ELEMENTA
Science of the Anthropocene

Mulvaney, D, et al. 2020. Pandemic disruptions in energy and the environment. *Elem Sci Anth*, 8: XX. DOI: https://doi.org/10.1525/elementa.052

COMMENTARY

Pandemic disruptions in energy and the environment

Dustin Mulvaney[1], Joshua Busby[2], and Morgan D. Bazilian[3]

Public health measures implemented during the coronavirus pandemic have had significant global impacts on energy systems. Some changes may be ephemeral: as industries go back to work and supply chains relink once production resumes, energy use and emissions have and will continue to rebound. Some may be more durable, such as reductions in commuter and business travel and increases in teleworking. The crisis has exposed the persistent vulnerability of communities of color and those living in poverty, as well as highlighting weaknesses in just-in-time production systems and inequities of supply chains. The social and policy response to the societal impacts of the coronavirus crisis will affect energy systems and the environment in complex and dynamic ways over the long run. Strategic policy responses by nations, communities, organizations, and individuals could go a long way toward reshaping energy systems and impacts on communities and the environment. Here, we highlight themes for continued investigation and research into socioecological interactions between the Great Lockdown and pathways for recovery with a focus on energy systems and the environment.

Keywords: Coronavirus, COVID-19, Energy and the environment, Global environmental change, Environmental inequality

1. Introduction

The public health measures taken to protect human lives from the novel coronavirus pandemic are causing severe disruptions in social and economic activities around the world. The measures include "shelter-in-place" and social distancing efforts affecting up to 4 billion people, what some are calling "the Great Lockdown" (International Monetary Fund, 2020). A concurrent crash in the global oil market and accompanying financial losses cascaded through other extractive industries, supply chains, manufacturers, logistics operations, and even recyclers. The pandemic has destroyed capital value in some parts of the economy, contributed to dramatic declines in demand for gasoline and aviation fuels, and led producers of commodities like aluminum and steel to face closures from supply gluts that far outweigh demand, complicated further by coronavirus outbreaks among miners across the globe (*Financial Times*, 2020).

As other commercial and industrial activities grind to a halt, demand for electric power and natural gas has been steady, but geographically varied (Honoré, 2020). Forecast deployment of new wind and solar farms is down in some countries hard hit by the pandemic (Associated Press, 2020; IEA, 2020a). The crisis has affected employment across the energy sector. In the United States, nearly 600,000 workers in clean energy industries lost jobs in March and April 2020 (E2, 2020); 106,000 jobs were added back in June, the first month of clean energy job growth in the United States since the pandemic started (BW Research, 2020a). The Great Lockdown's effect across large segments of the economy will have ripple effects that will impact energy industries and, consequently, society and environment for years to come. Some effects will be ephemeral, while others more durable. The long-lasting pandemic disruptions in energy and the environment are the focus of this commentary.

The most immediate environmental visualizations of the reduction in human activity came from the U.S. National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) whose satellite imagery detailed pronounced improvements in air quality—most notably particulate matter, volatile organic compounds, and nitrogen pollution—around the world. Severely curtailed transportation led to reduced use of gasoline and jet fuel and the associated precursors that lead to ground-level smog formation. These pictures were reinforced by widely disseminated spatial data showing improvements in air quality from densely populated urban cores such as Wuhan, China, to rural highway corridors such as California's Central Valley (NASA, 2020; World Economic Forum, 2020). U.S. Environmental Protection Agency (EPA) air pollution monitoring data taken from the Port of Long Beach in Los Angeles suggested the air in March 2020

[1] Environmental Studies Department, San José State University, San José, California, USA

[2] LBJ School of Public Affairs, University of Texas, Austin, Texas, USA

[3] The Payne Institute for Public Policy, Colorado School of Mines, Golden, Colorado, USA

* Corresponding author:
Email: dustin.mulvaney@sjsu.edu

was the cleanest since monitoring began in 1980 (EPA, 2020). Government data collected in New Delhi, India, found that particulate matter from vehicles and construction dust levels were the lowest levels since detailed records were kept (about 40 years). Air pollution hotspot maps and images depicting clear skies around Los Angeles, Delhi, London, and other major cities with storied histories of air pollution were widely shared in digital, print, and social media as "evidence" of silver linings in the pandemic in the late winter and spring 2020 (San Jose Mercury News, 2020).

Global greenhouse gas (GHG) emissions fell by 5.8% through the first quarter of 2020 as the lockdowns spread from China to Europe and the rest of the world (Lui et al., 2020). Shutdowns in China caused an emissions drop of 25% from January through March (Carbon Brief, 2020a). Overall, GHG emission reductions could drop from 5% to 8% in 2020 (Diffenbaugh et al., 2020; IEA, 2020a, 2020b), with U.S. emissions falling by as much as 11% (Energy Innovation, 2020). Although these are the most severe disruptions in energy use and GHG emissions in more than 70 years, these modest declines also reveal how challenging it will be to decarbonize the economy by midcentury. Annual decarbonization rates will need to greatly exceed emission decreases caused by the coronavirus in the first half of 2020. Moreover, emissions have quickly rebounded in China. Although emissions are still down in 2020 compared to the first months of 2019, emissions in May 2020 were 4%–5% higher than the previous May (Carbon Brief, 2020b).

Any humane read of the extraordinary situation created by the pandemic and resulting public health measures should first dispense with any misleading and misanthropic interpretations that see a "bright side" for the environment in economic paralysis. Any environmental change that follows the silencing of normal human activity—work, school, everyday routines, access to care—are symptoms of a society in disarray and should not be mistaken for environmental progress. The global economic depression is causing deep hardships for the unemployed and essential workers and could dim prospects for investments in mitigation or adaptation. Reduced economic activity has led to a 20% reduction in clean technology investment (IEA, 2020a) and could result in less philanthropy, less social investment, more deregulation, and the loss of small innovative businesses. Smaller enterprises may not survive a severe economic downturn of even a modest duration.

To understand how "pandemic disruptions" translate to themes in energy and the environment, we started by collecting financial and business sectoral impacts reported in media coverage and press releases across four broad categories of energy and the environment: unequal exposures, transportation fuels, electric power, and manufacturing supply chains. Then, we used Google Scholar with the search terms "energy" plus "environment" against each of "COVID-19," "pandemic," and "coronavirus" to find relevant supplemental scholarly analysis and research on these topics and limited the search to 2020. The scope of this commentary is global, but our analysis emphasizes the response in the United States with which we are most familiar. Energy and environmental inequality are explored in more depth in Section 2. Sections 3, 4, and 5 consider sectoral impacts in transport, power, and manufacturing. Section 6 concludes with thoughts about the road to recovery and prospects of a green stimulus in different country contexts. Resources to find data on electricity use patterns are in the supplemental information (Text S1).

2. Exposing inequality

The coronavirus crisis exposed severe environmental injustices associated with both energy use and energy access. Early satellite images depicting reduced air pollution—clear skies over Los Angeles, views to the Himalayas from the Indian state of Punjab for the first time in decades—revealed new possibilities for communities and the environment. However, these soon gave way to the same old persistent air pollution problems and inequities, with some places rebounding to exceed prior pollution levels (Zheng et al., 2020).

Communities living with long-term exposure to air pollution are substantially more vulnerable to the COVID-19 disease caused by the novel coronavirus because they have higher exposure to pollutants, fewer resources, and are more vulnerable owing to preexisting comorbidities (Bullard et al., 2020). A study suggested that long-term exposure to fine particulate matter ($PM_{2.5}$) air pollution in the United States resulted in higher rates of COVID-19 mortality (Wu et al., 2020). These exposures are more likely to be distributed with significant racial disparities (Brandt et al., 2020). Remote sensing data measuring nitrogen dioxide coupled with mortality data in Italy, Spain, France, and Germany showed that 78% of fatalities through March 2020 were in the five most polluted regions in those countries, suggesting that long-term nitrogen dioxide exposures may be an important contributor to COVID-19 mortality (Ogen, 2020). Research from Lombardi, in northern Italy, an early epicenter of the pandemic, showed prolonged exposures to PM_{10}, $PM_{2.5}$, ozone (O_3), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) increased the lethality of COVID-19 (Conticini et al., 2020).

