronavirus (COVID-19) using ambient nano-aerosols	Leung, WWF	Sep Purif Technol	10.1016/j.seppur.2020.116887
81	Decontamination methods for reuse of filtering facepiece respirators	Su-Velez, BM	JAMA Otolaryngol Head Neck Surg	10.1001/jamaoto.2020.1423
82	Electrostatic charged nanofiber filter for filtering airborne novel coronavirus (COVID-19) and nano-aerosols	Leung, WWF	Saf Sci	10.1016/j.ssci.2020.104830
83	Engineering graphene oxide/water interface from first principles to experiments for electrostatic protective composites	Valentini, L	Sep Purif Technol	10.1016/j.seppur.2020.116886
84	Industrial lubricant removal using an ultrasonically activated water stream, with potential application for Coronavirus decontamination and infection prevention for SARS-CoV-2	Malakout-ikhah, M	Polymers (Basel)	10.3390/polym12071596
85	Internet of things (IoT) based coordination system in Agri-food supply chain: development of an efficient framework using DEMATEL-ISM	Yadav, S	Trans Inst Met Finish	10.1080/00202967.2020.1805221
86	Nanobiotechnology model arising from coronavirus interacting with the AQP channels along the respiratory regions and estimating the infectivity rate of the COVID19 outbreak based on temperature and direct contact rate	Al Garalleh, H	Oper Manag Res	10.1007/s12063-020-00164-x
87	Photocatalytic nanowires-based air filter: towards reusable protective masks	Horvath, E	Nanosci Nanotechnol Lett	10.1166/nnl.2020.3077
88	Properties and reactivities of niclosamide in different media, a potential antiviral to treatment of COVID-19 by Using DFT calculations and molecular docking	Romani, D	Adv Funct Mater	10.1002/adfm.202004615

Table S3: Articles returned from WoS and excluded sorted by exclusion reason (cont'd)

No.	Title	First author	Journal	DOI
<i>Technology design (cont'd)</i>				
89	Electrostatic charged nanofiber filter for filtering airborne novel coronavirus (COVID-19) and nano-aerosols	O'Brien, S	Biointerface Res Appl Chem	10.3390/en13174528
90	Synergy of thermochemical treatment of dried distillers grains with solubles with bioethanol production for increased sustainability and profitability	Londhe, V	Energies	10.1016/j.msec.2020.111330
91	Unfolding the future: self-controlled catalytic nanomotor in healthcare system	Roos, YH	Mat Sci Eng C-Mater	10.1007/s12393-020-09234-z
92	Water and pathogenic viruses inactivation – food engineering perspectives	Bhattarai, K	Food Eng Rev	10.3390/agriculture10060224
<i>Topography – No connection (or tangential connection) to COVID-19</i>				
93	Influence of topography on sustainable land management: an analysis of socioeconomic and eodemographic conditions of Nepal	Chaudhuri, S	Agriculture-Basel	10.1063/5.0015984
<i>Transmission of COVID-19</i>				
94	Modeling the role of respiratory droplets in Covid-19 type pandemics	Chaudhuri, S	Phys Fluids	10.1063/5.0015984
95	Persistence of SARS-CoV-2 in the environment and COVID-19 transmission risk from environmental matrices and surfaces	Carraturo, F	Environ Pollut	10.1016/j.envpol.2020.115010
96	Quantifying aerosolization of facial plastic surgery procedures in the COVID-19 era: safety and particle generation in craniomaxillofacial trauma and rhinoplasty	Gadkaree, SK	Facial Plast Surg Aesthetic Med	10.1089/fpsa.m.2020.0322
97	Review of novel human beta-coronavirus (2019-nCoV or SARS-CoV-2) from the food industry perspective – appropriate approaches to food production technology	Goli, M	Food Sci Nutr	10.1002/fsn3.1892
98	Synanthropic rodents as virus reservoirs and transmitters	Gravinatti, ML	Rev Soc Bras Med Trop	10.1590/0037-8682-0486-2019

