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The Nexus of Energy Supply and Human Health

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Abstract

Uses of main primary energy resources, such as coal, oil, and solid biomass, are directly linked with adverse impacts on human health. Air pollution emitted from various activities in the energy supply chains is the main risk factor to human health, along with accidental and occupational risk exposures. Estimates of premature deaths are over four million per year for ambient air pollution (2015) and household or indoor air pollution (2012). More than 80 percent of the mortality from ambient air pollution emitted from the energy supply chains occurs in developing countries. The impact of household air pollution, mainly from traditional biomass used for cooking and space heating, disproportionately falls on women and children under age five years. Acute respiratory infections, mainly caused by household air pollution, are one of the largest categories of deaths (64 percent) of children under age five years in developing countries. These statistics indicate the deep nexus between the energy supply chain and human health. Yet, the negative implications for human health from energy use often receive inadequate consideration. It is critically important to take account of these human health impacts in developing energy supply plans and energy policies in developing countries.

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The Nexus of Energy Supply and Human Health[‡]

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The Nexus of Energy Supply and Human Health

1. Introduction

Energy is an essential input to economic growth and the welfare of human beings. However, energy also causes negative impacts to human health at various stages of the energy supply chain, from production to utilization. Energy production, such as coal and uranium mining, energy transformation such as electricity generation from coal or oil and its utilization at the end-use level, such as using fuelwood for cooking are associated with direct and indirect impacts to human health. Among the adverse health impacts originating from various stages of energy supply. Energy mining and production activities, such as coal mining, oil and gas drilling, can be the source of accidents and also pose a risk of long-term exposure of mining and drilling crews to harmful substances or pollutants. Energy transformation activities, such as power generation and charcoal production, could be a source of occupational as well as air pollution related health effects in addition to risks of accidents. Energy consumption activities, particularly burning of solid fuels, such as coal, and wood fuel for cooking emit harmful emissions, such as particulate matter that causes health risks, especially to women and children who are more likely to be exposed these emissions. In fact, indoor or household air pollution is a key risk factor to human health in low income countries around the world because almost one-third of the population in the world currently relies on these solid fuels for cooking (World Bank, 2015).

As we will discuss later in this paper, air pollution is one of the main risk factors to human health as it enhances respiratory diseases, heart attacks, strokes, lung cancers and other health problems. Cohen et al. (2017) show that ambient air pollution alone, which is mainly caused by burning of fossil fuels in power generation, industries and transportation, is the fifth largest contributor to global mortality in 2015, after high blood pressure, smoking, diabetes and high cholesterol. Most of the impacts occur in developing countries. According to the World Health Organization (WHO) ambient air pollution (AAP) and household air pollution (HAP) cause more than 7 million deaths a year globally with a disproportionate majority of deaths occurring in low- and middle-income countries. Cohen et al. (2017) estimate that exposure to PM2·5 caused 3·7 million to 4·8 million deaths and 90·8 million to 115·1 million disability-adjusted life-years

(DALYs) in 2015. These mortality and morbidity represent, respectively 7·6% and 4.2% of global deaths and DALYs in that year. Similarly, household air pollution caused 4.3 million deaths in 2012 (WHO, 2016). The impacts of HAP not only occur in low and middle income countries but also mostly affect women and children. These statistics indicate the degree of linkage between the energy supply/consumption system and human health.

It is also important to note that coal, petroleum products and biomass, the main sources of ambient and household air pollution account for more than 70% of global energy supply (IEA, 2016); in year 2014, coal, oil and biomass accounted for 28.6%, 31.3% and 10.3% of the global primary energy supply. The share of these fuels would not change significantly by 2035 unless rapid decarbonization of the global economy is achieved to meet targets under the Paris Climate Accord. According to BP Energy Outlook (BP, 2017), oil and coal would still occupy almost 60% of the total primary energy supply by 2035.

Considering the predominance of the fossil fuel based global energy supply system now and for several decades to come and also considering the harmful air pollution emitted from burning of fossil fuels and biomass, it is expected that the energy system (production, transformation and utilization) would continue to be a major concern to human health. This paper, therefore, aims to explain, in-depth, how various activities in the energy supply/consumption chain starting from mining/production to final consumption of energy are linked to human health.

Both energy and health economics are rich in literature examining corresponding issues. However, literature focusing on cross-cutting issues between these two disciplines is very limited. One comprehensive review in this direction is Smith et al. (2013), which presents human health impacts of different types of fuel (coal, petroleum, natural gas, renewables). Our study is different from Smith et al. in several respects. First, our study presents more recent information on health impacts, particularly through air pollution. Second, it systematically presents the health impacts through type or channel of impact: accidents, occupation and air pollution. Third, it provides detailed accounts of accidental impacts since the 1950s. Fourth, it derives policy implications from the analysis.

In this review paper, we first discuss the three key channels (accidental, occupational and air pollution) that energy supply chain affects human health. Energy supply chain also impacts human health through climate change as fossil fuels are the main source of global warming.

However, we have not included this indirect health impacts in this review. This is because health impacts from climate change are indirect impacts to human health. Second, this topic has been well covered in existing literature, particularly in Chapter 11 of the Working Group II of the Intergovernmental Panel on Climate Change (Smith et al. 2014). Earlier, Haines et al. (2009) also elaborated the impacts of climate change on human health.

2. Sources of Health Impacts from Energy Supply Chains

Figure 1 and Table 1 illustrate the medium and sources of human health impacts at various stages of the energy supply chain. Each stage of energy supply (i.e., mining and production, physical and chemical transformation and utilization) is associated with various impacts to human health. The impacts can be classified into three categories: accidental (e.g., coal mining explosion, oil tanker explosion), occupational (e.g., asthma and lung cancers to coal miners) and health impacts caused by air pollution resulted from energy supply chain (e.g., asthma and cancers caused by air pollution released from household cooking using solid fuels). The sources of impacts could be several such as radiation, exposure to toxic substances and indoor or outdoor air pollution.

Table 1 clarifies, with examples, how different stages of the energy supply chain are linked with health impacts. For example, some energy mining releases substances (e.g., acid mine drainage, sediments, dissolved solids, and toxic substances), which contaminate soils or are leaked into ground water. These substances could, for example, include heavy metals, such as lead, arsenic, cadmium, nickel, selenium, mercury and chromium. These substances could lead to damages of the nervous systems and kidneys, cause cardiovascular disease, carcinogens (lung, bladder, kidney, and skin cancers) and impact on respiratory and immune systems. Similarly, oxides of sulfur and nitrogen cause asthma, chronic obstructive pulmonary disease (COPD), cardiac disease and ischemic stroke. Table 1(b) briefly presents the types of diseases caused by various air pollutants.

Figure 1: Energy supply chain, medium and source of health impact

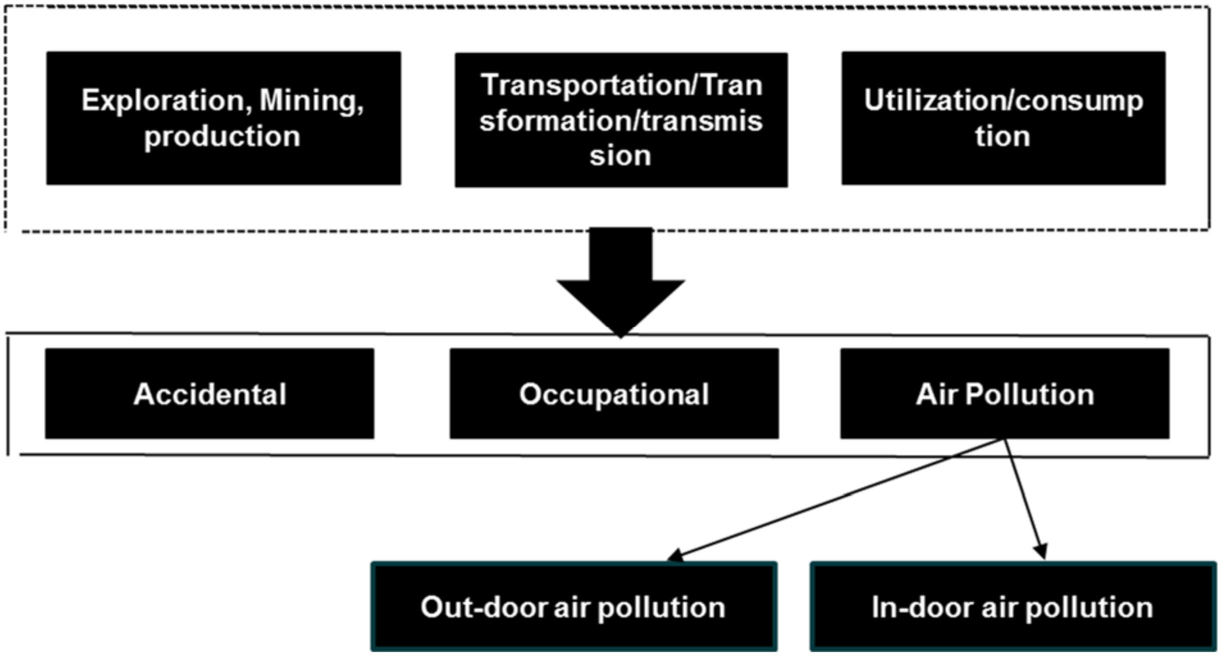


Table 1. Examples of energy supply chain, medium and source of health impacts

(a) Energy supply chain and medium of health impacts

Energy supply activity	Medium of health impacts
Mining	Surface and ground water pollution (e.g., acid mine drainage, sediments, dissolved solids, and toxic substances); exposure to toxic substances; dust and particulate air pollution; high mortality and morbidity
Transportation	Major accidents (oil tanker blasts, oil and gas pipeline explosions), air pollution (railway or truck transportation)
Oil and gas drilling	Toxic substances from drilling liquids and muds (e.g., Polycyclic aromatic hydrocarbons, cadmium, chromium, lead, mercury, chromate and barite)
Transformation (power generation), and consumption at end-use (e.g., cooking)	Particulate Matters (PM), carbon monoxide (CO), methane ($CH4$), carcinogenic PAH, oxides of sulfur and nitrogen, volatile organic compounds (VOC), toxic substances (e.g., benzene, formaldehyde, sulfur mercury, arsenic, fluorine, selenium) All these pollutants are harmful to human health at varying ways and degrees
Radiation	Nuclear radiation, radiation from coal fly ash

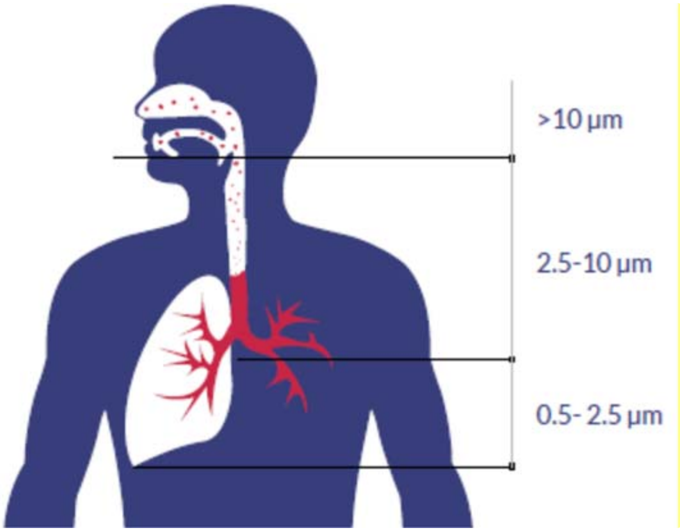
(b) Sources and actual health impacts

Air pollutants	Health impacts or diseases
Sulphur dioxide and nitrous oxides	Asthma; chronic obstructive pulmonary disease (COPD); cardiac disease; ischemic stroke
Transportation	Asthma, COPD, lung cancer, cardiac arrhythmias; acute myocardial infarction, congestive heart failure, ischemic stroke
Particular matter (PM10, PM2.5)	Cardiovascular and respiratory diseases, as well as of lung cancer
Polycyclic Aromatic Hydrocarbons (PAHs)	Adverse effects on liver, kidney, and testes; may impair the reproductive system
Volatile Organic Compounds (VOCs)	Impaired lung functions, impaired memory, respiratory symptoms, effects to the liver and kidneys, probable carcinogen
Heavy metals (Lead, Arsenic, Cadmium, Nickel, Selenium, Mercury Chromium, etc.	Damages the nervous systems, kidneys; cardiovascular disease, carcinogens (lung, bladder, kidney, and skin cancers), impacts on respiratory and immune systems

Source: WHO (2006).

