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The future environmental and health impacts of coal

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ABSTRACT

In the United States, coal consumption in the last 12 years has declined from 1,045,140 million short tons in 2007 to 539,420 million short tons in 2019, a decrease of almost 50%. During that period the number of electric power coal generators has declined from 1,470 to 738 accounting for 21% of capacity. An even more dramatic decrease in coal use has occurred in Western Europe. This significant reduction in coal use and the concomitant closure of coal mines and coal-burning power plants will result in substantially cleaner air, reductions in respiratory problems such as asthma, less heart disease, fewer hospitalizations, and other health benefits, as well as a reduction in occupational health problems such as silicosis and Coal Workers' Pneumoconiosis (Black Lung Disease). However, in China, India, Russia and in several other Asian countries some projections indicate an increase in coal production and use. In some situations, the coal is burned in old, highly polluting power plants. In these regions the health impacts of coal use could worsen. In addition, millions of people in these regions still burn coal in their homes resulting in maximal exposure to the pollutants such as arsenic, selenium, fluorine, and mercury released from coal combustion.

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1. Introduction

Researchers posit that the habitual, human-controlled creation and use of fire began approximately 300,000–400,000 years ago by our hominin ancestors (Roebroeks and Villa, 2011; Gowlett, 2016). Wood, and organic alternatives such as “peat, cut turf, animal dung, animal bone, seaweed, and straw,” fueled the earliest fires (Hirst, 2019). This possession and manipulation of fire not only influenced human biology (Gowlett, 2010, 2016), but helped shape human behavior and transform societies and culture (Johnston et al., 2016; Pyne, 2016). The shift from biomass to fossil fuels (i.e., coal, petroleum, and natural gas) as an energy source is a relatively recent development within the larger narrative of human development and technological progress, but has played a critical role in the creation and advancement of industrial civilizations, and the development of modern technologies.

Coal, the “largest source of solid fuel in the world” (Miller, 2011a), launched a revolution: as populations grew and biomass resources dwindled, coal supported the evolution of general manufacturing, iron and steel production, power generation (e.g., steam), railways, and other industries (Fouquet and Pearson, 1998; Kennedy, 2020). Once referred to as “Old King Coal” (Mackay, 1859; Mathis, 2018), this unassuming, combustible “black stuff that arises mysteriously from nowhere” (Orwell, 1937) served as the primary source of heat, steam, and electricity for decades (Fig. 1) and provided the means to allow “humanity [to] transform nature's cold, cruel world into one more comfortable, [and] more civilized” (Freese, 2003). In his 1937 essay “Down the Mine”, author George Orwell wrote, “Our civilization ... is founded on coal.] The machines that keep us alive, and the machines that make machines, are all directly or indirectly dependent upon coal. Practically everything we do, from eating an ice to crossing the Atlantic, and from baking a loaf to writing a novel, involves the use of coal, directly or indirectly.” (Orwell, 1937). However, in the past decade the industry has fallen on hard times as demand and productivity have plummeted (Fig. 2). This precipitous change in the coal industry has had negative
consequences for those involved with, or dependent on, coal. On the other hand, the waning reliability on coal presents positive outcomes for the environment and for human health. Over the past 20–30 years (and particularly within the last decade), an increasing concern about the threats that environmental deterioration poses to the planet has galvanized an international response as scientists, governments, global leaders, policy makers, intergovernmental organizations, and other stakeholders have coalesced around an urgent need to take action. Central to these discussions is developing policy/energy usage within the context of climate change. The removal of coal from the global energy mix has been internationally prioritized as governments seek to reduce greenhouse gas emissions, and restrict the development of coal mines, power plants, and associated infrastructure (Brown and Spiegel, 2019). Further, the absence of any practical methods to eliminate carbon dioxide from the atmosphere or to minimize CO2 emissions from fossil fuel power plants has significantly influenced utilities and governments to turn away from coal. More recently, coal use has declined dramatically in the United States (U.S.) and in Europe, partly motivated by their pledged support of the 2015 Paris Agreement (e.g., Parra et al., 2019). As of July 2020, 15 European countries had announced their intentions to phase-out coal while Austria, Belgium and Sweden are now coal-free (Europe Beyond Coal, 2020). A number of countries (e.g. France and Germany) have shut down their last coal burning power plants or closed their coal mines in 2004 (Bezzina, 2004) and 2018 (Campbell, 2020; Reuter et al., 2020), respectively. Several other countries have committed to phase out coal use, including Canada, Mexico, Hungary, UK, France, Germany, Denmark, Finland, South Korea, and Japan (Casey, 2020). The reasons for this are manifold and likely, to a large extent, irreversible. Perhaps the most compelling reason for this trend is the relative cost of fuel (Fig. 3). The costs of alternative fuels (e.g., natural gas, wind energy and solar power) for generating electricity have fallen below the cost of coal rendering coal in many regions uneconomic (Cohan, 2018). The Bloomberg News reports: “It comes down to cost. Coal power is more expensive than gas and renewables in many places and, hence, is the first fuel priced out of the market when demand falls. Its plunging use amid the lockdowns is a boon for efforts to fight climate change, hastening a shift that was already underway to weed out the dirtiest fossil fuel” (Wade et al., 2020). The U.S. Energy Information Administration (EIA) reported that renewables (i.e., wind, solar, and hydroelectric power) surpassed coal for total electricity generation in 2019 (EIA, 2020c). Industry analysts predict coal’s share of U.S. electricity generation could fall to just 10% in five years, down from 50% a decade ago (Watts and Ambrose, 2020).