Table S4: Articles returned from Web of Science and reviewed for causal relations

No.	Title	First author	Journal	DOI
99	An updated min-review on environmental route of the SARS-CoV-2 transmission	Hoseinzadeh, E	Ecotoxicol Environ Saf	10.1016/j.ecoenv.2020.111015
100	Anthropogenic gadolinium in freshwater and drinking water systems	Brunjes, R	Water Res	10.1016/j.watres.2020.115966
101	Assuring food security in Singapore, a small island state facing COVID-19	Teng, P	Food Secur	10.1007/s12571-020-01077-0
102	Baby pangolins on my plate: possible lessons to learn from the COVID-19 pandemic	Volpato, G	J Ethnobiol Ethnomed	10.1186/s13002-020-00366-4
103	Can the coronavirus disease be transmitted from food? A review of evidence, risks, policies and knowledge gaps	Han, J	Environ Chem Lett	10.1007/s10311-020-01101-x
104	Challenges of COVID-19 in children in low- and middle-income countries	Zar, HJ	Paediatr Respir Rev	10.1016/j.prrv.2020.06.016
105	Changes in weight and nutritional habits in adults with obesity during the lockdown period caused by the COVID-19 virus emergency	Pellegrini, M	Nutrients	10.3390/nu12072016
106	Cleaning the River Ganga: impact of lockdown on water quality and future implications on river rejuvenation strategies	Dutta, V	Sci Total Environ	10.1016/j.scitotenv.2020.140756
107	Communicable diseases (including COVID-19) – induced global depression: caused by inadequate healthcare expenditures, population density, and mass panic	Anser, MK	Front Public Health	10.3389/fpubh.2020.00398
108	Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: feasibility, economy, opportunities and challenges	Hart, OE	Sci Total Environ	10.1016/j.scitotenv.2020.138875
109	Coronavirus 2019 and health systems affected by protracted conflict: the case of Syria	Abbara, A	Int J Infect Dis	10.1016/j.ijid.2020.05.003
110	Coronavirus disease (COVID-19) and immunity booster green foods: a mini review	Arshad, MS	Food Sci Nutr	10.1002/fsn3.1719
111	COVID-19 (SARS-CoV-2) pandemic: fears, facts and preventive measures	Ayenigbara, IO	Germs	10.18683/germs.2020.1208

Table S4: Articles returned from Web of Science and reviewed for causal relations (cont'd)

No.	Title	First author	Journal	DOI
112	Covid-19 and dietary socioecology: risk minimisation	Watanabe, S	Asia Pac J Clin Nutr	10.6133/apjcn.20200729(2).0001
113	COVID-19 and food and nutritional (in) security: action by the Brazilian Federal Government during the pandemic, with budget cuts and institutional dismantlement	Alpino, TDA	Cad Saude Publica	10.1590/0102-311X00161320
114	COVID-19 and labour in agriculture: Economic and productive impacts in an agricultural area of the Mediterranean	Cortignani, R	Ital J Agron	10.4081/ija.2020.1653
115	COVID-19 and quarantine orders: A practical approach	Botes, WM	SAMJ S Afr Med J	10.7196/SAMJ.2020.v110i6.14794
116	Covid-19 and spatial planning A few issues concerning public policy	Lai, S	TeMA J Land Use Mob Environ	10.6092/1970-9870/6846
117	COVID-19 and surface water quality: improved lake water quality during the lockdown	Yunus, AP	Sci Total Environ	10.1016/j.scitotenv.2020.139012
118	COVID-19 and the Rohingya refugees in Bangladesh: the challenges and recommendations	Islam, MN	Asia Pac J Public Health	10.1177/1010539520932707
119	COVID-19 lockdown measures reveal human impact on water transparency in the Venice Lagoon	Braga, F	Sci Total Environ	10.1016/j.scitotenv.2020.139612
120	COVID-19 pandemic and lockdown: cause of sleep disruption, depression, somatic pain, and increased screen exposure of office workers and students of India	Majumdar, P	Chronobiol Int	10.1080/07420528.2020.1786107
121	COVID-19 pandemic and mitigation strategies: implications for maternal and child health and nutrition	Akseer, N	Am J Clin Nutr	10.1093/ajcn/nqaa171
122	COVID-19 pandemic and Rohingya refugees in Bangladesh: What are the major concerns?	Banik, R	Glob Public Health	10.1080/17441692.2020.1812103
123	Covid-19, environmental engineering and the end of the world as we know it	Pawlowski, A	Probl Ekoroż-woju	