Figure 2 illustrates how air pollution either ambient air pollution or household (indoor) air pollution affects human health. Incomplete combustion of fossil fuels (e.g. coal) in power generation, petroleum products (e.g., gasoline, diesel) in transportation and solid fuels (e.g., fuel wood, charcoal, agricultural residues) in household cooking emits substantial quantities of harmful air pollutants and contaminants including small particulate matter (PM), carbon monoxide (CO), methane (CH4), carcinogenic polyaromatic hydrocarbons (PAH), volatile organic compounds (VOC), benzene and formaldehyde and sulfur and mercury (Smith et al., 2013). All these pollutants are harmful to human health in varying ways and degrees. Among these pollutants, particulate matter poses the greatest risks to human health. Large particulate matters (with diameter 10 µm and higher), such as dust or pollen, get lodged in the nasal cavity, upper airways or thoracic cavity. Smaller particles (with diameter 2.5 µm or smaller) can reach deeper into the smaller airways of the body and deposit on the alveoli – the tiny sacs in the lungs where oxygen exchanges with carbon dioxide in the blood (WHO, 2016b).

Figure 2. Illustration of how particulate matters impact human health



Source: WHO (2016b)

Among the various mediums (accidents, occupation and air pollution), air pollution causes the greater risks to human health. Exposure to elevated concentrations of particulate matters, specifically with size of 10 microns (PM10) or less (PM2.5) in diameter, are the main contributors to these risks, specifically through cardiovascular and respiratory disease, and cancers. Table 2 summarizes the characteristics of key air pollutants with human health risk, main diseases caused by them and tolerable limits of their concentration as specified by the World Health Organization (WHO, 2006).

Table 2. Major air pollutants with human health risks, their potential impacts and WHO thresholds

Pollutants	Impacts	Safety threshold (WHO 2005 Guidelines)
Parliculate matters (PM): mixture of solid and liquid particles of organic and inorganic substances with diameter of 10 microns or less, (≤ PM10) including sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water.	Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as of lung cancer	PM2.5: 10µg/m^3 (annual mean) and 25µg/m^3 (24-hour mean) PM10: 20µg/m^3 (annual mean) and 50 µg/m^3 (24-hour mean)

Ozone at ground level: a pollutant generated from photochemical reaction with other chemical compounds, which are themselves are pollutants (e.g., nitrogen oxides from vehicle and industry emissions and volatile organic compounds emitted by vehicles, solvents and industry); sunny weather can generate highest levels of ozone pollution.	It can cause breathing problems, trigger asthma, reduce lung function and cause lung diseases	100 μg/m3 8-hour mean
Nitrogen dioxide (NO_2)	Long-term exposure can increase bronchitis in asthmatic children and reduce lung function	40 $\mu g/m^3$ (annual mean) and 200 $\mu g/m^3$ (1-hour mean)
Sulfur dioxide (SO_2)	It can affect the respiratory system and the functions of the lungs (coughing, mucus secretion, aggravation of asthma and chronic bronchitis) and causes irritation of the eyes	20 $\mu g/m^3$ (24-hour mean) and 500 $\mu g/m^3$ (10-minute mean)

Source: WHO (2006)

3. Accidental Risks in Energy Supply Systems

Almost every activity under energy supply chains poses adverse impacts to human health through accidents. For example, every stage of coal mining or production – both surface mining and underground mining,[1] coal washing or processing,[2] and coal transportation (Lockwood et al., 2009) are prone to accidents. Some studies (e.g., Burgherr and Hirschberg, 2014) have analyzed accidental impacts from the energy sector, from coal mining to LPG use in kitchen. Based on

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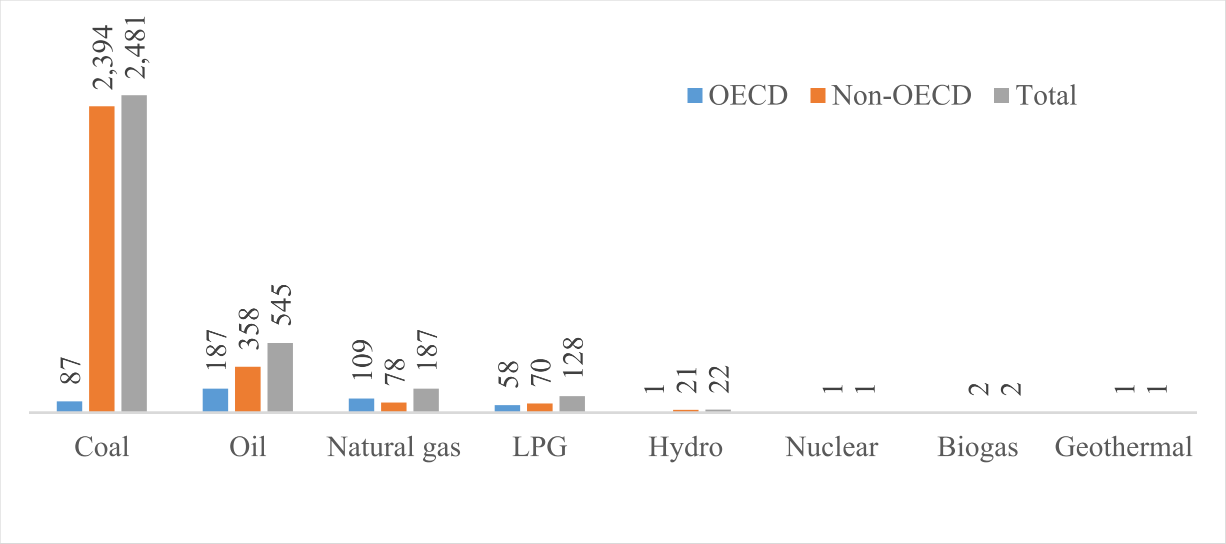
[1] Surface mining is used when coal reserves is open or buried less than 200 feet underground. It includes removing top soils and layers of rock to expose large beds of coal and its extraction using heavy machineries. Underground mining involves when coal reserve is buried several hundred feet below the surface. Deep wells with elevators and deep mine shafts are used in this process.

[2] When coal is extracted from mine, it is sent to, normally using conveyor belts, to preparation plants located at the mining site to clean or wash it removing dirt, rock, ash, sulfur, and other unwanted materials. Cleaning or washing increases heating value of coal per unit of weight.

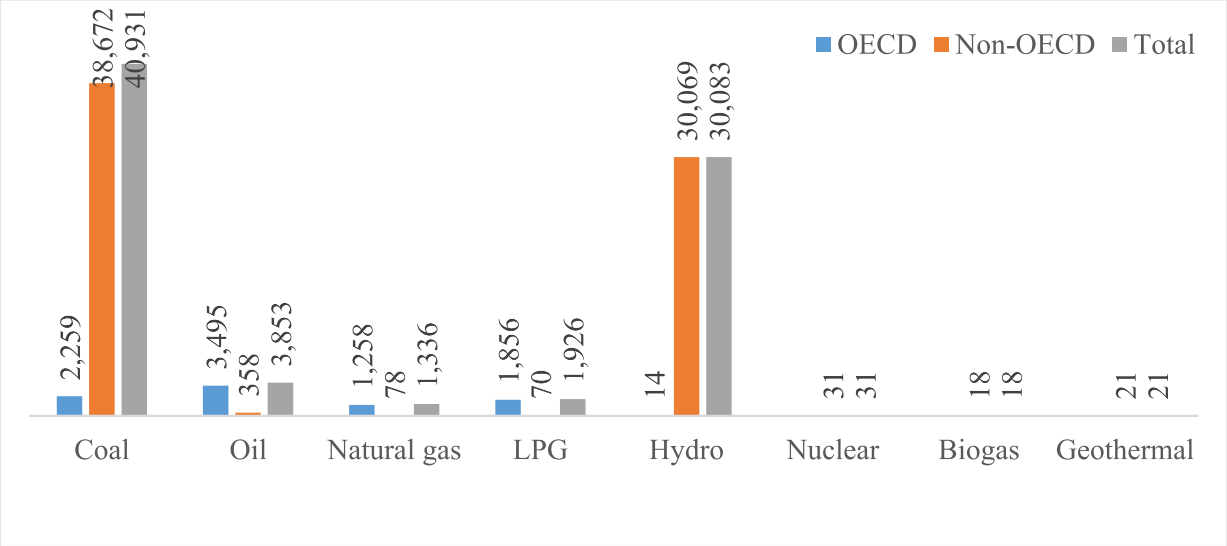
Burgherr and Hirschberg (2014), Figure 3 presents statistics of accidents and corresponding fatalities from energy sector activities occurred during 1970-2008 period.

Figure 3: Energy sector accidents during the 1970-2008 period
(excludes accidents less than 5 fatalities)

(a) Number of accidents



(b) Number of fatalities



Note: 85% of the total accidents and 70% fatalities in the coal sector in Non-OECD countries occurred in China. Moreover, 26,108 fatalities out of total 30,083 fatalities from hydropower accidents during the 1970-2008 period caused by a single accident in China's Banqiao dam and Shimantan Reservoir Dam systems that occurred in August 1975.

Source: Burgherr and Hirschberg, 2014

As illustrated in Figure 3, there occurred 3,367 accidents in the energy sector that caused more than 5 fatalities during the 1970-2008 period. Those accidents caused a total 78,199 fatalities. Of the total accidents, 87% occurred in Non-OECD countries. Eighty-nine percent of the total fatalities in the energy sector accidents also occurred in Non-OECD countries.

Coal is the main source accidents and corresponding deaths; 2,481 accidents in the coal sector killed 40,931 people during the 1970-2008 period (see Figure 3). It accounts for 74% of the total energy sector accidents and 52% of the total fatalities. Of the total coal sector accidents, 97% occurred in Non-OECD countries resulting in 95% of the total coal sector accident fatalities. China alone accounted for 85% of accidents and 70% of fatalities in the coal sector in Non-OECD countries (Burgherr and Hirschberg, 2014).

Most of the accidents in the coal sector occurred in coal mining. Table A1 in the Appendix presents selected coal mining accidents since 1950 to present examples of major coal mine accidents around the world. The two main sources of coal mine accidents are underground explosions and flooding of mines. One of largest coal mine accidents was the underground explosion in Laobaidong coal mine, located near Datong in the Shanxi province of China on May 9, 1960. The accident was caused by coal dust and methane explosion and it was the most fatal coal mine disaster since the inception of People's Republic of China in 1949 and killed 684 coal minors.[3] The most recent coal mining accident occurred in Soma, Turkey on 13 May 2014 where one of the pits was engulfed with fire and carbon monoxide killing 301 miners burning alive or suffocating.[4] It was the largest coal mine disaster in Turkey's history.