The systematic injustices in the U.S. health care system exacerbate these public health problems, a point made by environmental justice scholars like Robert Bullard for decades (Bullard, 2007). Environmental inequalities are illuminated and exacerbated during crises, bringing attention to where vulnerabilities are most acute. People of color in the United States are more likely to be uninsured for health care, experience loss of jobs, or lose access to health care (Kaiser Foundation, 2018). These structural inequities reveal how material wealth, occupation, and community exposures predict environmental injustice, risk of infection, and likelihood of death (Cole et al., 2020).

Workers in essential jobs are already exposed to workplace occupational hazards. Essential jobs tend to go disproportionately to people of color and the poor, with Black workers in the United States the most routinely exposed to conditions that spread the novel coronavirus (Hawkins, 2020). The most hazardous work often comes with weak workplace protections, exacerbating structural

discrimination with the lack of paid sick leave, unemployment benefits, or affordable health care and childcare services (Yearby and Mohapatra, 2020). Miners already burdened with pulmonary disease from particulate matter exposures in mines have tested positive for coronavirus (Kuykendall, 2020). The sharp increase in plastics, required for medical supplies in response to the pandemic (Klemeš, 2020), reinforces unequal pollution exposure and environmental racism from plastics waste disposal emissions for those who live near incinerators (Silva et al., 2020).

Inequality in energy access is an injustice underscored by pandemics. Economic dislocation and income loss will force some to forego paying utility bills. In the United States, an average urban household spends 3.5% of their income on energy, which climbs to 4.4% for rural households (Graff and Carley, 2020). Stay-at-home orders during summer in the northern hemisphere regions resulted in higher residential air conditioning use and higher summer bills (Lawrence Berkeley National Laboratory, 2020). Shutting power to homes and apartments in need of cooling (e.g., in Arizona, Nevada, and Texas) would result in greater incidence of heat stroke as a public health threat. U.S. cities, for example, that normally operate cooling centers in the summer to help low-income residents are canceling or limiting such services as a result of fears about spreading the coronavirus (National Public Radio, 2020a). Winter heating bills in cold climates and summer cooling bills in warm climates could significantly burden households. Some U.S. utilities have pledged not to cut off services to people with unpaid bills, and 25 U.S. states mandated that utilities cannot shut off for nonpayment during the first months of the crisis, though thousands may have disconnected services that predate the crisis (Pomerantz, 2020).

Programs to assist low-income residents with their bills through direct subsidies or energy efficiency also could be postponed, suspended, or canceled. In the United States, the Low-Income Home Energy Assistance Program, which helps low-income residents pay energy bills, received contingency funding from Congress, but at an insufficient amount, to help all the customers facing disconnections and late fees accruals (Graff and Carley, 2020). Surveys of customers in May 2020 found that 13% of customers were unable to pay energy bills, 9% received utility shutoff notices, and 4% were disconnected from service (Carley and Konisky, 2020). A U.S. federal weatherization program to retrofit low-income houses suspended all activities, and households may find obstacles to participating in this program, which reduces customer bills, until the pandemic subsides.

In the Navajo Nation, or Diné Bikéyah, deep energy poverty is a long-standing problem in the United States. It lacks access to modern energy services that can provide running water for sanitation and basic public health measures to respond to the pandemic (Brosemer et al., 2020). Large portions of Navajo Nation do not have regular electricity access, which often translates to a lack of modern water services, including hot water, essential for limiting the novel coronavirus spread (Kovich, 2020). The high prevalence of air pollution and health problems that already afflict these communities—Navajo Nation had the highest incidence of per capita coronavirus infection in North America over the first half of 2020—makes them even more vulnerable to severe illness. Better relations between the broader U.S. community and Navajo Nation could result in a better redistribution of resources (*Navajo Times*, 2020).

Global inequality in energy access is most acutely evident at times of crisis. Eight hundred sixty million people on the planet lack basic energy access (IEA, 2020b), and the lockdown may disrupt informal networks of fuel trading and sales that people depend on for livelihoods (Castán Broto and Kirshner, 2020). Three billion people without modern clean cooking fuels are exposed to high levels of indoor air pollution, and it is likely that COVID-19 mortality will be correlated with people's degree of exposure and underlying conditions (Nwanaji-Enwerem et al., 2020).

Emergency care provisioning in areas with unreliable energy will prove to be incredibly challenging in sub-Saharan Africa, where 60% of health care facilities lack adequate energy access across 27 countries (IEA, 2019). A lack of consistent energy services can translate into compromised nighttime care, inability to keep biological samples, vaccines, and medicines cool, or inability to power crucial medical devices like ventilators. The United Nations Secretary-General for Sustainable Energy for All, Damilola Ogunbiyi, called for critical support to ensure that global clinics and hospitals and other frontline defenders have the tools they need to directly fight the pandemic (2020). Another possible set of solutions include deployment of mini-grids and other decentralized power solutions that could improve health care outcomes, offer livelihood opportunities, and ensure "access to affordable, reliable, sustainable, and modern energy for all" (United Nations, 2020).

3. Creating flash points in transportation fuels

Perhaps no visual captures the demand destruction and disruption wrought in transportation fuels better than 24 oil supertankers anchored off the Port of Long Beach, California, at the end of March 2020. By the first week of April 2020, U.S. sales of gasoline were at levels not seen in 50 years. Weekly demand for gasoline according to the Energy Information Agency (EIA, 2020a) fell to 6.7 million barrels, from about 10 million barrels the same period the year before. The demand crisis in global oil markets is poised to remake the industry. Different than other historical oil market crises such as 1973, 1979, and 2008, this moment has a strong exogenous demand reduction due to the virus, coupled with a supply side glut, in large part due to disagreement among the Organization of the Petroleum Exporting Countries and Russia talks in Vienna in February. This unique combined supply–demand pressure has ripple effects across the supply chain—upstream exploration, storage, transportation, oil field services, refinery output—with multiscalar implications for everything from employment and customer pricing to national

energy security to the budgets of major oil-producing nations (Kuzemko et al., 2020).

Shock waves are already moving through energy industries that are dramatically shaping people's everyday lives and decisions by organizations. New geopolitical alliances in the oil and gas sectors, most significantly among the expanded grouping of OPEC countries (or OPEC+ as it is referred) and United States, have emerged out of a price war to reinforce production controls (Meierding, 2020). The sharp price declines have caused widespread concern about and actual evidence of job layoffs in places where the cost of oil production far exceeds the current prices fetched in the global market. In the United States, for example, jobs in oil and gas fell by 51,000 according to unemployment claims for March 2020 (BW Research, 2020b). Texas overall could shed 1 million jobs in 2020 (CBS News, 2020). Oil major BP announced 10,000 jobs would be eliminated across global operations (Gemen, 2020). This price collapse and concern about stranded assets is causing oil majors to redirect planning efforts and write off resources that will not be developed like tar sands and deepwater projects (Reuters, 2020a). Communities reliant on tax revenues from fossil fuel industries for public services face unprecedented revenue shortfalls from low oil prices (Haggerty et al., 2018).

The most immediate economic impacts are to the communities that depend on jobs and tax revenues from unconventional oil and gas production. Refineries and blenders are idling production as deliveries to fueling stations and airports slow (Bloomberg, 2020a). In the United States, many of these communities fund vital services such as schools from such tax revenue and depend on this sector as the major source of employment. The double exposure of health crisis and demand shock is causing sudden increases in unemployment, which can worsen public health. A fallout from the wave of bankruptcies could leave governments responsible for billions in cleanup costs for thousands of wells that may be shut in from the price collapse (Santa Fe New Mexican, 2020). Wells that are shut in may prove challenging to restart for technical reasons (Jacobs, 2020).