Table S4: Articles returned from Web of Science and reviewed for causal relations (cont'd)

No.	Title	First author	Journal	DOI
124	COVID-19: socio-environmental challenges of Rohingya refugees in Bangladesh	Shammi, M	J Environ Health Sci Eng	10.1007/s40201-020-00489-6
125	Covid19 pandemic as a further driver of water scarcity in Africa	Boretti, A	GeoJournal	10.1007/s10708-020-10280-7
126	Dietary choices and habits during COVID-19 lockdown: experience from Poland	Sidor, A	Nutrients	10.3390/nu12061657
127	Diversified farms facing the Covid-19 pandemic: first signals from Italian case studies	Mastronardi, L	Sustainability	10.3390/su12145709
128	Effect of heat and humidity on the incidence and mortality due to COVID-19 pandemic in European countries	Meo, SA	Eur Rev Med Pharmacol Sci	10.26355/eurrev_202009_22874
129	Effects of COVID-19 home confinement on eating behaviour and physical activity: results of the ECLB-COVID19 international online survey	Ammar, A	Nutrients	10.3390/nu12061583
130	Fast deployment of COVID-19 disinfectant from common ethanol of gas stations in Brazil	Itiki, R	Health Policy Technol	10.1016/j.hlpt.2020.07.002
131	Frequent hand washing for COVID-19 prevention can cause hand dermatitis: management tips	Beiu, C	Cureus	10.7759/cureus.7506
132	Hand hygiene among health care workers during COVID-19 pandemic: challenges and recommendations	Araghi, F	Dermatitis	10.1097/DER.0000000000000639
133	Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic	Lal, R	Food Secur	10.1007/s12571-020-01058-3
134	How health inequality affect responses to the COVID-19 pandemic in Sub-Saharan Africa	Okoi, O	World Dev	10.1016/j.worlddev.2020.105067
135	How Indian agriculture should change after COVID-19	Kumar, A	Food Secur	10.1007/s12571-020-01063-6
136	ICT, social media and COVID-19: evidence from informal home-based business community in Kuwait City	Saleh, Y	J Enterprising Communities People Places Global Econ	10.1108/JEC-07-2020-0131

Table S4: Articles returned from Web of Science and reviewed for causal relations (cont'd)

No.	Title	First author	Journal	DOI
137	Impact of COVID-19 pandemic on agricultural wholesale prices in India: a comparative analysis across the phases of the lockdown	Ali, J	J Public Aff	10.1002/pa.2402
138	Impending scope of water sanitation and hygiene (WASH) in the post COVID19 pandemic era: an opportunity call	Kalpana, P	Indian J Community Health	
139	Imprints of pandemic lockdown on subsurface water quality in the coastal industrial city of Tuticorin, South India: A revival perspective	Selvam, S	Sci Total Environ	10.1007/s10708-020-10280-7
140	Indian agriculture, air pollution, and public health in the age of COVID	McDonald, AJ	World Dev	10.3390/nu12061657
141	Indigenous smallholder struggles in Peru: nutrition security, agrobiodiversity, and food sovereignty amid transforming global systems and climate change	Zimmerer, KS	J Lat Am Geogr	10.3390/su12145709
142	Indirect impact of COVID-19 on environment: a brief study in Indian context	Lokhandwala, S	Environ Res	10.26355/eurrev_202009_22874
143	Individual risk management strategy and potential therapeutic options for the COVID-19 pandemic	Gasmi, A	Clin Immunol	10.1016/j.clim.2020.108409
144	Influence of COVID-19 spread on water drinking demand: the case of Puglia Region (Southern Italy)	Balacco, G;	Sustainability	10.3390/su12155919
145	Introduction to modern climate change	Ahmed, M	Sci Total Environ	10.1016/j.scitotenv.2020.139397
146	LGBTQ plus farmer health in COVID-19	Wypler, J	J Agromedicine	10.1080/1059924X.2020.1814923
147	Making COVID-19 prevention etiquette of social distancing a reality for the homeless and slum dwellers in Ghana: lessons for consideration	Morgan, AK	Local Environ	10.1080/13549839.2020.1789854
148	Maternal health and non-communicable disease prevention: An investment case for the post COVID-19 world and need for better health economic data	Kapur, A	Int J Gynaecol Obstet	10.1002/ijgo.13198