Explosions of oil and gas wells, pipelines and tankers are another the major sources of accidental impacts of human health from energy supply chain. During the 1970-2008 period, Burgherr and Hirschberg, (2014) reported 732 accidents in the oil and gas sector (excluding LPG related accidents) causing deaths of 5,189 people. The liquefied petroleum gas (LPG), the most popular fuel for cooking in developing world, caused 128 accidents killing 1,336 people during the 1970-2008 period (Figure 3). Tables A2 and A3 in the appendix present selected of oil and gas production and transportation related explosions since 1950 to show examples of major

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[3] The Globe and Mail, May 14, 2014, https://www.theglobeandmail.com/news/world/turkish-tragedy-among-the-worlds-worst-mining-disasters/article18662842/

[4] BBC News, 13 May 2015. http://www.bbc.com/news/world-europe-32709431

accidents in the oil and gas industry. One of the biggest accidents in the developed world so far was the Gulf of Mexico accident occurred on April 20, 2010 where a deep-water horizontal drilling rig, owned and operated by British Petroleum, exploded. It caused a fire on the mobile offshore drilling unit and caused deaths of 11 workers and seriously injured 17 others. The oil spill caused by this accident is considered the largest accidental marine oil spill in the world, and the largest environmental disaster in U.S. history.[5]

Some notable and relatively recent oil and gas transportation (pipeline, tanker) related accidents include 2013 Lac-Mégantic accident in Quebec, Canada (July7); 1998 oil pipeline explosion in Nigeria (October 18), 1989 Ufa train disaster in former Soviet Union (June 4). The 2013 Lac-Mégantic accident occurred when an oil tanker train (73 tank cars) carrying light crude oil exploded causing 47 deaths; It was the fourth-deadliest rail accident in Canadian history.[6] The 1998 Nigerian oil pipeline accident occurred in Niger Delta (October 18, 1998) due to a cigarette ignited fire on leaked oil around the oil pipeline and caused deaths of more than 1,000 people.[7]The Ufa accident ignited by wheel sparks from two passenger trains heading in opposite directions at a site where a leaking natural gas liquids (mainly propane and butane) created a highly flammable cloud of fuel vapor, killed 575 people and injured another 800 people.[8]

In the United States, the Centers for Diseases Control and Prevention (CDC) reports that during the recent oil and gas boom period (2003-2013), 1,189 work-related fatalities occurred in the oil and gas extraction industry; two-thirds of these fatalities were attributed to transportation incidents and contact with objects/equipment (Mason et al. 2015).

Hydropower accidents are few in number, 22 during the 1970-2008 period, but they caused 38% of the energy sectors total accidental deaths during the period (see Figure 3). 87% of the hydropower accident fatalities during the period occurred in a single accident in China, Banqiao

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[5] Goldenberg, Suzanne; MacAlister, Terry (November 28, 2012). "BP suspended from new US federal contracts over Deepwater disaster". The Guardian. London; Zeller, Jr., Tom (May 28, 2010). "Estimates Suggest Spill Is Biggest in U.S. History". The New York Times; "Bird Habitats Threatened by Oil Spill" from National Wildlife". National Wildlife Federation. April 30, 2010.

[6] Associated Press, July 11, 2013.
http://www.syracuse.com/news/index.ssf/2013/07/canadian_train_derailment_death_roll_at_50_residents_of_lac-megantic_jeer_rail_c.html

[7] Greenleft Weekly, July 19, 2000 NIGERIA: Hundreds die in pipeline disaster by Norm Dixion.
https://www.greenleft.org.au/content/nigeria-hundreds-die-pipeline-disaster. Retrieved June 17, 2017.

[8] Russia remembers 1989 Ufa train disaster". RIA Novosti. 2009-06-04,
https://sputniknews.com/russia/20090604155167464/

dam and Shimantan Reservoir Dam systems that occurred in August 1975 killing 26,108 people. The dam systems built on the Ru River in Henan Province in Central China collapsed due to heavy rainstorm inundating thousands of square kilometers. Besides the 26,108 direct deaths caused by flooding and inundation, the accident was estimated to cause deaths of another 145,000 people through subsequent epidemics and famine.[9]

Contrary to general perception, the numbers of accidents and fatalities are much smaller from nuclear energy sector. During the 1970-2008, one nuclear plant accident killed 31 people (Figure 3). The Chernobyl nuclear disaster in current Ukraine occurred on April 26, 1986 where the Chernobyl 4 nuclear reactor exploded dissipating the large amounts of radioactive materials. Of 600 workers present on the site during the accident, 134 received high doses and suffered from radiation sickness. Of these, 28 died in the first three months and another 19 died in 1987-2004 of various causes. 530,000 people who were involved in recovery operations between 1986 and 1990 have got minor radiations and bear a potential risk of late consequences such as cancer and other diseases.[10] The most recent nuclear disaster is the Fukushima Daiichi nuclear reactors in Japan caused by the 2011 (March 11), tsunami triggered by massive earthquake. The tsunami disabled the cooling systems of Fukushima Daiichi nuclear reactors Unit 1, 2, 3 and 4 thereby resulting in meltdowns and explosions and releasing radioactive materials for three days. Despite the scale of the disaster, no immediate deaths were linked to radiation due to the accident reported, however, some studies (Normile, 2012; Hoeve and Jacobson, 2012) estimate, based on the linear no-threshold theory of radiation safety, 130–640 deaths in the long-run due to the radiation. Selected list of power plant accidents is presented in Table A4 in the Appendix to show examples of major accidents in the power generation industry.

4. Occupational Risks in Energy Supply Systems

Occupational impacts here refer to health impacts due to long-term exposure of people working in energy supply chain including coal mines, power plants, oil refinery, gas processing plants and energy transportation business. These people get exposed to harmful substances (e.g., dust in coal

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[9] Yi Si, "The World's Most Catastrophic Dam Failures: The August 1975 Collapse of the Banqiao and Shimantan Dams," in Dai Qing, The River Dragon Has Come!, M.E. Sharpe, New York, 1998. http://www.sjsu.edu/faculty/watkins/aug1975.htm. Retrieved on June 7 2017.

[10] Chernobyl: The Chernobyl accident - UNSCEAR's assessments of the radiation effects, http://www.unscear.org/unscear/en/chernobyl.html, retrieved on June 10, 2017.

mines or coal power plants) or situations (e.g., long-term exposure to heavy noise and vibrations in power plants, oil refineries) and their health gets affected adversely. A large number of studies (e.g., Attfield and Seixas, 1995; Kuempel et al. 1995; Attfield and Kuempel, 2008) have confirmed various types of diseases are caused due to long term exposure in coal mining. Examining a group of 3,194 underground bituminous coal miners and ex-miners between 1985 and 1988, Attfield and Seixas (1995) finds that miners who work for 40 years in bituminous coal mines in the United States have a higher risk of having progressive massive fibrosis (type of severe pneumonia). Examining the quantitative relationship between exposure to respirable coal mine dust and mortality from nonmalignant respiratory diseases in a group of 8,878 working male coal miners who were medically examined from 1969 to 1971 and followed to 1979, Kuempel et al. (1995) finds increasing standardized mortality ratios with increasing cumulative exposure category. The study concluded that miners exposed at or below the current U.S. coal dust standard of 2 mg/m3 over a working lifetime, have an elevated risk of dying from pneumoconiosis or from chronic bronchitis or emphysema. Evaluating mortality experience over 22–24 years of 8,899 working coal miners initially medically examined in 1969–1971 at 31 U.S. coal mines, Attfield and Kuempel (2008) shows that exposure to coal mine dust leads to increased mortality, even in the absence of smoking.

A number of literature have also investigated the occupational impacts of coal mining on human health in the nearby areas (Coggon and Tylor, 1998; Hendryx and Ahern, 2008; Hendryx and Ahern, 2009; Hendryx et al. 2008). Using data from a survey of 16,493 West Virginians, Hendryx and Ahern (2008) finds that high levels of coal production are associated with worse adjusted health status and with higher rates of cardiopulmonary disease, COPD, hypertension, lung disease, and kidney disease. Through a national county-level analysis to identify contributions of smoking rates, socioeconomic variables, coal-mining intensity and other variables to age-adjusted lung cancer mortality in Appalachia, Hendryx et al. (2008) finds that lung cancer mortality for the years 2000–2004 is higher in areas of heavy Appalachian coal mining after adjustments for smoking, poverty, education, age, sex, race and other covariates. Comparing data from 3,141 counties for years 1979-2005 including counties in Appalachia with levels of coal mining above the median, Appalachian counties with levels of mining below the median, non-mining counties in Appalachia, and other counties in the nation, Hendryx and Ahern (2009) finds 1,736 to 2,889 excess annual age-adjusted deaths in coal mining areas. Reviewing a large body of literature examining the relationship between exposure of coal miners to dust from coal mines and loss of their lung function, Coggon and Tylor (1998) confirms that coal mining increases the risks of COPD in coal miners. Through monitoring of emission levels of surface coal mining in Jharia Coalfield in India, Ghosh and Majee (2007) reports that emission levels of TSP, PM10 and benzene soluble materials are much higher in the mining area as compared to those in ambient air outside the mining area; obviously these pollutants cause adverse impacts on coal minors' health.

Oil refineries also poses a health risks to workers as inhalation of oil vapors and dermal contact of crude oil, feed stocks, benzene could have adverse health impacts including cancers. Based on a review and meta-analyses of cohort studies of more than 350,000 petroleum workers in the United States, the United Kingdom, Canada, Australia, Finland, Sweden, and Italy, Wong and Raabe (2000) concludes that exposure to various petroleum chemicals could cause a small increase of skin cancer mortality (10%). Follow up investigation of a cohort of 1,583 workers employed during the 1949–1982 period in a northern Italy oil refinery plant, Consonni et al. (1999) observes elevated mortality from lymphoma and leukemia. The study also finds excess risk among workers with 15 or more years of employment.

A few studies are available examining occupational health impacts on electric utility workers. van Wijngaarden et al. (2001) finds, through an investigation of mortality patterns of a cohort of 138,905 male electric utility workers in the United States, that electric utility workers had excess risk of total mortality, cardiovascular disease and some cancers. Further investigation of deaths of electric utilities workers, Savitz et al. (2000) finds that both cumulative and average magnetic field exposure is positively associated with brain cancer mortality in the United States.

Mining and the production of nuclear fuels, such as Uranium, poses several risks to human health. Long exposure to radon decay products causes greatest risks from nuclear fuel mining and processing. Radon's alpha-emitting radioactive decay products are strongly and causally linked to lung cancer in humans (NRC, 2012). Similarly, uranium's radioactive decay by alpha, beta, or gamma emissions also pose hazards to uranium miners and processors. However, despite the fears of the general public or a bad perception in general, the existing literature does not present significant health risks from mining of nuclear fuels and nuclear power plants. Using data from randomly selected 136 nuclear facilities and using several models, Baker and Hoel (2007) conduct a meta-analysis to examines the linkage between childhood leukemia and proximity of nuclear facilities. While the analysis shows an increase in childhood leukemia near nuclear facilities, it does not support a hypothesis to explain the excess; the majority of studies find elevated childhood leukemia rates, but not statistically significant.

5. Air Pollution Impacts from the Energy Supply Chain

As illustrated in the next section, air pollution is the largest source of human health risks as compared to accidents and occupational impacts linked to energy supply and consumption activities.

5.1 Health Impacts of Ambient Air Pollution

Air pollution is one of the major environmental risks to human health. Exposure to elevated concentrations of particulate matters, specifically with size of 10 microns (PM10) or less (PM2.5) in diameter, are the main contributors to these risks as they cause cardiovascular and respiratory disease, and cancers.

There are hundreds of studies examining the linkage between ambient air pollution and human health. Anderson et al. (2012) reviews such studies published over 30 years between 1990 and 2010 to determine the linkage between PM and human health. The study concludes that the effects of PM on cardiovascular diseases are most pronounced. Similar relationship exists, but at lower scale, between PM and respiratory diseases. It suggests further studies for the relationship between PM and cerebrovascular disease.

With evaluation of 79 risk factors to human health in 195 countries from 1990 to 2015, the 2015 Global Burden of Diseases, Injuries, and Risk Factors Study (GBD 2015) finds that air pollution is the fifth largest contributor to global mortality and morbidity, particularly in low- and middle-income countries after high blood pressure, smoking, diabetes and high cholesterol. Cohen et al. (2017) estimates that long-term exposure to ambient PM2·5 caused 4·2 million deaths in 2015 representing 7·6% of total global mortality.[11] The study also estimates that 103·1 million

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[11] In order to produce these estimates, Cohen at al. (2017) used (i) spatially and temporally resolved estimates of population-weighted exposure, (ii) specification of a theoretical minimum risk exposure level (TMREL), (iii) estimation of relative risks across the exposure distribution, and (iv) estimates of the deaths and disability-adjusted life-years (DALYs) for diseases linked causally to air pollution to attribute the deaths and DALYs to ambient air

years of healthy life got lost in 2015 due to this exposure. Another ambient air pollutant ozone was estimated to cause an additional 254,000 deaths in the same year (Cohen, 2015). Although global rates of mortality and morbidity due to PM2·5 exposure have decreased during the 1990-2015 period, the absolute numbers of deaths and disability-adjusted life-years have increased.