The oil price crash could impact industries in unpredictable ways. Photovoltaic manufacturer SunPower is headquartered in San Jose, California, but owned by French oil major Total, whose revenues fell off with the lockdown. SunPower announced they would be temporarily shuttering operations due to the loss of rooftop solar and battery customers (Securities and Exchange Commission, 2020). The loss of oil revenue could stall any investments energy companies make in cleaner alternatives and reduce exploration of innovative carbon capture technologies. Other rooftop photovoltaic installers do not have these financial backstops, and keeping business has been a struggle for those who depend on door-to-door sales leads to maintain and expand their customer base. The Solar Energy Industries Association anticipates that the United States could lose a quarter million jobs with a one third reduction in overall solar deployment because of the coronavirus. On the other hand, rooftop installer SunRun experienced an increase in sales once they switched to online sales (*PV Magazine*, 2020). These effects are not limited to the United States. In India, the economic lockdown led to a disruption in the workforce employed in many industries, including the construction of new solar plants. Moreover, the fall in demand for electricity is increasing the financial problems of the distribution companies that buy power, making it harder for them to pay energy generators, including from solar providers (Busby, 2020).

There are spillovers to agriculture as well. In the U.S. Midwest, an oversupply of ethanol could cause prices to fall or markets to disappear. Leading ethanol producer POET idled several very large ethanol plants in South Dakota and Iowa in late March, delayed a new startup, and altered its corn purchasing at 27 plants (Progressive Farmer, 2020). Analysts suspect that half of U.S. ethanol production came offline at the peak in April. Lost production could have devastating impacts on rural communities, the rural businesses that support them, and the large workforce in the ethanol production system. The idling of ethanol plants has revealed a secondary, surprising vulnerability. A by-product of ethanol fermentation is CO_2, and the shortage of the gas shut down scores of processing plants in March and April in the United States (Compressed Gas Association, 2020). The loss of CO_2 supply is a vulnerability to wastewater treatment facilities, which require the material but compete with the food and beverage industries for the food grade quality supplies produced at ethanol plants (*The Guardian*, 2020a).

In the long term, it is unclear whether transportation fuel demands will recover. Work from home options for some portion of the workforce could be permanent, keeping many automobiles off the streets (KQED, 2020). It is difficult to imagine the same pace, need, or interest in flying, as many learn new ways of staying connected (teleconferencing, telecommuting) and performing remote tasks without the need to commute (remote medicine, distance learning). But there could also be a rebound in transportation fuels because automobile use is seen as safer and more hygienic than mass transit for social distancing. Increased driving could be reinforced by low gasoline prices, as could the continued trend of larger automobiles. Public transit rides could continue to sharply decline if people are not willing to be in contact with others. The lack of riders will impact the budget of transit agencies. Will people want to participate in ride-sharing again or will that be viewed as a public health risk? This is why it will be critical to deliver policy prescriptions that are appropriate for what the unfolding future will look like. One way or another, the collection of organizations and energy landscapes that power transportation will look very different on the other side of this pandemic.

4. Shaping new currents in electricity use patterns

The coronavirus pandemic is shaping nature–society interactions with energy systems, the electricity grid, use patterns, and operating procedures. The shelter-in-place orders led most people in the developed world to stay at home temporarily, where they were dependent on

a reliable electricity grid. These changes in commuter patterns alongside shuttered commercial, retail, and industrial electricity users affected the electricity grid in different ways, depending in part on the composition of the electricity grid customers. Areas dependent on service industries or industrial customers that were shut down have shown more severe declines in electricity use. U.S. retail sales of electricity are expected to fall by 3.6% in 2020 compared to 2019 (EIA, 2020b).

Take, for example, Austin, Texas, where a shelter-in-place order in mid-March led to extensive nonessential work from home and widespread layoffs. Residential electricity use promptly went up by 20% according to a sample of customers, even correcting for warmer weather and increased electric loads for cooling (Pecan Street, 2020). Analysts found that rooftop solar power generation was impacted, limiting daytime rooftop exports to the grid. The Electric Reliability Council of Texas, responsible for balancing power in the state overall, estimated that power use was 10%–12% below average. Across the country in New York, the Independent System Operator reported overall load drops close to 10% in conjunction with power demand expanding across the day different from the cadence of normal routines (RTO Insider, 2020). Research later confirmed that home electricity use no longer has distinct weekday morning and evening peaks (Chen et al., 2020).

Other regions are seeing declining demand overall. Residential power demand has similar load shapes—there are morning and evening residential electricity peaks, with midday and overnight lulls. All across Europe, peak loads and power consumption are down. The *Wall Street Journal* (2020) reported declines of about 18% in Italy. California's Independent System Operator, that manages the states portion of the electric grid, says power demand in March 2020 was 5%–8% lower. Grid operators reportedly had to curtail more solar power than normal and even take actions to prevent overloaded distribution circuits. They found that the morning peak power demand was specifically down, suggesting a pattern spreading power use across the morning for residential loads as families and people deviate from a more punctuated daily work and school routine. New York State saw power demand fall by 4%–5%. Declines in power use from customers mean lower revenues to utilities. Lower revenues have led utilities to seek wind and solar power, with its lower operating costs, over natural gas where possible (IEA, 2020a).

More important than the specifics of electric power demand during the crisis is what behaviors and commuter patterns stick afterward (Kuzemko et al., 2020). Shifts in norms, behaviors, and customs are reconfiguring workspace mobility, literally changing how we get around and experience places (National Public Radio, 2020b). Airline industries are preparing for a future with less business travel and other changes that could permanently eliminate demand. Bicycle sales are rapidly growing as people explore alternative mobilities (Deutsche Welle, 2020). This is already an area of opportunity for detailed empirical work for sociologists, anthropologists, urban planners, and geographers.

Attitudes toward public transportation will be heavily shaped by riders' apprehensions and concerns about coronavirus exposure. A survey of 25,000 Americans by International Business Machines Corporation (2020) found greater than 20% of riders who regularly used public transportation—buses, subways, or trains—say they no longer would; 28% said they will likely use public transportation less frequently. The reduced use of public transportation would increase vehicle miles traveled by automobiles. On the other hand, telework, teleconferencing, and fewer flights are all possibilities where energy use could see more permanent declines. What will be the lasting effect of some of these changes in patterns?

Similar issues are happening everywhere strict public health measures are taken. These demand changes lead to a cascade of impacts upstream in energy extraction and electricity generation. In the week following lockdown, 40 thermal coal power plants equal to about 30 GW shut down in India, and power fell by 20% (Quartz India, 2020; *The Economic Times*, 2020). Falling demand means fuel stockpiles are reaching stockyard capacities, and mines that supply the generators have stopped lifting coal, with coal imports to India falling by 27% in March (Reuters, 2020b). These dynamics have impacted international coal markets, which in turn lowers production and employment in coal-producing regions. The Powder River Basin supplies 40% of coal production in the United States but has declined by 30% this year (Kuykendahl and Dholakia, 2020). Continued production declines are deeply affecting coal communities in the United States, where overseas coal markets are the last hope to make up for lost revenues to pay for community social services like education (Bleizeffer and Adams, 2020).