Table S4: Articles returned from Web of Science and reviewed for causal relations (cont'd)

No.	Title	First author	Journal	DOI
149	Measuring Italian citizens' engagement in the first wave of the COVID-19 pandemic containment measures: a cross-sectional study	Graffigna, G	PLoS One	10.1371/journal.pone.0238613
150	Migrant workers at crossroads-the Covid-19 pandemic and the migrant experience in India	Suresh, R	Soc Work Public Health	10.1080/19371918.2020.1808552
151	Nowhere to hide: The significant impact of coronavirus disease 2019 (COVID-19) measures on elite and semi-elite South African athletes	Pillay, L	J Sci Med Sport	10.1016/j.jsams.2020.05.016
152	Pandemics and food systems-towards a proactive food safety approach to disease prevention & management	Aiyar, A	Food Secur	10.1007/s12571-020-01074-3
153	Physical activity and nutrition guidelines to help with the fight against COVID-19	Khorami-pour, K	J Sports Sci	10.1080/02640414.2020.1807089
154	Physics-based Bathymetry and Water Quality Retrieval Using PlanetScope Imagery: Impacts of 2020 COVID-19 Lockdown and 2019 Extreme Flood in the Venice Lagoon	Niroumand-Jadidi, M	Remote Sens	10.3390/rs12152381
155	Positive and Negative Changes in Food Habits, Physical Activity Patterns, and Weight Status during COVID-19 Confinement: Associated Factors in the Chilean Population	Reyes-Olavarria, D	Int J Environ Res Public Health	10.3390/ijerph17155431
156	Post-travel screening of symptomatic and asymptomatic travelers	Korzeniewski, K	Int Marit Health	10.5603/IMH.2020.0023
157	Potential consequences of COVID-19 for sustainable meat consumption: the role of food safety concerns and responsibility attributions	Yang, XS	Br Food J	10.1108/BFJ-04-2020-0332
158	Resilience and Vulnerabilities of the North American Food System during the Covid-19 Pandemic	Orden, D	Eurochoices	10.1111/1746-692X.12273
159	Review of novel human beta-coronavirus (2019-nCoV or SARS-CoV-2) from the food industry perspective-Food plant health principles	Goli, M	J Food Saf	10.1111/jfs.12853

Table S4: Articles returned from Web of Science and reviewed for causal relations (cont'd)