The aging infrastructure of coal fired power plants is another factor resulting in closures. Between 2002 and 2018, 275 of the 530 U.S. coal plants were shut down or converted to natural gas (Richardson et al., 2017; Trabish, 2018), with plans to retire additional plants by 2030 (Richardson et al., 2017). Most coal plants in the United States were built before 1990 (U.S. Energy Information Agency, 2017, Fig. 4), and the average age of a U.S. coal plant is 39 years (Cohan, 2018). Further, no new coal-fired power plants are scheduled to be built (Fig. 5).

The final nail in coal’s coffin may be the reluctance and even refusal for banks and other funding sources to provide financial support for coal-related projects. For example: “Financing a thermal coal project in Australia just got a little bit harder after Westpac Banking Corp. said it would exit the sector by 2030, leaving Australia and New Zealand Banking Group Ltd. as the last of the country’s big...
four yet to commit to dropping the most polluting fuel” (Thornhill, 2020). This growing institutional reluctance to invest in the coal industry is driven by increased pressure from various stakeholders and organizations to shift to cleaner forms of energy, as countries develop short- and long-term energy strategies to fulfill their commitments to the 2015 Paris Agreement (e.g., European Commission, 2019; Simon, 2019). In May 2020, the Energy and Policy Institute reported that, “Major financial institutions have announced new policies that limit how they do business with companies that remain reliant on coal ... [and] nearly all ... make clear that major banks expect electric utilities to move away from coal over the next decade” (Smyth, 2020). These decisions are punctuated by a growing sense of urgency that we are running out of time to limit global warming and rapidly approaching a point of no return (e.g., Associated Press, 2019; Hutt, 2019; Lenton et al., 2019). Further, dwindling financial resources are underpinned by a growing global movement to divest from fossil fuels (Financing the Future, 2019; Tyler-Davies, 2019; Cheeseman, 2020; Go Fossil Free, 2020).

Undoubtedly, coal has powered human progress and fundamentally transformed society; however, the impacts from long-term use of fossil fuels on the environment and to human health, including environmental pollution, anthropogenic climate change, and dwindling resources, are significant. There is growing acceptance of the role that coal combustion plays in contributing to global warming and climate change, as well as the consequences of coal extraction, processing, and utilization on human and environmental health, resulting in a mounting chorus that demands the end of coal use. The magnitude of these challenges is substantial, and solutions will require a globally interconnected, transdisciplinary effort to effectively address these issues. For decades, the United Nations (UN) and the World Health Organization (WHO) have, with support from various (international) non-governmental organizations (INGOs/NGOs), largely led efforts to bring global recognition to these problems, and provide platforms to assess progress and facilitate change, within a framework of shifting political, economic, humanitarian, and environmental conditions. More recently, the need for a global response has received public support from scientific organizations, and prompted the creation of inter- and transdisciplinary collaborations (e.g., The Lancet Countdown) as researchers are urged to actively engage at the “boundaries between science, policy, and society” (Bednarek et al., 2016; McEntee, 2020).

What follows are our opinions on what the impacts may be of consolidation of the coal industry on the environment and human health. We acknowledge that we have no crystal ball, no inside information, nor sophisticated statistical models. We are simply offering our perspectives based on a combined 75+ years of experience working in various facets of coal science, the environmental and human health impacts of coal, and the development of energy resources (see for example: Finkelman, 1981; Finkelman et al., 1999; Finkelman, 2004; Finkelman and Greb, 2008; Hendryx and Ahern, 2008; Liu et al., 2008a; Liu et al., 2008b; Palmer et al., 2010; Wolfe et al., 2015; Wolfe and Wilkin, 2017 Hendryx et al., 2020). For a more detailed discussion of the impacts of this trend on CO2 emissions and the economy see Rauner et al. (2020).

2. What does all of this mean for the environment and human health?

Coal, in a sense, is nature’s version of Dr. Jekyll and Mr. Hyde: the same physicochemical properties that make it an (economically) attractive fuel also take a “heavy toll on human health and the environment” (United Nations, 2020a). Direct and indirect impacts to air, water, soil, ecosystems, and animal and human health occur during each phase of the coal “life cycle”, from resource extraction to the final waste disposal (e., Dai et al., 2017). Many of these impacts have a cascading effect, facilitating additional threats and potentially amplifying consequences “down the line”. The combination of these impacts, compounded by a growing global population and energy demands, pose serious consequences to ecosystems and human health (UNEP, 2019c). The top two environmental concerns, as reported by the United Nations in their 2019 Global Environment Outlook Report (UNEP, 2019c) are climate change and biodiversity. Joyce Msuya, Acting Executive Director of UN Environment Programme, stated, “The science is clear: The health and prosperity of humanity is directly tied with the state of our environment” (UN News, 2019).