Based on data provided by Cohen et al. (2017), Figure 4 presents distribution of global mortality and morbidity due to ambient air pollution to the type of diseases enhanced by the ambient air pollution. Of the total ambient air pollution caused deaths of 4.2 million in 2015, 36% can be attributed to ischemic heart disease and about 20% each to cerebrovascular diseases and chronic obstructive pulmonary disease. Seven percent of the total deaths were caused by lung cancer (Figure 4a). Ambient air pollution poses a major risk to elderly people. Of the total people died due ambient air pollution in 2015, more than 50% were those with age greater than 70 years. About 42% of the total ambient air quality related death in 2015 were women. Of the total morbidity, measured in terms of disability-adjusted life-years (DALYs) in 2015, that was caused by ambient air pollution, 31% was caused by ischemic heart disease followed by lower respiratory infection with 28% of the total DALYs (Figure 4b).

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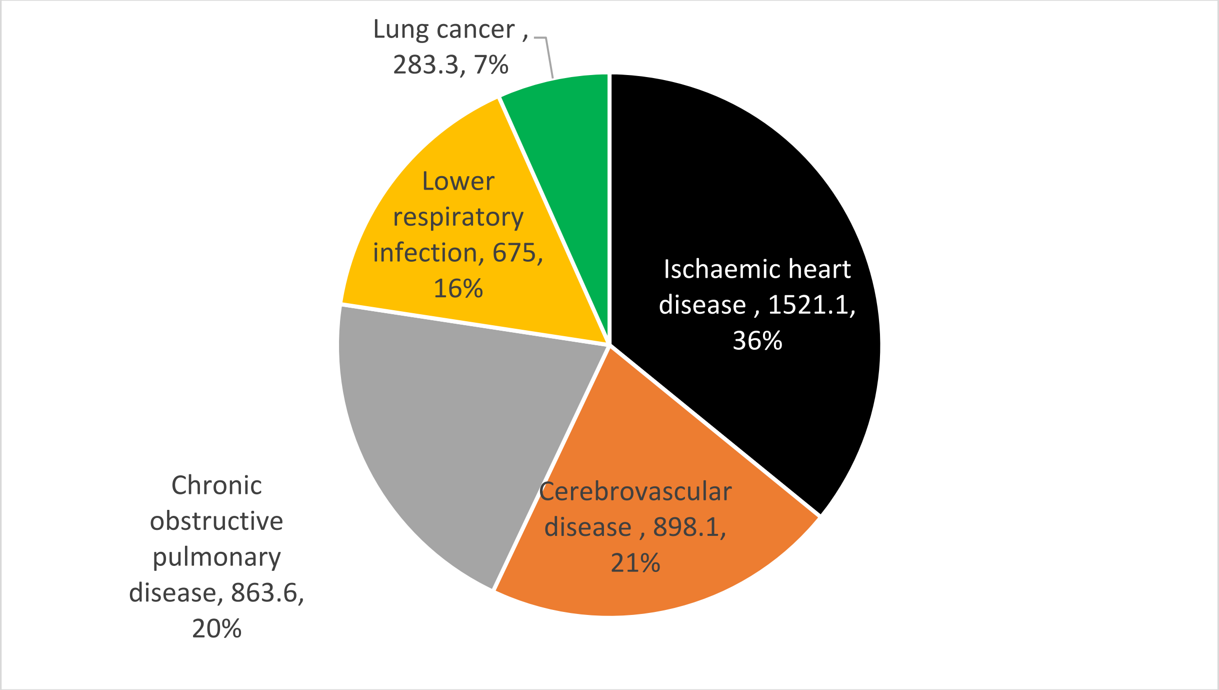
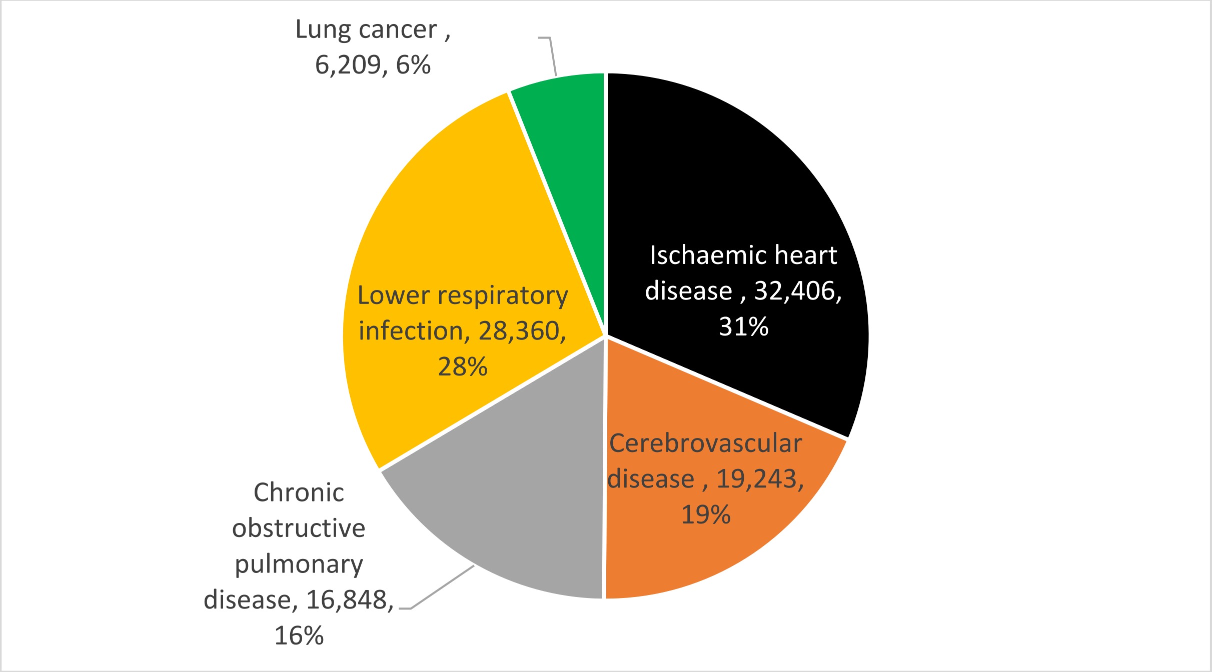
pollution. Exposure is quantified based on population-weighted annual mean concentrations of PM2·5 and ozone. Global annual mean exposure to PM2·5 was estimated at 0·1 × 0·1° (~11 km × 11 km at the equator) resolution using estimates from satellites combined with a chemical transport model, surface measurements, and geographical data. Uniformly distributed TMREL values were 2·4 to 5·9 μg/m³ for PM2·5 and 33·3 to 41·9 parts per billion for ozone. Risks across exposure distribution were determined based on integrated exposure–response functions (IERs). IERs assign concentrations of PM2·5 to each type of exposure on an equivalent μg/m³ basis assuming that risk is determined by the 24-h PM2·5 inhaled dose regardless of the exposure source. The relative risk of COPD mortality from ozone exposure using a linear exposure–response function for respiratory mortality. DALYs and deaths attributable to ambient air pollution were calculated by applying the year-specific, location specific, age-specific, and sex-specific PAF to the numbers of DALYs and deaths. PAF (population-attributable fraction) is the proportion of deaths and DALYs attributable to exposure above the TMREL.

Figure 4. Ambient Air Pollution caused Mortalities and Morbidities by type of Diseases in 2015 (Unit: Thousand and %)

(a) Mortality



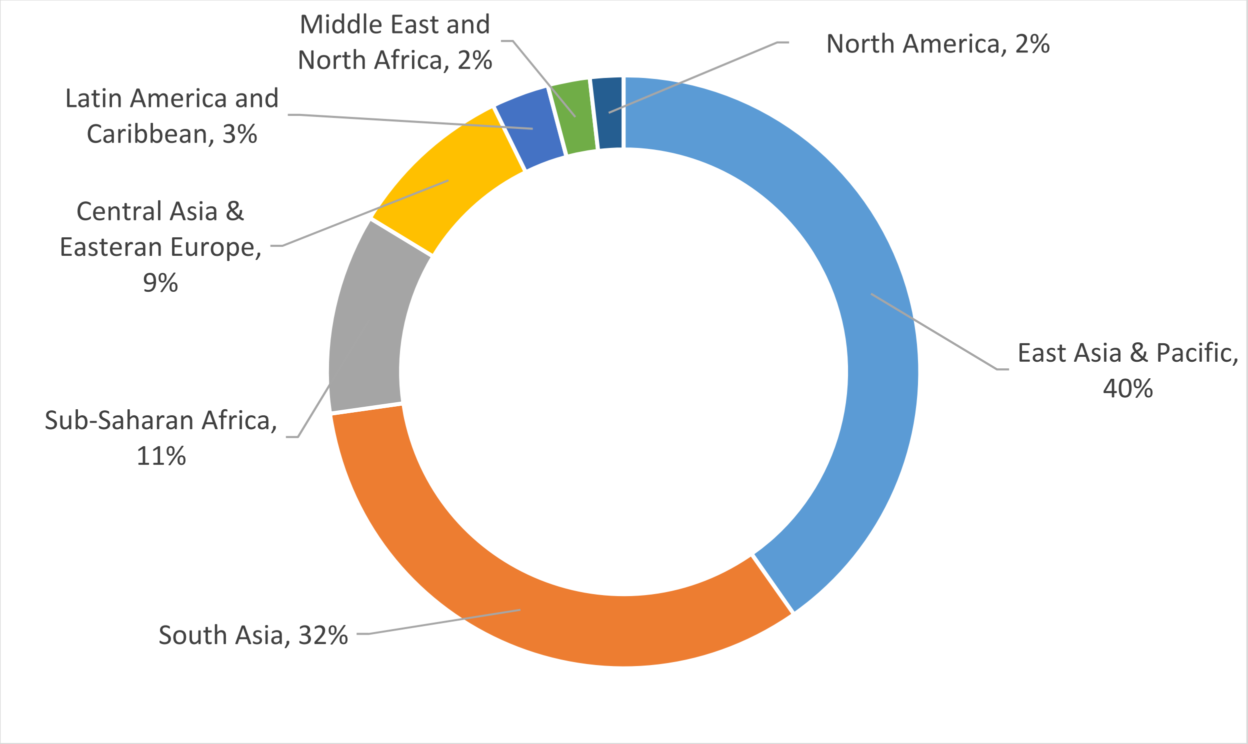
(b) Morbidity



Source: Cohen et al. (2017)

The distribution of global mortality due to ambient air pollution for year 2013, is presented in Figure 5 based on World Bank & IHME (2016). As can be seen from the figure, almost 90% of global mortality due to ambient air pollution occurs in developing countries with the greatest number in East Asia & Pacific region, followed by South Asia region. South Asian countries have the highest mortality rate due to ambient air pollution with 136.3, 135.5 and 133.2 deaths per hundred thousand population, respectively in Pakistan, India and Bangladesh in 2015 (Cohen et all. 2017).

Figure 5. Geographic Distribution of Ambient Air Pollution Related Mortality in 2013



Source: World Bank & IHME (2016)

5.2. Health Impacts of Household Air Pollution

Household air pollution (HAP) also called indoor air pollution refers to the air pollution that occurs mostly inside a household and is mainly caused by burning of solid fuels, particularly, biomass used for cooking or home heating. WHO (2016) reports that burning biomass and fossil fuels in households is the primary source of indoor or household air pollution from elevated PM level. Over a 24-hour period, levels of PM10 in biomass-using homes in Africa, Asia or Latin America can range from 300 to 3000 micrograms per cubic meter (μg/m3) with the peak as high as 10,000 μg/m3 during cooking time. These values are many folds higher than the standards set by the World Health Organization (WHO). WHO standards suggest that 24-hour mean concentration of PM10 should not exceed 50 μg/m3 (WHO, 2005).