In 2019, public policy debates about resilience in the power sector at the U.S. Federal Energy Regulatory Commission focused on the somewhat dubious notion that resilience meant having enough fuel onsite to ensure power plants could operate during emergency shutdowns. One of the lessons of the coronavirus pandemic so far is that the critical resources to have onsite may actually be the operators. There are stories throughout the world now of plant operators and critical personnel sleeping onsite to ensure they are not infected. New York's Independent System Operator (NYISO) asked its operators to live onsite to ensure key personnel remain healthy (Energy and Environment News, 2020). An Electric Power Research Institute (2020) report sent to its membership described best practices in facility hygiene, staffing plans, and accelerated training to manage a potential outbreak and maintain operations.

Some electric utilities were already in crisis before the outbreak, and the economic pause could deepen their challenges. In the midst of the coronavirus outbreak, the northern California electric utility Pacific Gas and Electric emerged from bankruptcy after a series of devastating wildfires linked to their equipment. The last steps in the long-awaited wildfire settlement were upended by a sharp decline in the value of the stock that wildfire victims were supposed to get as compensation for the wildfires caused by equipment owned and managed by the electric utility.

The potential trifecta of coronavirus pandemic, catastrophic wildfires, and rolling blackouts for public safety power outages during the lockdown would be enormously catastrophic for California, and emergency responders and firefighters are already planning for contingencies. These hazards compounded by climate-attributable risks highlight the importance of disaster preparedness, coordination, and response (Phillips et al., 2020).

5. Revealing vulnerabilities in manufacturing and supply chains

The coronavirus may highlight challenges lurking in the emerging technologies and production systems that are poised to help the energy transition. Photovoltaic cells, electric vehicles and engines, batteries, and fuel cells compete in production systems that rely on just-in-time production and contract manufacturing. The COVID-19 outbreak brought into focus the resilience of supply chains for these crucial clean technologies. The disease hit the center of global photovoltaic manufacturing immediately after the Chinese New Year, meaning the impacts of lockdown were augmented by the holiday. The situation was further complicated by logistical problems at container ports in China—where 70%–80% of photovoltaic cells and modules are made—creating a massive backlog of exports. These ripple effects extended beyond the manufacturing sector to solar industry installations. By August 2020, photovoltaic manufacturing in China was up compared to 2019, but exports were down as project development and installations remained slow (Stoker, 2020). The first 6 months of 2020 will see delays or cancellations for nearly 40% of utility-scale solar capacity, likely lasting longer. Analysts at Wood MacKenzie (2020) predict wind turbine installations to fall by 20% in 2020.

Lithium chemicals and lithium-ion battery manufacturers in China temporarily shut down factories during the outbreak because of stay-at-home orders. Lithium hydroxide requires special care in transportation and has a short shelf life. The lockdowns resulted in doubled transportation costs and raised prices for lithium hydroxide. CATL and BYD, two major Chinese battery makers for electric cars, were planning on continued production delays many months after the epicenter of the virus moved away from China. Similarly, Tesla battery production was hamstrung by a migratory labor force locked in place far from their Shanghai factory in the first months of the pandemic. Battery production in 2020 is expected to fall by tens of gigawatt hours from prepandemic projections (IEA, 2020a).

Behind each of these manufacturing plants and the associated supply chains are communities and workers directly impacted. Electronics and photovoltaics manufacturing relies heavily on migratory workforces in China, Malaysia, Singapore, India, Mexico, and beyond. This means shutdowns that result in lost incomes directly affect livelihoods and their ability to remit income to their hometowns. The World Bank projects that global remittances are set to fall by $142 billion in 2020 (Reuters, 2020c). The implications for struggling households in fragile economies could be disastrous for humanity.

Mining activities are particularly vulnerable to disruption (Laing, 2020). Mine closures or worker shortages impacted systems of production as supply chains locked down from hard rock lithium mining in Australia to brine operations in Chile and silver mines in Peru (*The Guardian*, 2020b). The classification of categories of mining labor as essential work also highlights inequities in supply chains. Where mines remain open, workers work under conditions that enhance disease spread among a worker population already burdened with pulmonary illnesses. In June 2020, dozens of organizations signed a petition seeking worker justice in indigenous, artisanal, and marginalized mining communities in the developing world (Mining Watch, 2020). As the global economic recession continues, there will be pressure to increase mining as some nations rely on national budgets from extractives industries, others seek recovery plans by metal-intensive renewables deployment, and financial sector concerns about currencies may push more investment in commodities more generally.

Many major automakers were in the midst of announcements and commitments to electric vehicles and retooling their supply chains, but several were forced to pause these efforts. Ford, General Motors, and Fiat Chrysler all shut down plants that assemble plug-in hybrid vehicles. Electric vehicle production at Volkswagen and Renault halted in Europe. These impacts, coupled with falling fuel prices, might have short-term implications for electric vehicle sales, but in the long term, climate governance and consumer interest will likely keep electric vehicle deployment prospects strong (IEA, 2020b; Kanda and Kivimaa, 2020).

Industry is an enormous user of energy—it is also a very heterogeneous sector, employing one in five people in the world (IEA, 2020b). The impacts across supply chains from cement, to steel, to minerals are varied but typify the slowdown elsewhere. Blast furnaces, refineries, coking plants, and steel production all are indicators of industrial activity that have shown declines in affected areas. One study of the first quarter of 2020 found that 29% of the global decrease in GHG emissions were from industry, with declines in cement production being the biggest contributor (Liu et al., 2020). In the United States, the slump in production has translated into lower demand by industry for natural gas, ultimately lowering Henry Hub spot prices (Lazar, 2020). This could result in a decline in natural gas use by as much as 3.9% in 2020, with a 7.1% decrease in demand from industry (EIA, 2020c).

Manufacturers may learn from the pandemic experience and make supply chains more robust and resilient to disruption through redundancy or reshoring. Reactions to the supply chain impacts from the 2011 tsunami and earthquake in Japan, and the SARS coronavirus a decade earlier, reveal how companies responded by changing sourcing patterns and by developing production contingency plans. Supply chain disruptions could result in reshuffling production systems to mitigate future shutdown impacts or make systems more resilient. India, for

example, is seeking to reduce its reliance on Chinese imports of solar panels through a series of tariff and nontariff barriers (Gopal, 2020).

6. Resetting the path forward

Responses to the coronavirus pandemic and corresponding global economic crisis will have long-lasting effects on energy and the environment. Some view the associated global lockdowns as a "socioeconomic disruption" with "a singular perturbation" on humanity's influence on components of the Earth System (Diffenbaugh et al., 2020). We emphasize that the human response to such disruptions warrants a wider lens that captures the dynamics caused by the social response. Such analysis should include not just earth system scientists and economists but also social scientists and policy makers. Public policies, investments, and social and behavioral changes instigated by the coronavirus could leave durable and transformative disruptions in critical infrastructures like public transportation, health care, housing, electricity transmission, broadband, clean water systems, and the walkability of cities.

Resetting the path forward starts with recognizing and addressing the structural inequalities made so apparent during the crisis. Access to modern electricity in the most vulnerable parts of the world would improve the lives of hundreds of millions of people. The coronavirus pandemic raises the salience of calls for strategic national investments in infrastructures and industrial policy, which can be used to target structural inequalities. Public policy investments in energy access, health care, and reducing community exposure to pollution could yield significant social improvements. High levels of unemployment coupled with favorable borrowing terms may help some countries to favor investments that benefit the most vulnerable (Regulatory Assistance Project, 2020). But many nations also face steep budget cuts, and public spending can be politically challenged where there are many critical competing priorities. As a result, public support for government subsidies for renewables and energy efficiency could be undermined in the short term.

Continuing support for clean energy through regulatory intervention will be crucial to a sustainable path forward. Addressing gaps in climate and air pollution policies could spur private investments in low-carbon disruptive technologies. Interactions between capital and tax equity markets have been critical to renewable energy investments and research and development. Extending these policies in the near term could accelerate the realization of long-term benefits. Voluntary purchases of renewable electricity by private companies like Facebook, Google, and Apple as they seek internally established corporate climate goals were the leading category of electricity sales in 2019, and the erosion of capital could undermine these efforts. Companies may find it more challenging to dedicate staff and budget to meet 100% renewables or clean energy procurement goals or utilize tax credits for renewables and energy efficiency.