Among the environmental consequences of coal mining and utilization are: visual blight, which is the sometimes temporary, sometime permanent, destruction of the environment necessitated by coal mining and ancillary activities. This situation is particularly evident in Mountain Top Removal (Fig. 6). Other environmental issues associated with coal mining include land subsidence, polluted streams, and acid mine drainage. Commercial coal combustion brings a different set of environmental issues including acid rain (one of the few issues, such as acid rain, that have been largely eliminated; Fig. 7), release of particulate (fly ash), and emission of greenhouse gases including carbon dioxide. A portion of these byproducts (about 40%) have been beneficially used in bricks and blocks for construction and many other products. But the majority has to be disposed of and has occasionally led to environmental disasters such as breached ash disposal ponds (Fig. 8).
3. Health concerns and consequences

3.1. Dust emission

The extraction, storage, transportation, and utilization of coal produces fugitive dust (e.g., Miller, 2011b), which poses a significant risk to human and animal health, and the environment. Dust generated during extraction presents an occupational hazard for miners and has been linked to pulmonary diseases such as coal workers’ pneumoconiosis (CWP, “black lung disease”), chronic obstructive pulmonary disease (COPD), and silicosis (NIOSH, 2011). Emissions from coal-fired power plants, especially those without the latest pollution control technology, may contain hazardous air pollutants, exposing individuals to mercury, sulfur dioxide, nitrogen oxides, particulate matter, toxic heavy metals (e.g., As, Pb, Cd, Se), radioactive elements (e.g., uranium, radium, thorium), carbon monoxide, nitrogen oxides (NOx) and volatile organic compounds (Finkelman, 1994; Union of Concerned Scientists, 2008). Further, recent studies on nanoparticles generated during coal mining and coal combustion raises questions about potential health impacts of these particles (Duarte et al., 2019; Silva et al., 2020). George D. Thurston, a professor of population health and environmental medicine at New York University stated, “Our results indicate that, pound for pound, coal-burning particles contribute roughly five times as much to heart disease mortality risk as the average air pollution particle in the United States,” (Fears, 2015). In addition to cardiovascular effects, exposure to coal dust/emissions has been linked to respiratory effects and compromised lung function, increased susceptibility to viral and bacterial infections, low birthweight in newborn infants, increased infant mortality, neurological effects, and decreased life expectancy (Lockwood et al., 2009; Burt et al., 2013 and references therein). Power plants with modern pollution control systems are capable of capturing more than 99% of the particles generated. In contrast, emissions from aging power plant infrastructure, especially those that were ‘grandfathered’ into regulatory legislation and exempted from incorporating pollution control systems to reduce atmospheric discharges, contribute to a range of health problems and over 800,000 premature deaths per year globally (EndCoal, 2020). Within the United States, adverse health outcomes attributable to emissions from coal plants (as of 2010) – where coal-fired power plants account for nearly 50% of electricity generation (Earth Talk, 2015) - affect close to 2 million people annually, with a total monetized value exceeding $100 billion per year (Table 1; Clean Air Task Force, 2010). In 2012, coal-
related air pollution resulted in high death toll in China (Smith, 2014). The ‘Coal Kills’ report (Goenka and Guttikunda, 2013) estimated that, in India, coal contributes to 80,000 to 115,000 premature deaths annually. In Europe, coal kills around 23,300 people annually and the economic costs of the health impacts from coal combustion are valued at about US$70 billion per year, with 250,600 life years lost (EndCoal, 2020). We consider these statistics to be estimates showing the order of magnitude of the health impacts associated with exposure to coal dust and coal-fired power plant emissions.

3.2. Occupational health problems of coal miners

Since the advent of coal mining some 4,000 years ago in China, untold numbers of coal miners have died in cave-ins, floods, explosions and other accidents. Although coal mining is far safer in today’s world than in the past, mining related health problems are globally wide-spread (Cunningham, 2014). Occupational health impacts include pulmonary diseases such as chronic bronchitis, chronic obstructive pulmonary disease (COPD), coal workers’ pneumoconiosis (CWP, “black lung disease”), emphysema, progressive massive fibrosis (PMF), and silicosis (Markandya and Wilkinson, 2007; NIOSH, 2011). Diseases such as silicosis and Coal Workers Pneumoconiosis (CWP; Black Lung Disease) continue to take a heavy toll on the health of coal miners: in 2013, CWP resulted in 25,000 deaths globally (GBD, 2015). Within the United States, the National Institute for Occupational Safety and Health (NIOSH) Coal Workers Health Surveillance Program is reporting a resurgence in CWP and PMF, particularly within central Appalachia (NIOSH, 2018); the prevalence of PWF among miners living within this region reached the “highest level ever recorded” in 2015 (Blackley et al., 2018).