The adverse health impacts of indoor air pollution from biomass include child pneumonia, other acute respiratory illnesses, chronic obstructive pulmonary disease (COPD) and lung cancer (Smith et al., 2004). According to the World Health Organization, around 3 billion people (or 40% of the current world population) still cook and heat their homes using solid fuels (i.e. wood, crop wastes, charcoal, coal and dung) in open fires and leaky stoves and each year more than 4 million deaths are caused by the household air pollutants emitted from cooking with solid fuels. Mainly women and young children are at risk, particularly in Sub-Saharan and South Asia regions (UNDP and WHO, 2009).

Many studies, published especially in medical or public health journals, have provided the linkages between HAP exposure and health impacts. While it is not possible to discuss all those studies here, we have presented a few examples of those studies.

Three recent meta-analyses (Kurmi et al., 2010; Hu et al., 2010; Po et al., 2011) find that exposure to smoke from burning biomass fuels for cooking and/or heating is associated with increased risk of COPD. There is also evidence of indoor air pollution impacts on child cognitive function, low birth weight, cervical cancer, adverse pregnancy outcomes, asthma, and tuberculosis (Velema et al., 2002; Pokhrel et al., 2010; Pope et al., 2010; Hosgood III et al., 2011; Dix-Cooper et al., 2012; Sumpter and Chandramohan, 2013; Trevor et al., 2013; Wong et al, 2013).

Epstein et al. (2013) examines the impact of cooking fuels on low birth weight (LBW < 2500 g), and neonatal mortality (death within 28 days of birth) using cross-sectional data from India's National Family Health Survey (NFHS-3) and finds that compared to households using cleaner fuels (in which the mean birth weight is 2901 g), the primary use of coal, kerosene, and biomass fuels is associated with significant decreases in mean birth weight (of −110 g for coal, −107 g for kerosene, and −78 g for biomass). It also finds risk of neonatal death strongly associated with household use of coal.

Adetona et al. (2013) finds that women in Trujillo, Peru who cooked exclusively with fuelwood or kerosene had higher exposure to polyaromatic hydrocarbons (PAH) compare to women who cooked with LPG or coal briquette. PAH is an organic compound chronic or long-term exposure to which could decrease immune function, damage kidney and liver and ause breathing problems, asthma-like symptoms, and lung function abnormalities. It is also carcinogenic.

Studies in India and Nepal reveal that non-smoking women exposed to biomass smoke have death rates from chronic respiratory disease comparable to those of heavy smokers who are males (Modi et al., 2005). Based on 2003-2004 district level household survey, Lakshmi et al. (2013) finds that biomass and kerosene cooking fuels are associated with stillbirth among married women aged 15-49, representing about 12% of stillbirths in India. In Gambia, girls under the age of five carried by their mothers while cooking have a six times greater risk of lung cancer than if their parents smoked cigarettes and were not exposed to HAP from cooking (Gaye 2007).

Dix-Cooper et al. (2012) investigated whether early life chronic exposure to wood smoke is associated with children's neurodevelopmental and behavioral performance in San Marcos, Guatemala and find that children’s neuropsychological tests were significantly associated with mothers’ 3rd trimester CO exposures during her pregnancy. The neuropsychological tests included visuo-spatial integration, short-term memory recall, long-term memory recall, and fine motor performance and these findings persisted even if they were adjustment for child sex, age, visual acuity, and socio-economic status.

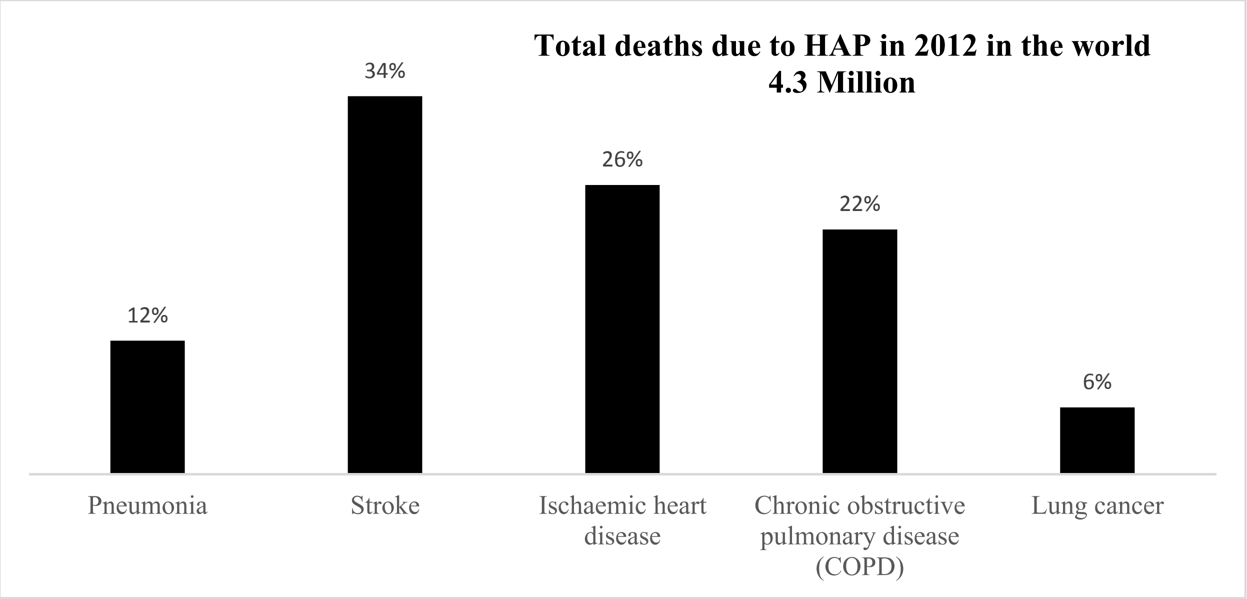
Pokhrel et al. (2010) investigates, in Nepal, the relationship between HAP exposure and tuberculosis with the cases of 125 female patients of 20 - 65 years’ age, who visited TB clinics and who had been newly diagnosed with active pulmonary TB by chest X-ray and positive active sputum smears. The study finds that use of indoor biomass and kerosene fuels are associated with TB in women.

Lakshmi et al. (2013) analyzed the data from 188,917 ever-married women aged 15–49 included in India's 2003–2004 District Level Household Survey-II to investigate the association between household use of cooking fuels (liquid petroleum gas/electricity, kerosene, biomass) and the risk of stillbirth. The study finds that women who cook with firewood were more likely to have experienced a stillbirth than those who cook with LPG/electricity. Moreover, kerosene lamp use was also associated with stillbirths compared to electric lighting.

Based on the latest information available from the World Health Organization (WHO, 2016), HAP causes 4.3 million deaths each year (Figure 6). Of the total, 34% is caused by stroke, 26% by ischemic heart dieses and 22% by COPD. Mortality caused by HAP accounts for almost 8% of global mortality, which is higher than that from malaria, tuberculosis and HIV/AIDS combined (WHO, 2016). WHO (2016) also reports, in terms of morbidity, that HAP poses the biggest environmental health risk factor worldwide, more critical compared to lack of access to clean water and sanitation.

WHO (2016) also reports that HAP doubles the risk of child mortality (under 5-year age) due to pneumonia, which is the single biggest killer of children aged under five years worldwide. The same report suggests that more than half of deaths of children below Age 5 due to acute lower respiratory infections (ALRI), is caused by HAP, and almost one-quarter of all premature deaths from stroke can be attributed to the chronic exposure to HAP. Similarly, approximately 15% of all deaths due to ischemic heart disease (or over a million premature deaths annually), can be attributed to HAP and more than one-third of premature deaths from COPD in adults in low- and middle-income countries are due to HAP exposure. Furthermore, approximately 17% of annual premature lung cancer deaths in adults are attributable to HAP. Besides, HAP causes other health risks such as such as low birth weight and stillbirths, cervical cancer, tuberculosis, asthma, ear and upper respiratory infections, and with nasopharyngeal and laryngeal cancers.

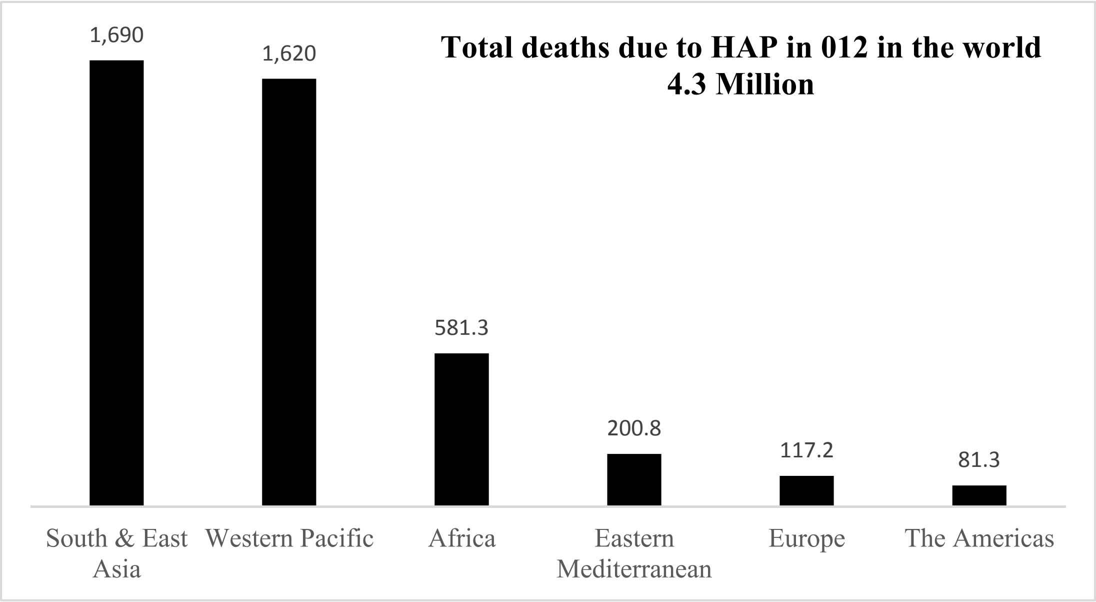
Figure 6: Mortality from Household Indoor Air Pollution in 2012



Source: WHO (2016)

Women and children in low income countries are the most vulnerable to HAP related health impacts as 60% of all premature deaths attributed to HAP occur in women and children (WHO, 2016). This is because, women and children get higher level of exposure to HAP due to their greater involvement in daily cooking and other domestic activities. In terms of geographic distribution of HAP mortality, regions with higher poverty incidence where traditional biomass (wood fuel, animal waste and agriculture residues) are the primary fuels for cooking and home heating, suffer the most (Figure 7). South-east Asia and the Western Pacific account for almost 80% of the global mortality due to HAP. India is the single country that suffers the highest from HAP with 1.3 million premature deaths each year from HAP.

Figure 7: Geographical Distribution of Mortality from Household Indoor Air Pollution in 2012



Source: WHO (2016)

Besides air pollution, activities in energy supply chains impact human health through water and soil contamination by release of the toxic substances. Coal mines pose risks to human health even after the mining operation is over as rainwater in abandoned mines reacts with exposed rock and oxidizes metal sulfide minerals, thereby releasing iron, aluminum, cadmium, and copper into the surrounding water system which could be a source of drinking water (Lashof et al. 2007). Coal washing forms slurry of polymer chemicals, which is injected into old mine shafts that can release arsenic, barium, lead, and manganese into nearby wells, contaminating local water supplies. Oil and gas drilling also cause water and soil contamination as drilling muds, chemical used for hydraulic fracturing contains high dose of hazardous substances. Jackson et al. (2014) argues that horizontal drilling and hydraulic fracturing create challenges for maintaining well integrity due to high pressures created in the reservoirs. The buildup pressure inside the well annulus pose a risk of forcing fracking fluids and drilling muds out of the wellbore and toxic chemical substances contained in the fluids and the muds could reach shallow groundwater. Although hydraulic fracturing occurs thousands of meters underground and is unlikely to directly contaminate shallow drinking water aquifers, it could connect the man-made hydraulic fractures (crakes) to a natural fault or fracture or some other underground pathways thereby allowing toxic fluids to migrate upward (Myers, 2012; Warner et al. 2012). However, studies examining water and soil contamination from activities in energy supply chains are very limited and mortality and morbidity data from energy activity related water and social contamination do not exist.