To forestall the loss of private sector momentum to clean energy, governments need to send clear signals through regulations and standards to hasten deployment and spur investment. Among the core policies of the $572 billion European Green Deal passed in July 2020 were strategic policies to encourage certain sectors through 2027 (Paraskova, 2020). Investments in hydrogen infrastructure and vehicle electrification were at the center of the package, leading some analysts to see natural gas disruptions by the mid-2020s (Honoré, 2020). Regulatory policies can also be used to unwind and break the prevailing carbon lock-in, such as elimination of coal finance, as the newly reelected South Korea government has promised with its planned Green New Deal.

International collaboration will be essential to ensure recovery investments make progress in clean technology deployment, carbon-based energy phaseouts, and to make strategic investments in innovation (Victor, 2019; IRENA, 2020). Climate action in the context of the uneven coronavirus experience highlights the critical need to center a just transition in any green economic recovery (Henry et al., 2020). Recovery plans in some nations are already tending to support familiar and legacy fossil fuel industries in China, Indonesia, the United States, Germany, India, and Russia (Bloomberg, 2020b). Political pressures by fossil fuel companies could result in these incumbent industries being the major beneficiaries of government support, giving them a lifeline by shielding them from lost production and destroyed demand. Continued investments in fossil fuels could be particularly problematic in developing economies where they could further "carbon lock-in" (Unruh, 2000) and lead to anachronistic, climate-polluting infrastructure or burdens of stranded assets (Cherp and Jewell, 2020). Record low interest rates make it attractive for organizations to make these investments now, especially since they often pay off in a short number of years. The industries that get supported and encouraged during this time will have major implications for energy systems and the environment long into the future.

The Great Lockdown is only the first act in a series of impacts that will emerge from COVID-19 (and future pandemics) on energy use patterns and the environment. From macroeconomic and national political responses to changes in human behavior at the household level, the response to the pandemic could have just as much a long-lasting impact on energy and the environment as the initial effects of public health measures in the first half of 2020. The European Green Deal, China's 14th five-year plan, and a potential green stimulus or Green New Deal in the United States could play a strong role in shaping what follows (Steffen et al., 2020). Importantly, organizations leading social mobilizations like Black Lives Matter in the United States, looking to correct structural inequalities that fall along disproportionately racial (Lennon, 2020) or colonial lines (Brosemer et al., 2020), could have a greater impact in shaping a green response if a Green New Deal is accompanied by a focus on addressing environmental justice. In August 2020, leading economists around the world echoed these points, calling attention to the ways the carbon economy "amplifies racial, social, and economic inequities" with appeals for a fundamental transformation of the energy economy (Sachs et al., 2020).

Other energy and environmental interactions are already rearranging how we get around, use energy, and move through space. Social behaviors and nature–society relations will continue to be reshaped as the coronavirus pandemic unfolds. Future research should focus less on the temporary disruptions in pollution, energy use, and supply chains and more on the durable disruptions in social norms, production system interdependencies, and public policy that can be mobilized to inform a better postpandemic future. As we have argued through this piece, energy systems and the environment will be disrupted not just from the coronavirus pandemic but also from humanity's collective response. The moment provides important opportunities to invest in environmental justice and climate stewardship, but barriers and pitfalls remain.

Data Accessibility Statement

Data supporting these arguments are in the supplmental information and the bibliography.

Supplemental file

The supplemental files for this article can be found as follows:

- Text S1. Selected national and regional electricity use data. docx.

Acknowledgments

The authors would like to thank two reviewers for detailed comments and suggestions, and helpful and insightful comments and guidance from Editor-in-Chief, Alastair Iles.

Competing interests

None to report. DM is *Elementa*'s Associate Editor, and he was not involved in the review process.

Author contributions

Dustin Mulvaney has been designated as the lead and corresponding author. Busby has been designated second author.

- Mulvaney led the data acquisition, writing tasks, and argument development.
- Bazilian, Busby, and Mulvaney contributed to conception of the core arguments in the paper
- Bazilian, Busby, and Mulvaney contributed to analysis and interpretation of data.
- Mulvaney led the writing and heavy editing of the draft, but all authors contributed ideas, feedback, and further helped develop the argument and provide empirical support.
- Refinement: Busby line-edited several drafts.
- Bazilian, Busby, and Mulvaney edited and approved the submitted version for publication.

References

Associated Press. 2020. Solar, wind energy struggle as coronavirus takes toll. Available at https://apnews.com/e3ea11613c2ad83f05bc85f75a26181a. Accessed 2 May, 2020.

Bazilian, M, Lemery, J. 2020. COVID-19—the Global South must not be forgotten. *The Hill*. Available at https://thehill.com/opinion/energy-environment/491220-covid-19-the-global-south-must-not-be-forgotten. Accessed 5 April, 2020.

Bleizeffer, D, Adams, M. 2020. Reckoning in coal country: How lax fiscal policy has left states flat-footed as mining declines. Available at https://energynews.us/2020/08/11/west/reckoning-in-coal-country-how-lax-fiscal-policy-has-left-states-flat-footed-as-mining-declines/. Accessed 11 August, 2020.

Bloomberg. 2020a. Marathon says it will idle 166,000 barrel-per-day Martinez, California refinery. Available at https://www.reuters.com/article/us-refinery-operations-marathon-pete-mar-idUSKBN21Z2GJ. Accessed 17 April, 2020.

Bloomberg. 2020b. EU approves biggest green stimulus in history with $572 billion plan. Available at https://www.bloomberg.com/news/articles/2020-07-21/eu-approves-biggest-green-stimulus-in-history-with-572-billion-plan. Accessed 21 July, 2020.

Brandt, EB, Beck, AF, Mersha, TB. 2020. Air pollution, racial disparities, and COVID-19 mortality. *J Allergy Clin Immunol* **146**(1): 61–63.

Brosemer, K, Schelly, C, Gagnon, V, Arola, KL, Pearce, JM, Bessette, D, Olabisi, LS. 2020. The energy crises revealed by COVID: Intersections of indigeneity, inequity, and health. *Energy Res Soc Sci* **68**: 101661.

Bullard, RD. 2007. Equity, unnatural man-made disasters, and race: Why environmental justice matters. *Res Soc Problems Public Policy* **15**: 51–85.

Bullard, RD, Patterson, J, Thomas, SB. 2020. Roundtable on the pandemics of racism, environmental injustice, and COVID-19 in America. *Environ Justice* **13**: 3. DOI: http://dx.doi.org/10.1089/env.2020.0019. Accessed 16 June, 2020.

Busby, J. 2020. *COVID-19 and other inflection points: Fifth annual review of solar scale-up in India*. Council on Foreign Relations. Available at https://www.cfr.org/blog/covid-19-and-other-inflection-points-fifth-annual-review-solar-scale-india. Accessed 22 June, 2020.

BW Research. 2020a. Clean energy employment initial impacts from the COVID-19 economic crisis. Available at https://assets.morningconsult.com/wp-uploads/2020/07/10092733/Clean-Energy-Jobs-June-COVID-19-Memo-Final.pdf. Accessed June 2020.

BW Research. 2020b. US energy employment initial impacts from the COVID-19 economic crisis. Available at https://bwresearch.com/covid/docs/BWResearch_EnergyJobsInitialCOVID-19Memo.pdf. Accessed March 2020.

Carbon Brief. 2020a. Analysis: Coronavirus temporarily reduced China's CO2 emissions by a quarter. Available at https://www.carbonbrief.org/analysis-coronavirus-has-temporarily-reduced-chinas-co2-emissions-by-a-quarter. Accessed 19 February, 2020.