3.3. Uncontrolled coal fires

Coal has a tendency to combust resulting in uncontrolled fires when exposed to air. These fires can ignite within coal waste piles, storage piles, and surface and underground mines (e.g., Hower et al., 2009; O’Keefe et al., 2010; Broadway, 2020). Once ignited underground the coal fires are extremely difficult to extinguish and have resulted in the abandonment of the entire town of Centralia, PA (Dekok, 1986). The fires can start from spontaneous combustion, precipitated by machine or human accidents, or intentionally ignited; once ignited, they can persist for years (e.g., Kolker et al., 2009; Melody and Johnston, 2015). Coal fires are globally widespread and pose a danger to human and animal populations, as well as the environment, and cause economic hardship by destroying a valuable resource, despoiling the local environment, polluting streams and air (Finkelman, 2004). Less well known are health outcomes resulting from exposure to coal fire emissions, which releases a variety of harmful organic compounds (e.g., Hower et al., 2013). Dhar et al. (2019) documented that villagers living within one mile of an active coal fire were 98% more likely to report a range of health issues than villagers living five miles from the fire. However, an even more serious health problem could be the result of the mobilization of potentially toxic elements such as arsenic, selenium and fluorine (Finkelman, 2004).

3.4. Residential coal use

Perhaps the most dangerous use of coal is in residential settings where coal is burned with little to no ventilation. Globally, approximately 3 billion people use unprocessed solid fuels, including coal, kerosene, and/or biomass (i.e., wood, animal dung, or crop waste), for cooking (WHO, 2018), often using indoor open fires or inefficient, simple stoves. Inefficient combustion of solid fuels, coupled with poor ventilation, exposes individuals (typically women, children, and the elderly) to elevated concentrations of (potentially toxic) air pollutants within the home (e.g., black carbon, carbon monoxide, complex organic compounds, metals, and particulate matter; e.g., Finkelman et al., 1999; Gordon et al., 2014; Balmes, 2019) and also contributes to ambient air pollution once it exists in the home. Serious health problems have been linked with house use of cooking using coal, including mental illness (Braithwaite et al., 2019), acute respiratory issues in children, lower respiratory infections, lung cancer, chronic obstructive pulmonary disease (COPD) in women, and cataracts (e.g., Smith, 2014; Hystad et al., 2019; Shaffer et al., 2019). Experts estimate that exposure to household air pollution (HAP) generated while cooking with solid fuels is responsible for 2–4 million premature deaths each year, and significantly impacts individuals living in low- and middle-income countries (GBD, 2018; WHO, 2018). See Shaffer et al., 2019 and references therein, for a discussion of air pollution exposure and global disease burden, and future directions.

3.5. Lignite-water syndrome

Prior to transportation and utilization (i.e., combustion) - and even before extraction - coal can impact human health. Researchers have suggested that leaching of organic compounds from low-rank coals (lignite, sub-bituminous coal, brown coal) into aquifers that are used for drinking water may contribute to a fatal kidney disease known as Balkan Endemic Nephropathy in Europe (Tatu et al., 1998) and Lignite-Water Syndrome in the U.S. (Chakraborty et al., 2017; Ojeda et al., 2018).

4. Environmental concerns and consequences

4.1. Global warming and climate change

The atmosphere has served as a faithful recorder of the transformative consequences to the environment caused by global industrialization and fossil fuel consumption. Of the direct impacts stemming from coal use, the emission of carbon dioxide (CO2) is one of the most significant, as it serves to amplify the planet’s natural greenhouse effect. Pre-industrial CO2 levels, determined from analysis of ice cores, are estimated to be around 280 ppmv (parts per million by volume; Etheridge et al., 1996). In the 1950s, fossil fuel emissions became the dominant contributor of anthropogenic emissions (Friedlingstein et al., 2019). In 2019, the average CO2 concentration at the Earth’s surface was 409.8 ± 0.1 ppm – “higher than at any point in at least the past 800,000 years” (Lindsey, 2020). Further, in addition to releasing CO2, many mines also produce methane (CH4), which is a potent greenhouse gas.

Collectively, the global energy sector contributes more
greenhouse gas emissions (73% worldwide) than any other sector (Ge and Friedrick, 2020); however, coal-fired power generation “continues to be the single largest emitter, accounting for 30% of all energy-related carbon dioxide emissions” (IEA, 2019b) and the “single largest source of global temperature increase” (Rice, 2019). Currently, global temperatures are slightly greater than 1°C above pre-industrial levels (WEF, 2020a). To avoid serious impacts caused by climate change, the consensus is that temperature increases should be limited to well below 2°C above pre-industrial levels – while pursuing efforts to restrict global warming to 1.5°C (e.g., IPCC, 2018). To meet these ambitious goals and strive for a “net-zero emissions future”, as outlined in the 2015 Paris Agreement, countries committed to developing national climate action plans to reduce their greenhouse emissions, or “NDCs” (nationally determined contributions), and adapt to the climate change impacts (e.g., UNFCC, 2020; WRI, 2020). Recent analyses and modeling of global greenhouse emission scenarios (IPCC, 2018; Christensen and Olhoff, 2019) suggest that these initial commitments were not sufficient and we “on course for a 3.2°C temperature rise” (UNEP, 2019a; 2019b). The United Nations asserts that countries, “must increase their NDC ambitions threefold to achieve the well below 2°C goal and more than fivefold to achieve the 1.5°C goal” (UNEP, 2019).