6. Comparison of Accidental, Occupational, and Air Pollution Impacts from Power Generation

It would be interesting to have a comparison of human health impacts from the energy supply chain through various channels – accidental, occupational and air pollution. However, lack of data preclude such a comparison. There are no reliable data on accidental impacts although we have listed major accidents in the energy chains in the appendix. Estimation of mortality and morbidity from energy supply chain specific occupational impacts. Existing literature provide the evidence of occupational impacts but do not provide reliable estimates of deaths and injuries. Moreover, a common yardstick for the comparison does not exist as well. Nevertheless, some studies attempted to compare accidental, occupational and air pollution impacts from different types of power generation expressing the impacts per unit of electricity generation from the corresponding generation type. Markandya and Wilkinson (2007) make such a comparison of health impacts from various types of electricity generation in Europe. Figure 8 presents this comparison.[12] As can be seen from the Figure 8(a), air pollution is the main source of mortality

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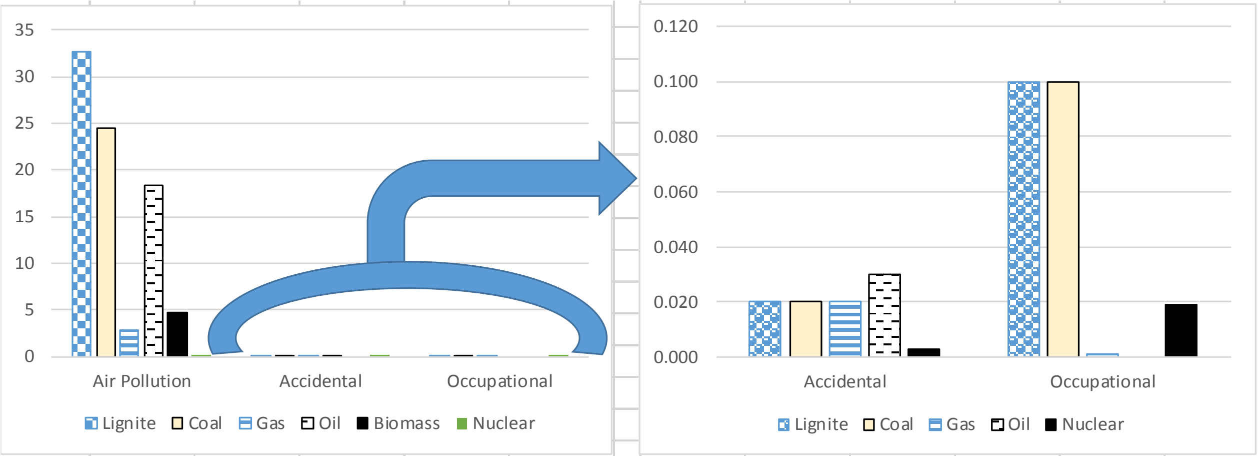
[12] The methods used in this estimation is called 'Impact-Pathway-Approach' developed by European Union project 'External Costs of Energy' or 'ExternE' that ran for 15 years from 1990 to 2005. It is a bottom-up approach, in which emissions from a source are traced through as they disperse into the environment, after which the effects of the

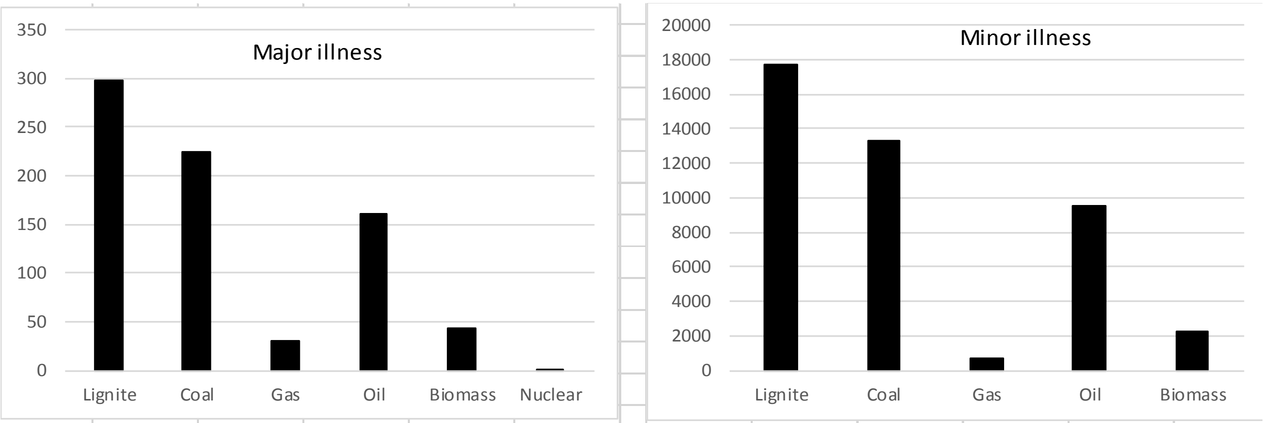
from power generation, and as expected, coal (both lignite and other coal) contributes the highest to the total mortality from air pollution caused by power plants.[13]

Figure 8. Mortality and morbidity rates of power generation in Europe

(a) Mortality: average number of death per TWh of power generation



(b) Morbidity: average number of illness per TWh of power generation



Note: Mortality number includes acute and chronic effects. Chronic effect deaths are between 88% and 99% of the total. For nuclear power, they include all cancer-related deaths. Serious illness includes respiratory and cerebrovascular hospital admissions, congestive heart failure, and chronic bronchitis. For nuclear power, they include all non-fatal cancers and hereditary effects. Minor illness includes restricted activity days, bronchodilator use cases, cough, and lower-respiratory symptom days in patients with asthma, and chronic cough episodes.

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dispersed pollutants, including on human health, are estimated. For more information, please visit http://www.externe.info/externe_2006.

[13] Note that the data are from 90's and early 2000; air pollution impacts might have gone down due to higher environmental standards, particularly on the emissions of local air pollutants.

Source: Markandya and Wilkinson (2007)

Compared to air pollution caused mortality, accidental and occupational mortality is negligible. Despite the general perception that nuclear power has the highest mortality rate, in fact its coal and lignite power generation that have higher mortality rate as compared to nuclear power generation. Like in the case of mortality, coal and lignite based power generation causes most morbidity rate, no matter whether it is minor illness or major illness.

Markandya and Wilkinson (2007) is not the only one reporting the scale of health impacts of coal based power generation, a number of other studies do so. For example, Greenpeace Indonesia (2015) reports that two air pollutants (PM2.5 and Ozone) from existing coal power plants cause an estimated 7,100 premature deaths each year in Indonesia, of which almost 40% from strokes, 36% from ischemic heart disease and remaining 24% from chronic obstructive pulmonary disease, lung cancer and other cardiovascular and respiratory diseases. In a similar study for Thailand, Greenpeace, Southeast Asia (2015) also reports that these two air pollutants emitted from coal fired plants in Thailand caused 1,550 premature deaths in year 2011.

7. Policy Implications and Conclusions

This review leads to several policy implications. First, air pollution, both ambient and household, is the major source of human health impacts from the energy supply chain (mining, production, transformation and utilization). More than six million people are estimated to die each year due to ambient and household air pollution emitted from the energy supply chain, making air pollution one of the main risk factors to human health. Therefore, control of local air pollution, specifically particulate matter, should be one of the main policy focuses in developing countries. At present, such environmental issues are often overshadowed by climate change agendas, whereas developing countries suffer more from local air pollution problems. The estimated deaths of more than 6 million people per year is clear evidence of how developing countries suffer more from local air pollution problems.

Most of the mortality and morbidity from energy supply chains occur among the poor. It mainly occurs in low- or middle-income countries and within those countries it mainly falls on low-income households, because they are more vulnerable and have lower affordability to cure the diseases. Poor households are not only vulnerable to air pollution related health impacts, they are also vulnerable to accidental and occupational health impacts. This is because much of the workforce is in coal mining, oil and gas drilling, oil tanker driving, and coal hauling in power plants comes from low-income households. In many developing countries, casual workers in mining, power plants and hydropower dams do not have proper health and safety measures and insurance plans.

Health impacts from the energy supply chain, particularly from household air pollution, disproportionally fall on women and children. About half of the global population and most of them in developing countries, use traditional biomass, the main source of household air pollution, for cooking. Women and small children (under age 5 years) are the ones who are most exposed to household air pollution and its health consequences. This implies that clean cooking either through switching to cleaner fuels or to low emitting more fuel-efficient biomass stoves should be a primary energy policy issue in the developing world.

Nuclear power traditionally has had a bad perception among the general public. Many countries do not allow nuclear power because of the perception problem. From the human health impact angle, however, nuclear power is not the worst. Historically, it has one of the lowest impacts on human health compared to other sources of energy. Nuclear power has lower accidental and occupational health impacts compared to other source of energy, particularly coal. Moreover, it does not produce air pollution, which is the main channel of health risks in the energy supply chains. Policy makers should consider a social cost approach that accounts for both environmental and human health impacts while making the choice of fuels to meet their energy needs, particularly electrical energy.

References

Adetona, O., Z. Li, A. Sjödin, L.C. Romanoff, M. Aguilar-Villalobos, L.L. Needham, D.B. Hall, B.E. Cassidy and L.P. Naeher, 2013. Biomonitoring of polycyclic aromatic hydrocarbon exposure in pregnant women in Trujillo, Peru—Comparison of different fuel types used for cooking. Environment International, Vol. 53, pp. 1-8.

Anderson, J.O., J.G. Thundiyil and A. Stolbach (2012). Clearing the Air: A Review of the Effects of Particulate Matter Air Pollution on Human Health. Journal of Medical Toxicology, Vol. 8, Issue 2, pp. 166–175.

Attfield, M.D. and N. S. Seixas (1995). Full Prevalence of pneumoconiosis and its relationship to dust exposure in a cohort of U.S. Bituminous coal miners and ex-miners. American Journal of Industrial Medicine. Vol. 27, Issue 1, pp. 137–151.

Attfield, M.D., E.D. Kuempel (2008). Mortality among U.S. underground coal miners: A 23-year follow-up. American Journal of Industrial Medicine. Vol. 51, Issue 4. pp. 231–245.

Baker, P.J. and D.G. Hoel (2007). Meta-analysis of standardized incidence and mortality rates of childhood leukaemia in proximity to nuclear facilities. Cancer Care, Vol. 16, Issue 4, pp. 355–363.

British Petroleum (2017). BP Energy Outlook 2017, BP. London.

Peter Burgherr and Stefan Hirschberg (2014) Comparative risk assessment of severe accidents in the energy sector, Energy Policy, Vol. 74, Supplement 1, pp. S45-S56.

Coggon and Taylor (1998). ‘Coal mining and chronic obstructive pulmonary disease: a review of the evidence’ Thorax 398.

Coggon, D. and A.N. Taylor (1998). Coal mining and chronic obstructive pulmonary disease: a review of the evidence. Thorax. Vol.53, pp.398–407.

Cohen, AJ, M. Brauer, R. Burnett, HR Anderson, J. Frostad, K. Estep, K. Balakrishnan, B. Brunekreef, L. Dandona, R. Dandona, V. Feigin, G. Freedman, B. Hubbell, A. Jobling, H. Kan, L. Knibbs, Y. Liu, R. Martin, L. Morawska, CA Pope III, H. Shin, K. Straif, G. Shaddick, M. Thomas, R. van Dingenen, A. van Donkelaar, T. Vos, CJL Murray, M H Forouzanfar (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. Lancet, Vol. 389, pp. 1907–18.