Carbon Brief. 2020b. Analysis: China's CO_2 emissions surged past pre-coronavirus levels in May. Available at https://www.carbonbrief.org/analysis-chinas-co2-emissions-surged-past-pre-coronavirus-levels-in-may. Accessed 29 June, 2020.

Carley, S, Konisky, D. 2020. Energy is a basic need, and many Americans are struggling to afford it in the COVID-19 recession. *The Conversation*, Available at https://theconversation.com/energy-is-a-basic-need-and-many-americans-are-struggling-to-afford-it-in-the-covid-19-recession-140416. Accessed 30 July, 2020.

Castán Broto, V, Kirshner, J. 2020. Energy access is needed to maintain health during pandemics. *Nature Energy*, Available at https://www.nature.com/articles/s41560-020-0625-6

CBS News. 2020. Oil slump could cost Texas 1 million jobs this year alone. Available at https://www.cbsnews.com/news/crude-oil-prices-slump-could-cost-texas-1-million-jobs-this-year-alone/. Accessed 22 April, 2020.

Chen, CF, de Rubens, GZ, 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.

Cherp, J, Jewell, J. COVID-19 weakens both sides in the battle between coal and renewables. *Behav Soc Sci*. Available at https://socialsciences.nature.com/posts/66644-by-disrupting-technology-diffusion-and-supply-chains-covid-19-may-harm-renewables-more-than-coal-but-still-weaken-coal-lock-in-in-developing-countries. Accessed 22 April, 2020.

Compressed Gas Association. 2020. Industry coalition sends letter to U.S. vice president warning of risk of carbon dioxide shortage. Available at https://www.cganet.com/industry-warns-risk-of-carbon-dioxide-shortage-in-us/. Accessed 7 April, 2020.

Conticini, E, Frediani, B, Caro, D. 2020. Can atmospheric pollution be considered a co-factor in extremely high-level of SARS-CoV-2 lethality in Northern Italy? *Environ Pollut* **261**: 114465.

Diffenbaugh, NS, Field, CB, Appel, EA, Azevedo, IL, Baldocchi, DD, Burke, M, Burney, J, Davis, SJ, Fiore, AM, Fletcher, SM, Hertel, TW, Horton, DE, Hsiang, SM, Jackson, RB, Jin, X, Levi, M, Lobell, DB, McKinley, GA, Moore, FC, Montgomery, A, Nadeau, KC, Pataki, DE, Randerson, JT, Reichstein, M, Schnell, JL, Seneviratne, SI, Singh, D, Steiner, AL, Wong-Parodi, G. 2020. The COVID-19 lockdowns: A window into the Earth System. *Nat Rev Earth Environ*. DOI: http://dx.doi.org/10.1038/s43017-020-0079-1.

Deutsche, W. 2020. COVID-19 causes 'bike explosion' as Germans long for a ride. Available at https://www.dw.com/en/covid-19-causes-bike-explosion-as-germans-long-for-a-ride/a-53905967. Accessed July 9, 2020.

E2. 2020. Clean energy & COVID-19 economic crisis. Available at https://e2.org/reports/clean-jobs-covid-economic-crisis-march-2020/. Accessed 13 May, 2020.

Electric Power Research Institute. 2020. Available at http://mydocs.epri.com/docs/public/covid19/3002018602R2.pdf.

Energy Choice Coalition. 2020. Wood MacKenzie, industry associations report coronavirus impact on energy transitions. Available at https://www.energychoicecoalition.org/blog/2020/4/17/wood-mackenzie-industry-associations-report-coronavirus-impact-on-energy-transition.

Energy and Environment News. 2020. 'We have never done this before.' *Inside N.Y.'s grid lockdown*. Available at https://www.eenews.net/stories/1062737239. Accessed March 30, 2020.

Energy Information Agency. 2020a. Weekly U.S. demand for motor gasoline. March 27, 2020. Available at https://www.eia.gov/petroleum/supply/weekly/. Accessed 1 July, 2020.

Energy Information Agency. 2020b. Short-term energy outlook. Available at https://www.eia.gov/outlooks/steo/. Accessed 11 August, 2020.

Energy Information Agency. 2020c. Short-term energy outlook. Available at https://www.eia.gov/outlooks/steo/pdf/steo_full.pdf. Accessed 1 May, 2020.

Energy Innovation. 2020. Estimating U.S. energy demand and emissions impacts of COVID-19 with the energy policy simulator. Available at https://energyinnovation.org/wp-content/uploads/2020/05/Modeling-COVID-Impacts-On-US-Emissions.pdf. Accessed May 2020.

Environmental Protection Agency. 2020. Air quality index data, Long Beach, Los Angeles, California, 1980–2020. Available at http://www.epa.gov/AQI.

Financial Times. 2020. Aluminium industry faces huge supply glut. Available at https://www.ft.com/content/93ae66a4-1962-4729-8695-49f42a879629. Accessed 27 March, 2020.

Gemen, B. 2020. BP to cut global workforce by 10,000 jobs. *Axios*. Available at https://www.axios.com/bp-cut-global-workforce-10000-jobs-f7f20048-6842-49cf-8279-2fe80607ecbf.html. Accessed 8 June, 2020.

Gopal, S. 2020. Costlier solar power a fallout of India-China border clash. *The Third Pole*. Available at https://www.thethirdpole.net/2020/07/27/costlier-solar-power-a-fallout-of-india-china-border-clash/. Accessed 27 July, 2020.

Graff, M, Carley, C. 2020. COVID–19 assistance needs to address energy insecurity. *Nature Energy*, Available at https://www.nature.com/articles/s41560-020-0620-y.pdf.

Haggerty, JH, Kroepsch, AC, Walsh, KB, Smith, KK, Bowen, DW. 2018. Geographies of impact and the impacts of geography: Unconventional oil

and gas in the American West. *Extr Ind Soc* **5**(4): 619–633.

Harris County Public Health. 2020. City of Houston and Harris County race and ethnicity data. Deceased cases as of April 15, 2020. Available at http://publichealth.harriscountytx.gov/Portals/27/Documents/Resources/2019%20nCoV/Case-Count/Race-Ethnicity-Data-for-COH-HCPH-April-15th.pdf?ver=2020-04-15-182710-407.

Hawkins, D. 2020. Differential occupational risk for COVID-19 and other infection exposure according to race and ethnicity. *Am J Ind Med* **63**: 817–820.

Henry, MS, Bazilian, MD, Markuson, C. 2020. Just transitions: Histories and futures in a post-COVID world. *Energy Res Soc Sci* 68: 101668.

Honoré, A. 2020. *Natural gas demand in Europe the impacts of COVOD-19 and other influences in 2020*. Oxford Institute for Energy Studies. Available at https://www.oxfordenergy.org/publications/natural-gas-demand-in-europe-the-impacts-of-covid-19-and-other-influences-in-2020/. Accessed 17 June, 2020.

Howarth, C, Bryant, P, Corner, A, Fankhauser, S, Gouldson, A, Whitmarsh, L, Willis, R. 2020. Building a social mandate for climate action: Lessons from COVID-19. *Environ Resour Econ*. July 8, 2020. DOI: http://dx.doi.org/10.1007/s10640-020-00446-9.

IBM. 2020. IBM Study: COVID-19 is significantly altering U.S. consumer behavior and plans post-crisis. Available at https://newsroom.ibm.com/2020-05-01-IBM-Study-COVID-19-Is-Significantly-Altering-U-S-Consumer-Behavior-and-Plans-Post-Crisis.

International Energy Agency. 2019. *Africa energy Outlook 2019*. World Energy Outlook Special Report. Paris. Available at https://www.iea.org/reports/africa-energy-outlook-2019. Accessed November 2019.