Central to discussions at the environment-health-energy mix nexus is developing policy and energy utilization strategies within the context of global warming and climate change (e.g., IPCC, 2019). UN Secretary General Antonio Guterres stated, in his opening speech at the 2019 United Nations Climate Change (COP25) conference in Madrid, “Either we stop this addiction to coal or all our efforts to tackle climate change will be doomed” (Guterres, 2019). To limit global warming to 1.5–2°C, it is imperative that fossil fuels (particularly coal) are phased out as an energy resource (UNEP, 2018; Christensen and Olhoff, 2019; UNEP, 2019b). Global greenhouse gas emissions need to be cut by 50% by 2030, as we aim for zero emissions by 2050. Delayed action in addressing and mitigating global climate change has serious implications as the world’s population (projected to reach 9.7 billion by 2050 and 10.9 billion in 2100 (UN, 2019)), energy demands, and ecosystem stressors continue to increase (e.g., Aengenheyster et al., 2018; Sorab, 2019). Direct impacts, many of which we are already experiencing (e.g., Borenstein, 2019; WMO, 2020), include increasingly harsh weather conditions, resulting in floods and storms, heat and cold stress, droughts, melting ice sheets, and UV radiation (BMJ, 2015; WMO, 2020). Ecological disruptions will impact human health through vector-, food-, and water-borne diseases and worsening air quality (BMJ, 2015; Silva et al., 2017). These effects will be compounded by society’s response to climate change: nutrition, occupational health, mental health, violence and conflict (BMJ, 2015; CDC, 2020).

4.2. Land alteration

Many of the phases within the coal lifecycle cause land-use change and damage resources (e.g., Dai et al., 2017; Giam et al., 2018). Direct and indirect effects are largely centered around the destruction of the landscape, including agricultural and forested areas, degradation of the physical environment and destruction of wildlife habitats and ecosystems, damage to recreational lands, land subsidence, increased methane emissions (contributing to climate change), sedimentation and erosion (Epstein et al., 2011; Miller, 2011a). Underground mining can trigger collapse and facilitate land subsidence, fundamentally altering the topology. Surface mining drastically alters the land surface through the removal of rock and soil and may lead to erosion and mass wasting. Mountaintop removal (MTR) is a form of large-scale surface coal mining that occurs in the steep terrain of Central Appalachia in the United States where other conventional forms of mining are often not practical. MTR involves clear cutting forests and using explosives and large dragline equipment to reach and extract coal. Large valley fills are created between mountain ridges that permanently bury headwater streams. The practice generates local air pollution that affects surrounding communities (Kurth et al., 2015), and leads to long-term surface water and groundwater contamination. Lindberg et al. (2011), for example, demonstrated that water quality remained significantly degraded twenty years after mining reclamation in an MTR watershed. Adverse environmental impacts likely have detrimental health effects on the people who live near these mining sites (Hendryx et al., 2020). Although MTR has been in decline as other energy sources have become more economically competitive, it is still in practice and its long-term impacts especially to water quality are severe.

4.3. Water quality

All facets of the global water cycle are impacted by coal extraction, processing, transportation, utilization and disposal, and impacts are spatially and temporally extensive. Mining activities directly affect surface and groundwater quality (i.e., contamination), quantity, and availability. Groundwater levels and flow direction may be altered during underground extraction activities, while surface mining typically degrades surface waters through stream runoff. Over the long term, these consequences may deplete water resources, and lead to permanent modifications of local and/or regional recharge zones (e.g., Miller, 2011a). MTR is particularly damaging to streams as the removal process buries headwater streams. For example, in Kentucky (United States), over 1,400 miles of streams have been buried and/or severely damaged (KFTC, 2020).

Acid mine discharges (AMD) from (abandoned) underground mines continues to be the most serious water quality and watershed degradation issue for coal mining areas. These outflows significantly increase the health risk to humans through contamination of drinking water sources, ingestion of impacted biota such as fish and mussels, exposure in recreational waters, and the remobilization of heavy metals leached from soils/sediment commonly associated with mining waste (Butler, 2006).

Structural failures related to short- and long-term storage of coal byproducts during processing (Fig. 8 (coal slurry) and utilization (storage of coal ash) contaminates water supplies (e.g., Kingston Fossil Plant coal ash spill; Bourne, 2019), poses a physical danger to animal and human life (e.g., 1966 Aberfan Disaster; Solly, 2019), and an increased risk of negative health outcomes due to exposure of toxic compounds (Gottlieb et al., 2018; Bourne, 2019). Further, water quality degradation affects stream biodiversity across multiple taxa, not only impacting taxonomic richness but abundance, as well (Giam et al., 2018). Similar impacts stem from accidents during coal transportation.

Water is a fundamental aspect of coal utilization: all coal plants are dependent on water resources to generate electricity. The usage of significant volumes of water places significant stress on local resources, including regional aquifers (e.g., Averyt et al., 2011).

It is important to note that impacts are not confined to freshwater environments – marine environments are also affected. The presence of coal dust on the ocean surface and on the seafloor has been documented, causing serious impacts to plants and aquatic biota (Ahrens and Morrisey, 2005; Johnson and Bustin, 2006) including localized ocean acidification as compounds within coal dust can react with seawater (De Place, 2016).