Consonni, D., A. C. Pesatori, A. Tironi, I. Bernucci, C. Zocchetti and P. A. Bertazzi (1999). Mortality study in an Italian oil refinery: Extension of the follow-up. American Journal of Industrial Medicine, Vol. 35, Issue 3, pp. 287–294.

Dix-Cooper, L., B. Eskenazi, C. Romero, J. Balmes and K.R. Smith, 2012. Neuro developmental performance among school age children in rural Guatemala is associated with prenatal and postnatal exposure to carbon monoxide, a marker for exposure to wood smoke. NeuroToxicology, Vol. 33, pp. 246-254.

Epstein, M.B., M.N. Bates, N.K. Arora, K. Balakrishnan, D.W. Jack and K.R. Smith, 2013. Household fuels, low birth weight, and neonatal death in India: The separate impacts of biomass, kerosene, and coal. International Journal of Hygiene and Environmental Health Vol. 216 (5), pp. 523-532.

Gaye, Amie "Access to Energy and Human Development," Human Development Report 2007/2008 (United Nations Development Program Human Development Report Office Occasional Paper, 2007).

Ghose, M. K. and S. R. Majee (2007). Characteristics of Hazardous Airborne Dust Around an Indian Surface Coal Mining Area. Environmental Monitoring and Assessment, Vol. 130, No. 1, pp. 17-25.

Greenpeace, Indonesia (2015). Human cost of coal power: http://www.greenpeace.org/seasia/Press-Centre/Press-Releases/Research-from-Harvard-reveals-health-impacts-of-Indonesias-coal-plants/

Greenpeace, Southeast Asia (2015). Human cost of coal power: How coal-fired power plants threaten the health of Thais. http://www.greenpeace.or.th/Thailand-human-cost-of-coal-power/en.pdf

Haines, A., A. J. McMichael, K. R. Smith, I. Roberts, J. Woodcock, A. Markandya, B. G. Armstrong, D. Campbell- Lendrum, A. D. Dangour, M. Davies, N. Bruce, C. Tonne, M. Barrett and P. Wilkinson, 2009. Public Health Benefits of Strategies to Reduce Greenhouse-Gas Emissions: Overview and Implications for Policy Makers. The Lancet, 374 (9707): 2104–2114.

Hendryx, M. and M. M. Ahern (2008). Relations between Health Indicators and Residential Proximity to Coal Mining in West Virginia. American Journal of Public Health: Vol. 98, No. 4, pp. 669-671.

Hendryx, M. and M. M. Ahern (2009). Mortality in Appalachian Coal Mining Regions: The Value of Statistical Life Lost. Public Health Reports, Vol. 124, No. 4, pp. 541-550.

Hendryx, M., K. O'Donnell and K. Horn (2008). Lung cancer mortality is elevated in coal-mining areas of Appalachia, Lung Cancer, Vol. 62, No. 1, pp. 1–7.

Hoeve, J.E.T and M. Z. Jacobson (2012). "Worldwide health effects of the Fukushima Daiichi nuclear accident". Energy & Environmental Science. Vol. 5, No. 9, pp. 8743 -8750.

Hosgood III, H. D., H. Wei, A. Sapkota, I. Choudhury, N. Bruce, K. R. Smith, N. Rothman and Q. Lan., 2011. Household coal use and lung cancer: systematic review and meta-analysis of case-control studies, with an emphasis on geographic variation. International Journal of Epidemiology, Vol. 40 (3), pp. 719-728.

Hu, G., Y. Zhou, J. Tian, W. Yao, J. Li, B. Li and P. Ran, 2010. Risk of COPD From Exposure to Biomass Smoke: A Metaanalysis. Chest, Vol. 138 (1), pp. 20-31.

International Energy Agency (2016). Key World Energy Statistics. IEA, Paris.

Jackson, RB, Avner Vengosh, JW Carey, RJ Davies, TH Darrah, F. O'Sullivan and G. P´etron (2014). The Environmental Costs and Benefits of Fracking. Annual Review of Environmental Resource. Vol. 39. Pp. 327-362.

Kirk R. Smith, Howard Frumkin, Kalpana Balakrishnan, Colin D. Butler, Zo¨e A. Chafe, Ian Fairlie, Patrick Kinney, Tord Kjellstrom, Denise L. Mauzerall, Thomas E. McKone, Anthony J. McMichael, and Mycle Schneider (2013). Energy and Human Health. Annual Review of Public Health, Vol. 34. Pp.159–188.

Kuempel, E. D., Leslie T. Stayner, Michael D. Attfield, C. Ralph Buncher (1995). Exposure-response analysis of mortality among coal miners in the United States. American Journal of Industrial Medicine. Vol. 28, Issue 2. pp. 167–184.

Kurmi, O.P., S. Semple, P. Simkhada, W.C.S. Smith and J.G. Ayres, 2010. COPD and chronic bronchitis risk of indoor air pollution from solid fuel: a systematic review and meta-analysis. Thorax, Vol. 65 (3), pp. 221-228.

Lakshmi, P.V.M., N.K. Virdi, A. Sharma, J.P. Tripathy, K.R. Smith, M.N. Bates and R. Kumar, 2013. Household air pollution and stillbirths in India: Analysis of the DLHS-II National Survey. Environmental Research, Vol. 121, pp.17-22.

Lashof DA, Delano D, Devine J et al. (2007). Coal in a changing climate. Natural Resources Defense Council. http://www.nrdc.org/globalwarming/coal/coalclimate.pdf.

Lockwood, A.H., Kristen Welker-Hood, Molly Rauch and Barbara Gottlieb (2009). Coal's Assault on Human Health: A Report from Physicians for Social Responsibility. Physicians for Social Responsibility, Washington, DC.

Markandya, A. and P. Wilkinson (2007). Electricity generation and health. Lancet, Vol. 370, pp. 979–90.

Mason, KL, KD Retzer, R Hill, JM Lincoln (2015). Occupational Fatalities During the Oil and Gas Boom — United States, 2003–2013, CDC Morbidity and Mortality Weekly Report. Vol. 64, No. 20 (May 29 Issue), pp. 551-554.

Modi, V., S. McDade, D. Lallement and J. Saghir, 2005. Energy Services for the Millennium Development Goals. The World Bank and the United Nations Development Program (UNDP).

Myers T. (2012). Potential contaminant pathways from hydraulically fractured shale to aquifers. Groundwater 50:872–82 83.

Narain, Urvashi, and Chris Sall (2016). "Methodology for Valuing the Health Impacts of Air Pollution: Discussion of Challenges and Proposed Solutions." World Bank, Washington DC.

National Research Council (2012). Potential Human Health Effects of Uranium Mining, Processing, and Reclamation (in Uranium Mining in Virginia: Scientific, Technical, Environmental, Human Health and Safety, and Regulatory Aspects of Uranium Mining and Processing in Virginia). National Academies Press. Washington, DC.

Normile, D. (2012). "Is Nuclear Power Good for You?". Science. 337 (6093): 395–396 (27 July 2012)). doi:10.1126/science.337.6093.395-b.

Pokhrel, A., Bates, M., Verma, S., Joshi, H., Sreeramareddy, C., and K.R. Smith. 2010. "Tuberculosis and indoor biomass and kerosene use in Nepal: a case-control study." Environmental Health Perspectives 118:558–564.

Pope, D. P., V. Mishra, L. Thompson, A. R. Siddiqui, E. A. Rehfuess, M. Weber and N. G. Bruce, 2010. Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries. Epidemiologic Reviews, Vol. 32 (1), pp.70-81.

Savitz, D.A., J. Cai, E. van Wijngaarden, D. Loomis, G. Mihlan, V. Dufort, R. C. Kleckner, L. Nylander-French, H. Kromhout, H. Zhou (2000). Case-cohort analysis of brain cancer and leukemia in electric utility workers using a refined magnetic field job-exposure matrix. American Journal of Industrial Medicine. Vol. 38, Issue 4, pp. 417-435.

Smith, K.R., A. Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn, 2014: Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709-754.

Sumpter, C. and D. Chandramohan, 2013. Systematic review and meta-analysis of the associations between indoor air pollution and tuberculosis. Tropical Medicine and International Health, Vol. 18 (1), pp. 101-108.

Trevor J., V. Antony and S.K. Jindal, 2013. The effect of biomass fuel exposure on the prevalence of asthma in adults in India - review of current evidence. doi:10.3109/02770903.2013.849269.

van Wijngaarden, E., D. A. Savitz, R. C. Kleckner, R. Kavet and D. Loomis (2001). Mortality patterns by occupation in a cohort of electric utility workers. American Journal of Industrial Medicine. Vol. 40, Issue 6, pp. 667–673.

Velema, J., A. Ferrera, M. Figueroa, R. Bulnes, L. Toro, O. De Barahona, L. Claros and W. Melchers, 2002. Burning wood in the kitchen increases the risk of cervical neoplasia in hpv-infected women in Honduras. International Journal of Cancer, Vol. 97, pp. 536-541.

Vengosh A, Jackson RB, Warner N, Darrah TH, Kondash A. 2014. A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. Environmental Science and Technology. 48:8334–48.

Warner NR, Jackson RB, Darrah TH, Osborn SG, Down A, et al. (2012). Geochemical evidence for possible natural migration of Marcellus formation brine to shallow aquifers in Pennsylvania. Proceedings of National Academy of Sciences, Vol. 109, pp. 11961–66.

Wong, G.W.K., B. Brunekreef, P. Ellwood, H.R. Anderson, M.I. Asher, J. Crane and C.K.W. Lai, 2013. Cooking fuels and prevalence of asthma: a global analysis of phase three of the International Study of Asthma and Allergies in Childhood (ISAAC). The Lancet Respiratory Medicine, Vol. 1 (5), pp. 386-394.

Wong, O. and G. K. Raabe (2000). A Critical Review of Cancer Epidemiology in the Petroleum Industry, with a Meta-analysis of a Combined Database of More Than 350,000 Workers. Regulatory Toxicology and Pharmacology. Vol. 32, pp. 78–98.

World Bank and Institute for Health Metrics and Evaluation (2016). The Cost of Air Pollution: Strengthening the Economic Case for Action. World Bank, Washington, DC.

World Health Organization (WHO). 2006. WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen dioxide and Sulfur dioxide: Global Update 2005 – Summary of Risk Assessment. WHO. Geneva.

World Health Organization (WHO). 2016a. Ambient air pollution: A global assessment of exposure and burden of disease. WHO. Geneva.

World Health Organization (WHO). 2016b. Burning opportunity: clean household energy for health, sustainable development, and wellbeing of women and children. WHO. Geneva.

Table A1: List of selected Coal Mining Accidents since 1950

Date	Location	Description	Number of deaths
21-Dec-1951	West Frankfurt, Illinois, USA	Orient 2 coal mine explosion	119
12-Oct-1954	Chhindwara, India	Flooding of Newton Chikli colliery	63
8-Aug-1956	Marcinelle, Belgium	Fire on Bois du Cazier mine	262
22-Jan-1959	Luzerne County, Pennsylvania	Flooding on River Slope Mine	12
9-May-1960	Datong, China	Underground explosion in Laobaidong mine	684
9-Nov-1963	Kyushu, Japan	Explosion and CO poisoning at the Miike coal mine	458
28-May-1965	Dhanabad, India	Underground explosion in Dhanbad coal mine	300
17-May-1965	South Wales	Cambrian Colliery in South Wales	31
21-Oct-1966	Aberfan disaster	Aberfan disaster	144
20-Nov-1968	Farmington, West Virginia	Farmington Mine Disaster	78
6-Jun-1972	Wankie, Zimbabwe	Series of underground explosion in Wankie coal mine	426
21-Mar-1973	West Yorkshire, England	Lofthouse Colliery disaster	7
27-Dec-1975	Dhanbad, India	Chasnala mining disaster	372
12-Sep-1983	Shemiranat, Tehran	Mohd.Darabi Coal mine disaster	14
16-Sep-1986	South Africa	Underground fire in Kinross mine	177
2-Jun-1988	Borken, Hessen, Germany	Lignite mine explosion	57
9-May-1992	Pictou County, Nova Scotia, Canada	Methane and coal dust explosion in Westray mine	26
9-May-1993	Nambija, Ecuador	Soil erosion on top of Nambija mine burrying miners	300
28-Aug-1994	Rajpura Dariba,	Flooding in Rajpura Dariba mine	63
10-May-1995	Vaal Reefs, South Africa	Fall of a locomotive on Vaal Reefsccoal mine	104
20 Jun 2003	Heilongjiang Province, China	Coal mine explosion	124
5-Apr-2010	Upper Big Branch Mine disaster	Upper Big Branch Mine disaster	29
5-Aug-2010	Atacama Desert, Chile	Copiapó mining accident	0
19-Nov-2010	New Zealand	Pike River Mine disaster	22
13-May-2014	Soma, Turkey	Soma mine disaster	300

Sources:

Kucuker H. "Occupational fatalities among coal mine workers in Zonguldak, Turkey, 1994–2003". Occup Med (Lond) 2006 Mar;56(2):144-6. PMID 16490795

Terazawa K, Takatori T, Tomii S, Nakano K. Methane asphyxia. Coal mine accident investigation of distribution of gas. Am J Forensic Med Pathol. 1985 Sep;6(3):211-4. PMID 3870672

Retzer, John. "Ten Worst Mining Disasters". Michigan, USA: Bogey Media. Archived from the original on 18 April 2010. Retrieved 17 May 2014.