No.	Title	First author	Journal	DOI
160	Review of Online Food Delivery Platforms and their Impacts on Sustainability	Li, C	Sustainability	10.3390/su12145528
161	Sanitizer aerosol-driven ocular surface disease (SADOSD)-A COVID-19 repercussion?	Shetty, R	Indian J Ophthalmol	10.4103/ijo.IJO_1308_20
162	SARS-CoV-2 pandemic: causes and current situation, historical lessons, and strategical therapeutic interventions	Shereen, MA	Biomed Res Ther	10.15419/bmrat.v7i5.608
163	Serving up food studies online: teaching about food from somewhere from nowhere	Levkoe, CZ	Food Cult Soc	10.1080/15528014.2020.1754041
164	Slum Health: Arresting COVID-19 and Improving Well-Being in Urban Informal Settlements	Corburn, J	J Urban Health	10.1007/s11524-020-00438-6
165	Social economic impact of COVID-19 outbreak in India	Kumar, MS	Int J Pervasive Comput Commun	10.1108/IJPC-06-2020-0053
166	Socially distanced school-based nutrition program under COVID 19 in the rural Niger Delta	Francis, NN	Extr Ind Soc	10.1016/j.exis.2020.04.007
167	Strategies and Solutions for Team Sports Athletes in Isolation due to COVID-19	Jukic, I	Sports	10.3390/sports8040056
168	Structural barriers to adhering to health behaviours in the context of the COVID-19 crisis: Considerations for low- and middle-income countries	Coetzee, BJ	Glob Public Health	10.1080/17441692.2020.1779331
169	Sustainability and development after COVID-19	Barbier, EB	World Dev	10.1016/j.worlddev.2020.105082
170	The Covid-19 pandemic effects in rural areas Turning challenges into opportunities for rural regeneration	de Luca, C	TeMA J Land Use Mob Environ	10.6092/1970-9870/6844
171	The Effects of COVID-19 Pandemic Outbreak on the Household Economy	Celik, B	J Res Med Dent Sci	
172	The Food Acquisition Program (PAA) as a strategy to face the challenges of COVID-19	Sambuichi, RHR	Rev De Adm Publica	10.1590/0034-761220200258x

Table S4: Articles returned from Web of Science and reviewed for causal relations (cont'd)

No.	Title	First author	Journal	DOI
173	The Impact of Isolation Measures Due to COVID-19 on Energy Intake and Physical Activity Levels in Australian University Students	Gallo, LA	Nutrients	10.3390/nu12061865
174	The impact of the Covid-19 health crisis on the water cycle in France	Paplorey, C	Houille Blanche	10.1051/lhb/2020031
175	The impacts of COVID-19 measures on global environment and fertility rate: double coincidence	Anser, MK	Air Qual Atmos Health	10.1007/s11869-020-00865-z
176	The management of coronavirus disease 2019 (COVID-19)	Liu, JL	J Med Virol	10.1002/jmv.25965
177	Understanding COVID-19 transmission, health impacts and mitigation: timely social distancing is the key	Kaur, S	Environ Dev Sustain	10.1007/s10668-020-00884-x
178	Unlocking the impacts of COVID-19 lockdowns: changes in thermal electricity generation water footprint and virtual water trade in Europe	Roidt, M	Environ Sci Technol Lett	10.1021/acs.estlett.0c00381
179	Wither the self-sufficiency illusion? Food security in Arab Gulf States and the impact of COVID-19	Woertz, E	Food Secur	10.1007/s12571-020-01081-4