4.4. Ecosystems and biodiversity

Conserving, preserving and protecting biodiversity, and the
ecological processes and ecosystem services it enables, is essential to long-term sustainability of our planet’s resources and human survival. And, after climate change, biodiversity is one of the top two environmental concerns, as reported by the United Nations in their 2019 Global Environment Outlook Report (UNEP, 2019c). However, despite global commitments to reduce biodiversity loss, and the development of strategies, frameworks and environmental policies by many nations to protect biodiversity at a national level, biodiversity continues to diminish at an alarming rate. Many conservation biologists predict an “immense loss of biodiversity within the next 100 years” (Cafaro, 2015), and assert that the sixth mass extinction event, driven by human activity, may be underway (Cafaro, 2015; Lancet Planetary Health, 2017). For decades the operational paradigm regarding mining-induced ecosystem impacts has been that any environmental issues resulting from extraction activities are localized, spatially and temporally transient, and easily rectified during site restoration/rehabilitation, when the worked area is returned to the “pre-mining landscape” (Sontner et al. 2018). However, emerging evidence suggests that ecosystem and biodiversity losses carry non-linear risks: by exceeding thresholds and/or crossing “tipping points”, ecosystems and services may be (irreversibly) compromised or damaged, triggering “catastrophic events” (WEF, 2020b). Land clearance, and associated mining activities and construction, disturbs and displaces wildlife populations as habitats are altered and destroyed (e.g., NWF, 2012; Jahshan, 2015). Coal combustion, especially where the latest pollution control technology in not employed, contributes to air pollution, injecting a proverbial “alphabet soup” of harmful compounds into the atmosphere (e.g., heavy metals, mercury, sulfur dioxide, nitrogen oxides, particulate matter, and others; Union of Concerned Scientists, 2008) which are linked to respiratory and cardiovascular diseases that impact wildlife and human health (e.g., Arcadia, 2017). Coal-fired power plants are also a major contributor of anthropogenic releases of mercury; once deposited onto terrestrial and aquatic surfaces, it is readily transformed and transported in the environment. Methylmercury (MeHg), the most abundant organic form, is an established environmental toxicant due to its ability to bioaccumulate in organisms (Clarkson, 2002; Sunderland et al., 2018) and biomagnify through successive trophic levels in a food web, leading to elevated concentrations in higher trophic-level organisms (Lavoie et al., 2013; Sheehan et al., 2014; Wu et al., 2019). While bio-accumulation and biomagnification within organisms is concerning, the primary consequence is increased vulnerability due to reproductive, neurological and immune problems as organisms develop within a disrupted and stressed environment (NWF, 2011).

It is important to note that the temporal and spatial interconnectedness, threshold dynamics, and feedback loops among and between human activities, climate, biogeochemical dynamics and ecological response are poorly constrained, with many unknowns (Lenton & Williams, 2013). This is particularly true when evaluating ecosystem services and biodiversity within the context of the global energy demands and consumption; however, “less than 1% of [scientific] papers in leading conservation journals [refer] to mining-related threats” (Sontner et al., 2018). The vital importance of this relationship was critically evaluated within the UN’s Sustainable Development Goals (UNDP, 2016), and explicitly integrated as an agenda item at the Convention on Biological Diversity to facilitate an ongoing conversation that engages stakeholders “in discussions around mainstreaming biodiversity into the energy and mining sectors” (UNEP, 2017).

5. The future: environmental and health legacies

An increasing concern about the environment and the threats that deterioration pose on the planet has galvanized a “global call” for unified intervention, underpinned by a coordinated, trans-disciplinary effort to increase public awareness of these issues and guide an effective response. Going forward, international policy will inevitably assert an influential role, as 2020 ushers in the UN’s “Decade of Action” to meet its 17 Sustainable Development Goals (SDGs), a “blueprint to achieve a better and more sustainable future for all”, by 2030 (UN, 2020b; 2020c). Within the last decade, the importance of integrating the environment, people, and climate has transitioned from being an academic concern (e.g., WEF, 2011) into a broadly societal concern as the forecasted realities of climate change come to pass, creating urgent public and environmental health issues. For example, in the “Global Risks Report 2020”, published by the World Economic Forum, “environmental concerns dominate the top long-term risks by likelihood among members of the World Economic Forum’s multi-stakeholder communities of leaders from business, government, academia and non-governmental and international organizations (WEF 2020a). Before 2010, environmental matters were absent from these reports (WEF 2020a).

5.1. The U.S. and Western Europe

The future of global coal use is a study in contradictions, although the long-term trajectory signals a decline. In the United States, coal consumption in the last 12 years has declined from 1,045,140 million short tons in 2007 to 539,420 million short tons in 2019: a decrease of almost 50% (EIA, 2019). During that period, the number of electric power coal generators decreased from 1,470 to 738 accounting for 21% of capacity (EIA, 2020a). In 2007, coal provided for 23,501 quadrillion BTUs of US electricity generation, 32.8% of total (EIA, 2020b). By 2019, although total electricity demand in the US had increased, coal provided 14,268 quadrillion BTUs (14.1% of total). Reductions in US coal use translate into a corresponding decrease in pollution from coal-fired power plants. However, many, if not most of these power plants are the older, less efficient, higher polluting power plants so the decrease in pollution is likely even greater.