"The world's worst coal mining disasters". Retrieved 16 August 2015.

"Chinazhaoge Blog" (in Chinese). sohu.com. Retrieved 7 August 2010.

Pittsburgh Post Gazette July 3,1960 page 3 section 1

History.com. "Mine explodes in Oklahoma". History.com. A+E Networks. Retrieved 10 February 2016.

http://www.dmm.org.uk/uknames/u1893-03.htm

McAteer, Davitt (December 6, 2007). Monongah: The Tragic Story of the 1907 Monongah Mine Disaster, the Worst Industrial Accident in US History. West Virginia University Press. p. 332. ISBN 1-933202-29-7

Table A2: List of selected accidents in oil and gas wells and refineries and storage facilities
Only large accidents are included

Date & Accident	Description	Impacts
1982: Sinking of Ocean Ranger, Canada[a]	On 15 February 1982, Ocean Ranger, a semi-submersible mobile offshore drilling and exploration platform sank on the Grand Banks of Newfoundland, Canada due to a high tide	All 84 crew members on board died
1984: Oil refinery explosion in Romeoville, Illinois[b]	On July 23, 1984, an explosion and fire took place at a Union Oil petroleum refinery in Romeoville, Illinois, outside Chicago	Deaths of 17 people
1984: San Juan Ixhuatepec, LPG storage disaster nearby Mexico City[c]	On 19 November 1984, a large LPG storage and distribution center in San Juan Ixhuatepec, 20 km north of Mexico City, exploded due to a fire ignited in LPG vapor cloud created due to leakage	500–600 people killed, and 5000–7000 others suffered with severe burns
1988: Norco, oil refinery, Louisiana, USA[d]	Fire and explosion due to escaped gas from a corroded pipe in one of the facility's catalytic cracking units	7 fatalities, 42 injured
2005: Texas refinery explosion[e]	On March 23, 2005, a hydrocarbon vapor cloud was ignited and exploded at the ISOM isomerization process unit at BP's Texas City refinery, which is US’s third largest refinery	Deaths of 5 workers and 180 others injured
2010: Gulf of Mexico, drilling rig explosion[f]	On April 20, 2010 where a deep-water horizontal drilling rig, owned and operated by British Petroleum, exploded. It caused a fire on the mobile offshore drilling unit	Deaths of 11 workers and seriously injured 17 others

[a] The New York Times (16 February 1982). “84 Feared Dead as Oil Drilling Rig Reportedly Sinks in North Atlantic". http://www.nytimes.com/1982/02/16/world/84-feared-dead-as-oil-drilling-rig-reportedly-sinks-in-north-atlantic.html?scp=7&sq=sinks%20in%20Atlantic&st=cse

[b] Chicago Tribune (2 November 1985). "Welding Cracks Caused Union Oil Blast Fatal To 17" by Dave Schneidman. http://articles.chicagotribune.com/1985-11-02/news/8503150149_1_cracks-weld-fire-marshal

[c] Arturson, G. (1987). "The tragedy of San Juanico--the most severe LPG disaster in history". Burns Incl Therm Inj. 13 (2): 87–102.

[d] Tim Haïdar (August 27, 2012), Five Deadliest Onshore Oil & Gas Blasts. Oil & Gas IQ, https://www.oilandgasiq.com/integrity-hse-maintenance/articles/five-deadliest-onshore-oil-gas-accidents

[e] BP Fatal Accident Investigation Report -Isomerization Unit Explosion Final Report, Texas City, Texas, USA. December 9, 2005.

The Guardian (November 28, 2012). "BP suspended from new US federal contracts over Deepwater disaster" by Suzanne Goldenberg and Terry MacAlister. https://www.theguardian.com/environment/2012/nov/28/epa-suspends-bp-oil-spill

Table A3: List of selected accidents in oil and gas transportation (pipelines and tankers)

Only large accidents are included

Date & Accident	Description	Impacts
1989: Ufa train disaster in former Soviet Union[a]	On June 4, 1989, Wheel sparks from two passenger trains heading in opposite directions ignited fire in a site about 50 kilometers from the city of Ufa where a highly flammable cloud of fuel vapor was created due to leakage natural gas liquids (mainly propane and butane)	killed 575 people and injured another 800 people
1998: Jesse, Niger Delta oil pipeline explosion, Nigeria[b]	On October 18, 1998, A cigarette ignited fire on leaked oil around the oil pipeline in Jesse, Niger Delta	Deaths of more than 1,000 people
2000: Another oil pipeline explosion in Jesse, Niger Delta, Nigeria[c]	On July 12, 2000 after about two years of major explosion, an oil pipeline again exploded due to fire when, apparently, villagers were scooping up spilled gasoline with buckets	250 deaths
2004: Nishapur train disaster, Iran[d]	On 18 February 2004, a runaway train with 51 wagons carrying sulphur, fertiliser, petrol and cotton wool crashed into the community in the middle of the night and exploded	295 confirmed deaths and over 460 injured, including 182 rescue workers and state officials
2006: Lagos oil pipeline explosion, Nigeria[e]	On December 26, 2006, a gasoline pipeline ruptured by thieves exploded in a poor neighborhood of Lagos	260 deaths
2009: Viareggio train crash, Italy[f]	A 14-car freight train carrying LPG got derailed and ploughed into houses in the small Italian town of Viareggio, causing an explosion and a fire	Deaths of 12 people and injured at least 50
2013: Lac-Mégantic tanker disaster, Quebec, Canada[g]	On July6, 2013, an oil tanker train (73 tank cars) carrying light crude oil derailed resulting in the fire and explosion of multiple tank cars in the town of Lac-Mégantic in Quebec	47 deaths

[a] Russia remembers 1989 Ufa train disaster". RIA Novosti. 2009-06-04, https://sputniknews.com/russia/20090604155167464/

[b] Greenleft Weekly (July 19, 2000). “ NIGERIA: Hundreds die in pipeline disaster” by Norm Dixion. https://www.greenleft.org.au/content/nigeria-hundreds-die-pipeline-disaster.

[c] Las Angeles Times (12 July 2000), “Pipeline Blast Kills as Many as 250 Nigerians”. http://articles.latimes.com/2000/jul/12/news/mn-51655

[d] BBC News (25 February, 2004), 'Error' caused Iran train blast. http://news.bbc.co.uk/2/hi/middle_east/3487290.stm

[e] Associate Press (December 27, 2006), “Gas Line Explodes in Nigeria, Killing at Least 260” http://www.nytimes.com/2006/12/27/world/africa/27nigeria.html

[f] The Guardian (30 June 2009). Train carrying liquid gas explodes in Italy killing 12. https://www.theguardian.com/world/2009/jun/30/train-crash-viareggio-lucca

[g] Associated Press (July 11, 2013). “Canada train derailment: Death toll at 50; Lac-Megantic residents jeer rail CEO”, by http://www.syracuse.com/news/index.ssf/2013/07/canadian_train_derailment_death_roll_at_50_residents_of_lac-megantic_jeer_rail_c.html

Table A4: List of selected accidents in power plants

Accidents with more than 5 fatalities were reported; also presented are accidents with large media coverage, such as Fukushima.

Date & Accident	Description	Impacts
1963: Vajont Dam, Italy[a]	On October 9, 1963, 260 million cubic metres of rock broke off from the top of Monte Toc and fell into the reservoir of the Vajont Dam on the border between Veneto and Friuli Venezia Giulia. It caused overflow of water causing flooding in the downstream valley	Destroyed several villages in the valley and killed almost 2,000 people
1975: Shimantan/Banqiao Dam Failure, Henan Province, China[b]	On August 8, 1975, the Shimantan and Banqiao dams built on the Ru River in Central China collapsed due to heavy rainstorm inundating thousands of square kilometers	It caused 26,000 deaths directly and another 145,000 deaths through subsequent epidemics and famine.
1979: Machchu-2 dam, Gujrat, India[c]	On August 11, 1979, unprecedented flooding caused by torrential rain triggered the collapse of the Machchu-2 dam on the Machhu river and inundated Morvi town of Rajkot district of Gujrat	1,500 deaths
1986: Chernobyl Nuclear Power Plant, Ukraine[d]	On 26 April 1986, Chernobyl 4 nuclear reactor exploded dissipating the large amounts of radioactive materials	Of 600 workers present on the site during the accident, 134 received high doses and suffered from radiation sickness. Of these, 28 died in the first three months and another 19 died in 1987-2004 of various causes. 530,000 people who were involved in recovery operations between 1986 and 1990 have got minor radiations and bear a potential risk of late consequences such as cancer and other diseases.
2009: Sayano–Shushenskaya Dam, Russia[e]	Water flooded a turbine room at the Sayano–Shushenskaya Dam located more than 3,000 km east of Moscow	72 fatalities
2011: Fukushima Daiichi nuclear disaster, Japan[f]	On 11 March 2011, a tsunami triggered by massive earthquake disabled the cooling systems of Fukushima Daiichi nuclear reactors Unit 1, 2, 3 and 4 thereby resulting in meltdowns and explosions and releasing radioactive materials for three days	No immediate death linked to radiation due to the accident, but some studies (Normile, 2012; Hoeve and Jacobson, 2012) estimate, based on the linear no-threshold theory of radiation safety, 130–640 deaths in the long-run due to the radiation

[a] Expecting Disaster: The 1963 Landslide of the Vajont Dam. Arcadia, 2011, No. 8. http://www.environmentandsociety.org/arcadia/expecting-disaster-1963-landslide-vajont-dam

[b] Shimantan/Banqiao Dam Failure - Thayer Watkins. "The Catastrophic Dam Failures in China in August 1975". San Jose State University. Retrieved on July 7 2017.

[c] Machchu dam: Noorani, A. G. (25 August 1979). "The Inundation of Morvi". Economic and Political Weekly. 14 (34): 1454 and Noorani, A. G. (21 April 1984). "Dissolving Commissions of Inquiry". Economic and Political Weekly. 19 (16): 667–668.

[d] Chernobyl: The Chernobyl accident - UNSCEAR's assessments of the radiation effects, http://www.unscear.org/unscear/en/chernobyl.html

[e] Ilya Naymushin (2009-08-17). "Russian dam disaster kills 10, scores missing". Reuters. http://www.reuters.com/article/us-russia-accident-sb-idUSTRE57G0M120090817?sp=true

[f] Normile, D. (27 July 2012). "Is Nuclear Power Good for You?". Science. 337 (6093): 395–396. doi:10.1126/science.337.6093.395-b; Hoeve, J.E.T. and M. Z. Jacobson (2012). "Worldwide health effects of the Fukushima Daiichi nuclear accident". Energy & Environmental Science. 5 (9): 8743.