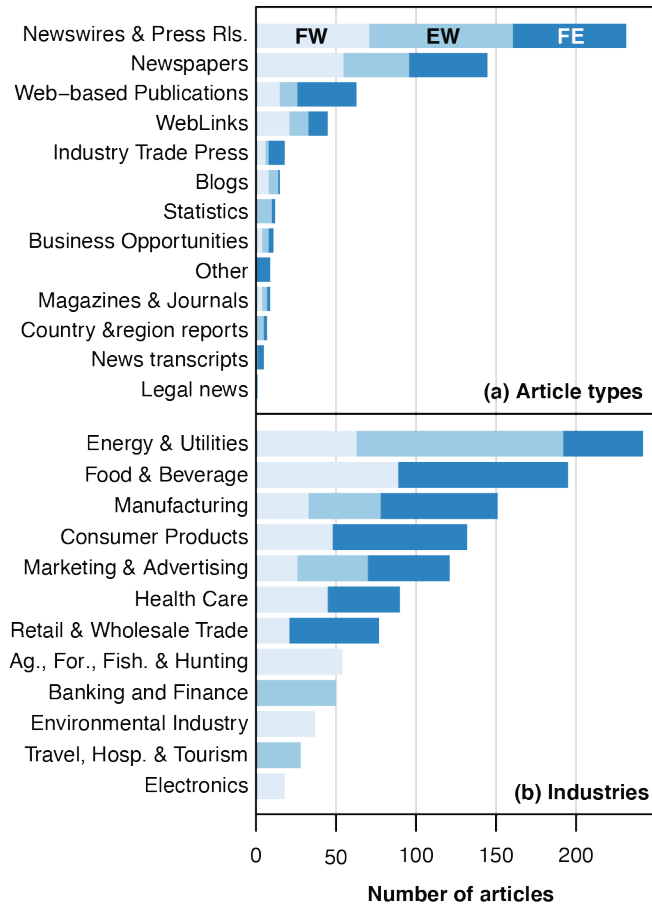


Figure S1: Distribution of news/media articles by (a) article type and (b) industry (FW = food-water; EW = energy-water; FE = food-energy; legend at top applies throughout). Articles returned may be counted in multiple categories.

Table S5: Summary of NexisUni search syntaxes

No.	F/E/W ^a	Search terms	Total results	English results	Intl. sources	U.S. sources	Reason for exclusion ^b
1	FEW	""COVID-19" OR "coronavirus" AND ""Water" OR "Energy" OR "Food""	2,103, 877	2,037,851	1,427,431	676,446	many irrelevant articles within first page
2	E	title(COVID-19) or title(coronaviruses) and title(energy)	6,024	5,924	3,931	2,093	too many results; many not relevant within first two pages
3	W	title(COVID-19) or title(coronaviruses) and title(water)	4,940	4,892	3,329	1,611	too many results; many not relevant within first two pages
4	F	title(COVID-19) or title(coronaviruses) and title(food)	21,330	20,999	15,064	6,266	too many results; many not relevant within first two pages
5	FEW	"coronavirus" or "COVID-19" and "food" and "water" and "energy"	31,611	31,535	18,182	13,353	many irrelevant articles within first page
6	FEW	title(coronaviruses) or title(COVID-19) and food and water and energy	5,162	5,153	3,335	1,827	too many results, many not relevant within first 2 pages
7	FEW	title(COVID-19) and title(food) and title(water) and title(energy)	0	0	0	0	no results

^a Search relevant to Food/Energy/Water component in this column

^b Searches 1–10 excluded; searches 11–13 included

Table S5: Summary of NexisUni search syntaxes (cont'd) ^a

No.	F/E/W	Search terms	Total results	English results	Intl. sources	U.S. sources	Reason for exclusion
8	FW	title(coronavirus) or title(COVID-19) and title(food) and title(water)	143	143	104	38	Included in Search 10
9	EW	title(coronavirus) or title(COVID-19) and title(energy) and title(water)	44	44	28	16	Included in Search 11
10	FE	title(coronavirus) or title(COVID-19) and title(energy) and title(food)	48	48	26	22	Included in Search 12
11	FW	title(coronavirus) or title(COVID*) or title(SARS-CoV-2) and title(food) or title(nutrition*) or title(hunger*) or title(crop*) or title(agricultur*) and title(water) or title(irrigat*)	184	184	133	51	n/a (Included)
12	EW	title(coronavirus) or title(COVID*) or title(SARS-CoV-2) and title(energy) or title(electri*) or title(heat*) or title(conditioning) or title(conditioner) and title(water) or title(irrigat*)	185	184	113	72	n/a (Included)
13	FE	title(coronavirus) or title(COVID*) or title(SARS-CoV-2) and title(food) or title(nutrition*) or title(hunger*) or title(crop*) or title(agricultur*) and title(energy) or title(electri*) or title(heat*) or title(conditioning) or title(conditioner)	203	201	153	50	n/a (Included)