Similarly, more than half of U.S. coal mines have closed since 2008 (Paraskova, 2019), and coal production in thousand short tons in 2019 was only 60% of 2008 production levels (EIA, 2020b). Most of the closed mines have been smaller, less efficient mines in Appalachia. With this trend there has been a concomitant decrease in pollution and environmental impacts from the mining, but long-term legacy effects from coal mining persist, especially with respect to impacts on water quality and poor land reclamation (Palmer et al., 2010; Lindbergh et al., 2011). Economic revitalization of former mining areas is also an area of continued concern but positive potential (Boettner et al., 2019).

Moreover, during the current coronavirus pandemic many factories and businesses have shut down or reduced hours reducing the demand for electricity, so power plants are not running at full capacity thus further reducing pollution. This reduction is likely to be temporary as post-pandemic economic recovery takes place. There are some negative aspects to this downward trend in coal mining and utilization, beyond the loss of jobs. Negative impacts also include the loss of funds generated from taxes, which would help support the local government’s reclamation efforts. There would also be a substantial decrease in taxes that are collected on the sales of coal and then deposited into the Black Lung Disability Trust Fund to finance payments of black lung benefits to afflicted miners.

In contrast, Europe is well-poised to transition to other energy resources. The European Union (EU) sees this as an opportunity and has responded by developing “The European Green Deal”, a
strategy that integrates economic growth with environmental sustainability. The Green New Deal provide a “roadmap for ... turning climate and environmental challenges into opportunities across all policy areas and making the transition just and inclusive for all”. Further, in a recent study by the World Economic Forum, which evaluated 115 countries on their existing energy sectors and ability and readiness to transition to sustainable energy resources, the top 10 countries were from Western and Northern Europe (WEF, 2019). A number of countries have also announced their intent to phase out coal, in an effort to fulfill their commitments to the Paris Agreement (e.g., Byrne, 2020; Europe Beyond Coal, 2020).

6. Benefits to human and environmental health

Reduction of coal combustion in power plants, with corresponding improvements in air quality, carry multiple public health benefits including reduced asthma (Orellano et al., 2017), heart disease, chronic lower respiratory disease, stroke and cancer (Gottlieb and Lockwood, 2018), and an improvement in neurocognitive development in children (Kalina et al., 2017).

6.1. Dust emission

The closure of a substantial number of coal-fired power plants should proportionally decrease the amount of dust emitted into the environment from coal combustion: i.e., as many of the decommissioned coal-fired power plants are the older (and theoretically generate more hazardous air pollutants), the reduction in dust emissions from coal combustion should be substantial. For example, the emission of carbon monoxide, nitrogen oxides, sulfur dioxide and volatile organic compounds from the Sandow coal plant in Southeast Central Texas dropped by nearly 100% from 2017 to 2018 (Mulder, 2020). Dust emissions from mining are also expected to decrease as mining activity declines. For example, air pollution in Central Texas has dropped sharply after one of the state’s largest coal mining operations closed in 2017, according to the Texas Commission on Environmental Quality (Collins, 2020).

A reduction in dust generation, with corresponding improvements in air quality, will benefit human health. A new study found a 55 percent reduction in lung-irritating pollutants and 400 fewer hospital admissions after one coal plant closed and others added scrubbers (Bruggers, 2020). This reduction should translate into a significant decrease in respiratory disease, heart disease, asthma, and other health problems attributed to the dust generated from coal combustion (Kravchenko and Lyerly, 2018).

6.2. Occupational health problems of coal miners

The closing of coal mines and coal-fired power plants should result in fewer workers, and those living within proximity of coal-fired power plants, being exposed to coal dust and the potentially harmful constituents within the coals (e.g. quartz and pyrite). Serious lung diseases such as CWP and PMF are progressive diseases, thus – at least within the United States – a continued increase in prevalence is expected in the foreseeable future (Blackley et al., 2018).

6.3. Uncontrolled coal fires

Fewer active coal mines should correspond to fewer (new) uncontrolled fires within the coal mines, on coal waste banks, and within storage piles. This will enable local ecosystems to recover and the improved air quality will benefit individuals living near or downwind from these fires. These anticipated improvements are contingent on our diligence in preventing, and extinguishing, any fires that occur.

6.4. Residential coal use

Residential coal use is rapidly disappearing as governments have banned the use of the dangerous coals and improving economies and modernization has helped wean millions away from this extremely dangerous way of burning coal (Finkelman and Centeno, 2019). Few people in the U.S. and Western Europe still rely on coal for domestic heating or cooking. The Navajos are the largest segment of the US population that has, until recently, utilized coal within their homes (Bunnell and Garcia, 2006) contributing to an extremely high incidence of respiratory disease. However, those living in lower- and middle-income countries remain vulnerable to health impacts resulting from household air pollution (HAP) from solid fuels used for cooking, as well as indirect consequences caused by global warming and climate change (e.g., NATO, 2012).

6.5. Lignite-water syndrome

This may be the only health issue attributed to coal that will not be impacted by the reduction in coal mining and combustion.

6.6. The environment

Transitioning away from coal, to cleaner forms of energy, will undoubtedly benefit ecosystems. The issue is how quickly this transition occurs: a ballooning global population and economic prosperity are exerting incredible pressure on the environment, creating an unsustainable situation. Given the complexity of global feedback loops, our physical environment is likely to get worse before it gets better. Within the last decade, climate change has transitioned from being an academic concern (e.g., WEF, 2011) into a broadly societal concern as the forecasted realities of climate change come to pass, creating urgent public and environmental health issues. Central to environmental improvement – and overall planetary health - is a collaborative, international commitment to limit global warming and “combat increasing rates of environmental damage to water sources, land, biodiversity and marine life” (Harvey, 2016). Time is of the essence: a recent study published in Nature Ecology and Evolution suggests that it may take our biosphere millions of years to recover from the current climate crisis (Lowery et al., 2020).