International Energy Agency. 2020a. The impact of the Covid-19 crisis on clean energy progress. Available at https://www.iea.org/articles/the-impact-of-the-covid-19-crisis-on-clean-energy-progress. Accessed 10 June, 2020.

International Energy Agency. 2020b. *Sustainable recovery*. World Energy Outlook Special Report in collaboration with the International Monetary Fund. Paris. Available at https://www.iea.org/reports/sustainable-recovery. Accessed July 2020.

International Renewable Energy Agency. 2020. *The post-COVID recovery: An agenda for resilience, development and equality*. Abu Dhabi. Available at https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Post-COVID_Recovery_2020.pdf.

Jacobs, S. 2020. The great shale shut-in: Uncharted territory for technical experts. *J Pet Technol*. Available at https://pubs.spe.org/en/jpt/jpt-article-detail/?art=6972. Accessed 30 April, 2020.

Kaiser Foundation. 2018. Uninsured rates for the nonelderly by race/ethnicity, Texas. Available at https://www.kff.org/uninsured/state-indicator/rate-by-raceethnicity/.

Kanda, W, Kivimaa, P. 2020. What opportunities could the COVID-19 outbreak offer for sustainability transitions research on electricity and mobility? *Energy Res Soc Sci* **68**: 101666.

Klemeš, JJ, Van Fan, Y, Tan, RR, Jiang, P. 2020. Minimising the present and future plastic waste, energy, and environmental footprints related to COVID-19. *Renew Sust Energ Rev* **127**: 109883.

Kovich, H. 2020. Rural matters—coronavirus and the Navajo nation. *N Engl J Med.* **383**: 105–107.

KQED. 2020. Coronavirus forces huge number of Californians off road, as tele-everything becomes new climate option. Available at https://www.kqed.org/science/1963716/coronavirus-forces-huge-number-of-californians-off-road-as-tele-everything-becomes-new-climate-option. Accessed 7 May, 2020.

Kuykendall, T. 2020. More US coal mines idled as 2 Pa. mine workers test positive for COVID-19. Available at https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/more-us-coal-mines-idled-as-2-pa-mine-workers-test-positive-for-covid-19-57815978. Accessed 30 March, 2020.

Kuykendall, T, Dholakia, G. 2020. "No place to go": US coal employment, production nosedive in wake of pandemic. *S&P Global*. Available at https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/no-place-to-go-us-coal-employment-production-nosedive-in-wake-of-pandemic-59870810. Accessed 11 August, 2020.

Kuzemko, C, Bradshaw, M, Bridge, G, Goldthau, A, Jewell, J, Overland, I, Scholten, D, Van de Graaf, T, Westphal, K. 2020. COVID-19 and the politics of sustainable energy transitions. *Energy Res Soc Sci* **68**: 101685.

Laing, T. 2020. The economic impact of the Coronavirus 2019 (COVID-2019): Implications for the mining industry. *The Extractive Industries and Society* **7**(2): 580–582.

Lazar, J. 2020. Synchronizing the electric regulatory response to COVID-19. May 5, 2020 Regulatory Assistance Program. Available at https://www.raponline.org/blog/synchronizing-the-electric-regulatory-response-to-covid-19/.

Lennon, M. 2020. Postcarbon amnesia: Toward a recognition of racial grief in renewable energy futures. *Sci Technology Human Values*. DOI: http://dx.doi.org/10.1177/0162243919900556.

Liu, Z, Deng, Z, Ciais, P, Lei, R, Davis, SJ, Feng, S, Zheng, B, Cui, D, Dou, X, He, P, Zhu, B, Lu 1, C, Ke, P, Sun, T, Wang, Y, Yue, X, Wang, Y, Lei, Y, Zhou, H, Cai, Z, Wu, Y, Guo, R, Han, T, Xue, J, Boucher, O, Chevallier, F, Boucher, E, Wei 1, Y, Zhang, Q, Guan, D, Gong, P, Kammen, D, He, K, Schellnhuber, HJ. 2020. COVID-19 causes record decline in global CO2 emissions. *Arxiv*. Available at https://arxiv.org/abs/2004.13614.

McCartney, S. 2020. What travel will look like after coronavirus? *Wall Street Journal*. Available at https://

www.wsj.com/articles/what-travel-will-look-like-after-coronavirus-11596026858. Accessed 29 July, 2020.

McGinty, JC. 2020. Coronavirus shutdowns shift energy costs to individuals. *Wall Street Journal*. Available at https://www.wsj.com/articles/coronavirus-shutdowns-shift-energy-costs-to-individuals-11596792600. Accessed 7 August, 2020.

Meierding, E. 2020. The oil price crash and international petro-politics. *Duck of Minerva.* Available at https://duckofminerva.com/2020/04/the-oil-price-crash-and-international-petro-politics.html. Accessed 24 April, 2020.

Mining Watch. 2020. Global solidarity with communities, indigenous peoples and workers at risk from mining pandemic profiteers. Available at https://miningwatch.ca/sites/default/files/global_solidarity_statement_on_mining_pandemic_profiteers.pdf. Accessed 2 June, 2020.

Nakada, LYK, Urban, RC. 2020. COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo state, Brazil. *Science of The Total Environment*, 730: 139087.

NASA. 2020. Airborne nitrogen dioxide plummets over China. *Earth Observatory*. Available at https://earthobservatory.nasa.gov/images/146362/airborne-nitrogen-dioxide-plummets-over-china.

National Public Radio. 2020a. Pandemic keep cooling center closed despite rising temperatures. Available at https://www.npr.org/2020/06/13/876522024/covid-19-pandemic-keeps-cooling-center-closed-despite-rising-temperatures. Accessed 13 June, 2020.

National Public Radio. 2020b. New York City is latest to close some streets to cars, making more space for people. Available at https://www.npr.org/sections/coronavirus-live-updates/2020/05/04/850357743/new-york-city-is-latest-to-close-some-streets-to-cars-making-more-space-for-peop. Accessed 4 May, 2020.

Navajo Times. 2020. *Sea change in the desert*. Available at https://navajotimes.com/reznews/sea-change-in-the-desert. Accessed 5 August, 2020.

Nwanaji-Enwerem, JC, Allen, JG, Beamer, PI. 2020. Another invisible enemy indoors: COVID-19, human health, the home, and United States indoor air policy. *J Expo Sci Env Epid* 30: 773-775.

Office of Massachusetts Attorney General. 2020. COVID-19's unequal effect in Massachusetts: Remedying the legacy of environmental injustice and building climate resilience. Available at https://www.mass.gov/doc/covid-19s-unequal-effects-in-massachusetts/download.

Ogen, Y. 2020. Assessing nitrogen dioxide (NO_2) levels as a contributing factor to coronavirus (COVID-19) fatality. *Sci Total Environ* **726**: 138605.

Ogunbiyi, O. 2020. *Opinion: Power in a pandemic—why energy access matters during coronavirus*. Available at https://news.trust.org/item/20200331134807-w6a0h/. Accessed 31 March, 2020.

Paraskova, T. 2020. EU presents $572 billion green stimulus package. *The Oil Price.* Available at https://oilprice.com/Latest-Energy-News/World-News/EU-Presents-572-Billion-Green-Stimulus-Package.html. Accessed 21 July, 2020.

Pecan Street. 2020. COVID-19 is changing residential electricity demand. Available at https://www.pecanstreet.org/2020/04/covid/. Accessed 6 April, 2020.

Phillips, CA, Caldas, A, Cleetus, R, Dahl, KA, Declet-Barreto, J, Licker, R, Delta Merner, L, Ortiz-Partida, JP, Phelan, AL, Spanger-Siegfried, E, Talati, S, Trisos, CH, Carlson, CJ. 2020. Compound climate risks in the COVID-19 pandemic. *Nat Clim Change* **10**: 586–588.