^a See footnotes on p. 21

Table S6: Summary of causal relations with articles invoking each

Causal relation	F/E/W^a	No. of news/media articles invoking relation	Journal articles invoking relation (from Table S4)
<i>Relations identified in scientific literature (solid lines in Figure 1)</i>			
SARS-CoV-2 transmission → COVID-19 mortality/morbidity		41	101, 104, 107, 114, 115, 118, 123, 124, 126, 127, 129, 134, 135, 136, 137, 138, 143, 144, 146, 148, 150, 151, 158, 161, 162, 164, 165, 166, 168, 171, 173, 174, 176, 178, 179
testing → SARS-CoV-2 transmission		51	101, 104, 105, 107, 110, 111, 112, 113, 114, 118, 121, 124, 126, 129, 133, 134, 135, 137, 138, 141, 143, 147, 148, 155, 158, 159, 160, 164, 165, 168, 173, 176, 179
hand washing → SARS- CoV-2 transmission		16	101, 104, 111, 114, 115, 118, 123, 124, 126, 127, 131, 134, 135, 136, 137, 150, 151, 158, 161, 162, 164, 165, 166, 171, 173
physical distancing → SARS-CoV-2 transmission		17	104, 111, 115, 118, 124, 126, 129, 138, 144, 146, 147, 156, 161, 164, 165, 168, 173, 176, 177, 178
physical distancing → psychosocial harm		3	104, 105, 110, 112, 115, 120, 121, 126, 129, 133, 143, 148, 151, 155, 162, 167, 170, 171, 176, 179
physical distancing → employment/economic activity		11	101, 114, 115, 123, 124, 126, 127, 135, 136, 137, 150, 151, 158, 162, 165, 166, 171, 173
COVID-19 mortality/morbidity → comorbidities		11	105, 113, 114, 121, 124, 133, 137, 141, 144, 148, 160, 168
COVID-19 mortality/morbidity → burden of disease		18	101, 113, 118, 121, 124, 133, 143, 164, 168, 176, 179
psychosocial harm → burden of disease		17	101, 105, 118, 126, 129, 148, 155, 158, 168, 179
economic support → purchasing power		17	107, 124, 126, 135, 137, 165, 168, 179

^a Search relevant to Food/Energy/Water component in this column

Table S6: Summary of causal relations with articles invoking each (cont'd)

Causal relation	F/E/W^a	No. of news/media articles invoking relation	Journal articles invoking relation (from Table S4)
<i>Relations identified in scientific literature (solid lines in Figure 1) (cont'd)</i>			
food/nutrition security/choices → comorbidities	F	2	110, 112, 121, 126, 129, 133, 143, 148, 176, 179
comorbidities → burden of disease		1	105, 124, 126, 129, 143, 148, 155, 168, 176
food supply → SARS-CoV-2 transmission	F	6	102, 103, 135, 152, 157, 158, 162
purchasing power → food/nutrition security/choices	F	17	101, 118, 126, 148, 158, 168, 179
comorbidities → COVID-19 mortality/morbidity		11	101, 124, 143, 148, 168, 176, 179
physical distancing → food supply	F	11	113, 114, 121, 133, 137, 141, 160
waterborne pathogens → comorbidities	W	3	118, 124, 138, 147, 164, 168
food supply → food/nutrition security/choices	F	14	101, 113, 121, 133, 179
comorbidities → SARS-CoV-2 transmission		0	110, 112, 122, 140, 153
water availability → hand washing	W	10	104, 134, 138, 164
employment/economic activity → purchasing power		4	107, 115, 137, 158
hand washing → comorbidities	W	1	130, 131, 132, 161
SARS-CoV-2 transmission → food supply	F	3	113, 144, 146
physical distancing → water demand	W	3	144, 146, 178
physical distancing → comorbidities		1	120, 153, 167
employment/economic activity → water quality	W	0	106, 117, 142
physical distancing → water quality	W	0	119, 139, 154
physical distancing → comorbidities		1	120, 153, 167
physical distancing → physical activity		0	129, 143, 173
water availability → food supply	F/W	6	101, 179
physical activity → comorbidities		0	129, 143
water demand → water availability	W	0	144
SARS-CoV-2 transmission → food/nutrition choices/security	F		157