7. The future: dealing with the environmental and health legacies elsewhere

Coal use has also been in decline in Europe and many other industrialized nations. More than 20 nations, including many in Europe, as well as Canada and Mexico have committed to reducing and eventually eliminating coal for power generation under the 2017 United Nations Climate Change Conference (Hendryx et al., 2020). Many of these nations renewed that commitment at the 2018 UN Climate Change Conference, with notable resistance from several countries including the United States, Brazil, Australia, Russia and others.

Despite declining trends in utilization in industrialized portions of the world, the downward trajectory of coal use is not universal. In fact, global coal consumption increased for three consecutive years between 2016 and 2018 and is near an all-time peak (IEA, 2019a). Increases are primarily driven by China, India, and Russia, but are occurring in other parts of Asia and the developing world. China, in particular, continues to increase its coal consumption, from 2,821 megatons in 2007 to 3,770 megatons in 2018 (Enerdata, 2020). Further, there are current plans for dozens of new coal-fired power plants in Africa (Economist, 2019).
7.1. China

China is a significant driver behind global energy consumption, accounting for almost half of the world’s coal use (Wood, 2019). When evaluating energy utilization within a climate-change-free scenario, researchers project that increasing incomes will cause household energy consumption to double by 2040 (Kemp-Duke, 2019). When accounting for climate change, scientists estimate a 36% increase in peak electricity consumption for every 1 °C increase in temperature (Kemp-Duke, 2019).

Nevertheless, there are signs of progress even in China. In China, less coal is being used in residential settings, one of the most dangerous methods of coal utilization due to immediate, direct, intense, and prolonged exposure to the pollutants released from coal combustion (Finkelman et al., 1999). Improved standards of living, access to electricity, more efficient stoves, education, and government regulations prohibiting the use of local mineralized coal have resulted in the reduction of severe health problems caused by residential coal combustion, such as coal in Guizhou province which boasts an astounding 35,000 ppm (parts per million) of arsenic, a known carcinogen (Finkelman et al., 1999). An ancillary benefit is that coal ash from these mineralized coals is no longer generated and dispersed on gardens and in the local environment.

China recently approved nearly 10 GW of new coal-fired power generation projects in the first quarter of 2020, roughly equal to the amount approved for all of 2019, amid a broader scramble to jumpstart an economy hobbled by the COVID-19 epidemic (Xuewan and Ge, 2020). Furthermore, they have embarked on an ambitious project to build a new fleet of modern power plants equipped with the most sophisticated pollution control technology (Myllyvirta et al., 2020). That said, smog continues to be an issue and there are disparities in the enforcement of environmental protection (Meng, 2019). Closure of old, polluting coal-burning power plants and factories and relocating the less polluting faculties away from population centers should help in reducing some health impacts.

7.2. Russia

Domestic coal consumption will increase by over 12 percent in Russia; it currently stands at around 196 million tons annually. The Asia-Pacific states, Southeast Asia, the Middle East and Africa will continue to be the major markets for Russian coal (Gerden, 2020). Russia is already exporting substantial amounts of coal to China (some 30 million tons per year) yet there remains great potential for a boost in exports in the coming years. The energy ministry expects exports to China to almost double within the next 10 years to 55 million tons, from their current level (RT, 2020).

7.3. India and Southeast Asia

India’s coal use is expected to increase by 4.6% per year through 2024. Overall, India’s coal demand is expected to grow by more than that of any other country, in absolute terms, over this period. Coal demand in Southeast Asia is forecast to grow by more than 5% per year through 2024, led by Indonesia and Viet Nam (IEA, 2018). The region’s strong economic growth will drive electricity and industrial consumption, which will both be fueled in part by coal. Pakistan has recently commissioned over 4 GW of new coal power plants, with similar capacity under construction. Bangladesh is about to commission the first unit of the 10 GW power plant it has in the pipeline (IEA, 2019a).

8. Concluding remarks

What are other consequences of this tsunami that has descended on the coal industry? We must be sensitive to the massive loss of jobs for miners, engineers, electricians, biologists, geologists, environmental coordinators, chemists, electricians, health and safety staff, etc. as well as the power plant workers and workers that transport the coal by train, truck, and barge (Fig. 9). There will also be job losses at the manufacturing plants who supply the mining equipment both large and small and at all the local businesses and shops that serve the miners and their families (Lewin, 2019).

Our comments in this paper are not intended to eliminate or even reduce concerns over the environmental and health impacts of coal mining and use. Rather they are offered as indicators of the direction these issues are moving in. Coal has had a long, profound and indelible imprint on our history and will continue to impact the Earth for years to come. So, although reduction in coal use is occurring in parts of our planet resulting in improving environmental quality, we must maintain diligence in our efforts to further minimize environmental and health impacts of coal mining and coal use.

Declaration of competing interest

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

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