Pomeranz, D. 2020. Caught in patchwork of policies and pledges, some utility customers may still be awaiting electricity restoration or racking up fees. *Energy and Policy Institute*. Available at https://www.energyandpolicy.org/utility-coronavirus-disconnect-fees/. Accessed 15 April, 2020.

Progressive Farmer. 2020. POET idles three plants, delays startup. Available at https://www.dtnpf.com/agriculture/web/ag/news/article/2020/04/07/poet-puts-ice-330-million-gallons. Accessed 7 April, 2020.

PV Magazine. 2020. Strong Q1 for first solar, enphase, sunrun. Available at https://www.pv-magazine.com/2020/05/08/strong-q1-for-first-solar-enphase-sunrun/. Accessed 8 May, 2020.

Quartz India. 2020. Within 10 days of the lockdown, India was consuming 20% less power than usual. Available at https://qz.com/india/1844956/indias-coronavirus-lockdown-drastically-cuts-power-consumption/. Accessed 23 April, 2020.

Reuters. 2020a. BP's stranded Canadian, Angolan assets expose wider industry risks. Available at https://www.reuters.com/article/us-bp-strandedassets-analysis/bps-stranded-canadian-angolan-assets-expose-wider-industry-risks-idUSKBN23V1ZY. Accessed 24 June, 2020.

Reuters. 2020b. India's virus lockdown gives world's most polluted capital clear skies, clean air. Available at https://www.reuters.com/article/us-health-coronavirus-india-pollution/indias-virus-lockdown-gives-worlds-most-polluted-capital-clear-skies-clean-air-idUSKCN22318V. Accessed 21 April, 2020.

Reuters. 2020c. Migrant wages sent home set to drop $142 billion in 2020: World Bank. Available at https://www.reuters.com/article/us-health-coronavirus-emerging/migrant-wages-sent-home-set-to-drop-142-billion-in-2020-world-bank-idUSKCN2241Y7. Accessed 22 April, 2020.

RTO Insider. 2020. NRG's Q1 retail earnings stave off COVID declines. Available at https://rtoinsider.com/nrg-q1-retail-earnings-stave-off-covid-declines-162403/. Accessed 8 May, 2020.

Sachs, J, Stiglitz, J, Mazzucato, M, Brown, C, Dutta-Gupta, I, Reich, R, Zucman, G. 2020. Letter from economists: To rebuild our world, we must end the

carbon economy. *The Guardian*. Available at https://www.theguardian.com/commentisfree/2020/aug/04/economists-letter-carbon-economy-climate-change-rebuild. Accessed 4 August, 2020.

San Jose Mercury News. 2020. Coronavirus: LA's air, usually terrible, is best in the world. Available at https://www.mercurynews.com/2020/04/07/coronavirus-las-air-usually-terrible-is-best-in-the-world/. Accessed 8 April, 2020.

Santa Fe New Mexican. 2020. Land commissioner: Oil, gas cleanup could cost billions. Available at https://www.santafenewmexican.com/news/coronavirus/land-commissioner-oil-gas-cleanup-could-cost-billions/article_1beb9892-7e68-11ea-b747-6fa046476432.html. Accessed 3 May, 2020.

Securities and Exchange Commission. K-1. SunPower Corporation. Available at https://www.sec.gov/Archives/edgar/data/867773/000086777320000025/spwr0420208-k.htm. Accessed 14 April, 2020.

Silva, G, Sreeddhar, P, Greene, H. 2020. Op-ed: Is medical waste . . . racist?—Disposal methods are threatening minority communities. *Med Page Today*, Available at https://www.medpagetoday.com/publichealthpolicy/ethics/87415. Accessed 6 July, 2020.

Steffen, B, Egli, F, Pahle, M, Schmidt, TS. 2020. Navigating the clean energy transition in the COVID-19 crisis. *Joule* **4**: 1–5.

Stoker, L. 2020. Chinese wafer, cell and module outputs all grow as upstream sector shrugs off pandemic: China Photovoltaic Industry Association. *PV-Tech*, Available at https://www.pv-tech.org/news/chinese-wafer-cell-and-module-capacities-all-grow-as-upstream-sector-shrugs. Accessed 22 July, 2020.

The Economic Times. 2020. Forty thermal power units stop lifting coal as demand sees sharp drop. Available at https://energy.economictimes.indiatimes.com/news/coal/forty-thermal-power-units-stop-lifting-coal-as-demand-sees-sharp-drop/75023213. Accessed 7 April, 2020.

The Guardian. 2020a. Coronavirus-driven CO_2 shortage threatens US food and water supply, officials say. Available at https://www.theguardian.com/us-news/2020/apr/20/carbon-dioxide-shortage-us-food-water-coronavirus. Accessed 20 April, 2020.

The Guardian. 2020b. Mines are hotspots for spread of COVID-19, study finds. Available at https://www.theguardian.com/environment/2020/jun/05/mines-coronavirus-hotspots-report-us-canada. Accessed 5 June, 2020.

United Nations. 2020. Ensure access to affordable, reliable, sustainable and modern energy for all. Available at https://unstats.un.org/sdgs/report/2019/goal-07/.

Unruh, GC. 2000. Understanding carbon lock-in. *Energy Policy* **28**(12): 817–830.

Vanderbilt, T. 2020. The pandemic shows what cars have done to cities. *The Atlantic*, Available at https://www.theatlantic.com/ideas/archive/2020/04/pandemic-shows-what-cities-have-surrendered-cars/610423/. Accessed 24 April, 2020.

Victor, D, Geels, F, Sharpe, S. 2020. Accelerating the low carbon transition: The case for stronger, more targeted and coordinated international action. *Brookings Institute*, Available at https://www.brookings.edu/research/accelerating-the-low-carbon-transition/. Accessed 9 December, 2020.

Wall Street Journal. 2020. U.S. Power use weakening after plunging in Italy amid coronavirus. Available at https://www.wsj.com/articles/plunge-in-italys-electricity-use-hints-at-coronavirus-risks-facing-u-s-11584532801. Accessed 18 March, 2020.

World Economic Forum. 2020. These images show the impact of coronavirus on electricity demand in Chinese cities. Available at https://www.weforum.org/agenda/2020/03/these-images-show-how-coronavirus-has-affected-electricity-demand-in-chinese-cities/.

Xiao, W, Nethery, RC, Sabath, BM, Braun, D, Dominici, F. 2020. Exposure to air pollution and COVID-19 mortality in the United States. *medRxiv*. DOI: http://dx.doi.org/10.1101/2020.04.05.20054502.

Yearby, R, Mohapatra, S. 2020. Structural discrimination in COVID-19 workplace protections. Health Affairs Blog, Saint Louis U. Legal Studies Research Paper No. 2020-09, Indiana University Robert H. McKinney School of Law Research Paper No. 2020-9.

Zheng, B, Geng, G, Ciais, P, Davis, SJ, Martin, RV, Meng, J, Wu N, Chevallier, F, Broquet, G, Boersma, F, van der, AR. 2020. Satellite-based estimates of decline and rebound in China's CO_2 emissions during COVID-19 pandemic. *arXiv preprint*. Available at https://arxiv.org/abs/2006.08196. Accessed 15 June, 2020.

How to cite this article: Mulvaney, D, Busby, J, Bazilian, MD. 2020. Pandemic disruptions in energy and the environment. *Elem Sci Anth,* 8: XX. DOI: https://doi.org/10.1525/elementa.052

Domain Editor-in-Chief: Alastair Iles, University of California, Berkeley, CA, USA

Knowledge Domain: Sustainability Transitions

Part of an Elementa Special Feature: COVID-19 and the Anthropocene

Published: 00, 0000 **Submitted:** May 14, 2020 **Accepted:** August 14, 2020

ELEMENTA Science of the Anthropocene

Elem Sci Anth is a peer-reviewed open access journal published by University of California Press.

OPEN ACCESS