^a Search relevant to Food/Energy/Water component in this column

Table S6: Summary of causal relations with articles invoking each (cont'd)

Causal relation	F/E/W ^a	No. of news/media articles invoking relation	Journal articles invoking relation (from Table S4)
<i>Relations not identified in scientific literature (dashed lines in Figure 1)</i>			
purchasing power → water security	W	12	
purchasing power → energy security	E	8	
economic support → physical distancing		4	
water security → physical distancing	W	3	
hand washing → physical distancing	W	2	
water demand → waterborne pathogens	W	2	
economic support → employment/economic activity		2	
physical distancing → hand washing	W	1	
physical distancing → energy demand	E	1	
masks → SARS-CoV-2 transmission ^b		1	
water availability → water security	W	1	
energy demand → energy security	E	0	
energy security → comorbidities	E	0	
<i>Relations omitted from Figure 1 for clarity</i>			
air pollution → comorbidities		0	140
burning ag fields → air pollution	F	0	140
food/nutrition security/choices → environment	F	0	157
SARS-CoV-2 transmission → commodities prices		0	137
health engagement → SARS-CoV-2 transmission		0	149
health engagement → employment/economic activity		0	149
ethanol → hand washing	W	0	130
healthcare system → water quality	W	0	100
economic support → resources for development		0	125
physical distancing → fertility rates		0	175
physical distancing → environment		0	175
conflict → SARS-CoV-2 transmission		0	109
health systems management → SARS-CoV-2 transmission		0	109

^a Search relevant to Food/Energy/Water component in this column

^b Grouped with testing, contact tracing and housing/shelter (solid lines) in Figure 1

Table S6: Summary of causal relations with articles invoking each (cont'd)

Causal relation	F/E/W^a	No. of news/media articles invoking relation	Journal articles invoking relation (from Table S4)
<i>Relations omitted from Figure 1 for clarity (cont'd)</i>			
natural disasters → burden of disease		0	124
physical distancing → fines		0	115
fines → purchasing power		0	115
physical distancing → educational outcomes		0	166
weather → SARS-CoV-2 transmission		0	128
weather → COVID-19 mortality/morbidity		0	128
identity inequality → SARS-CoV-2 transmission		0	146

^a Search relevant to Food/Energy/Water component in this column



Figure S2: Most frequent words in (a) food-water, (b) energy-water and (c) food-energy groups of news/media articles.

Table S7: Terms by semantic similarity to “government” for groups of popular press articles

Rank	Food-Energy	Food-Water	Energy-Water
1	pandemic	pandemic	report
2	virus	virus	state
3	president	country	virus
4	country	uk	lockdown
5	company	lockdown	country
6	us	state	crisis
7	administration	coronavirus	world
8	world	food	market
9	outbreak	world	outbreak
10	report	crisis	vendors
11	market	market	lockdown
12	department	centre	study
13	food	disease	forecast
14	disease	industry	region
15	public	region	situation
16	agency	outbreak	support
17	state	city	order
18	time	migrants	time
19	hospital	health	people
20	day	future	funding

Table S8: Terms by semantic similarity to “market” for groups of popular press articles

Rank	Food-Energy	Food-Water	Energy-Water
1	industry	pandemic	industry
2	virus	country	revenue
3	country	virus	report
4	food	government	pandemic
5	us	uk	sales
6	report	lockdown	country
7	production	outbreak	virus
8	pandemic	world	crisis
9	coronavirus	coronavirus	size
10	president	crisis	global
11	outbreak	centre	research
12	growth	food	coronavirus
13	lockdown	area	future
14	world	city	growth
15	company	house	trends
16	revenue	state	study
17	administration	growth	state
18	disease	disease	region
19	public	industry	department
20	government	globe	segment