K4D Knowledge, evidence and learning for development

Climate Change and Air Pollution

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Question

Describe the relationship between strategies to reduce carbon emissions from the energy sector including, but not limited to moving away from fossil fuels, and impacts on human exposure to air pollution. This should include:

- *Describing and quantifying the co-benefits of decarbonisation measures/policies and human exposure to air pollution.*
- *The tensions that potentially exist between decarbonisation of energy production and human exposure to air pollution*
- *Strategies/interventions which reduce carbon emissions from the energy sector and do not increase human exposure to air quality or exacerbate health inequalities*

Contents

1. Summary

The UK's Foreign, Commonwealth & Development Office (FCDO) commissioned this rapid literature review to explore the interactions between climate change and air pollution, with a focus upon human health impacts. In particular, the report explores potential synergies in tackling climate change and air pollution together. The impacts and implications of the transition from a carbon-intensive economy upon air quality and consequently human health are examined. The review is designed to generate discussion prior to an expert roundtable discussion.

Over the last 50 years, the global demand for energy has increased by over 185%. In 1970, the annual production of energy was estimated at 28.5 TWh, in 2020 it was 171.2 TWh. This growth has been predominantly driven by population growth and economic development. Much of this energy demand has been supplied by fossil fuels, in particular coal, oil and gas. In low and middle income countries, the use of traditional biomass fuels also represents a significant market share of energy production. These fuels have many benefits, including relatively low costs, tried and tested technologies and global supply chains. The production of energy occurs over multiple scales from the household stove for heating the house and cooking food, to international energy networks that extract fossil fuels from the ground to burn in power stations to supply electricity grids.

All energy generation by the combustion of hydrocarbons, whether in the form of fossil fuels or biomass, results in the release of greenhouse gases (GHGs) and air pollutants. Transportation is intricately linked to energy production, whether through the use of hydrocarbon fuels or the need of electricity production for newer electric vehicles.

Climate change, caused by increasing atmospheric concentrations of GHGs, has led to global warming. Currently, the earth's global average temperature is approximately 1°C above pre-industrial levels. The current trajectories of human activities, including population demographics, economic development, consumption, and energy production will likely cause increasingly severe consequences, which will impact upon human health, environmental health, livelihoods, food security, water supply, human security, and economic growth. Climate change has local and global impacts on the human health in multiple thematic areas including: the supply of water and food, water quality impacts, extreme heat, severe weather, changes to vector ecology e.g. malaria, and increasing allergen loads. The energy sector is the largest contributor to global GHG emissions.

Air pollution causes human morbidity and mortality, it is the leading environmental cause of premature death globally. Outdoor (ambient) air pollution causes approximately 4 million premature deaths annually, predominantly due to stroke, heart disease, lung cancer, and chronic respiratory diseases. More than 90% of the world's population lives in locations that exceed the WHO air quality limits. Indoor air pollution is also a serious environmental issue that negatively impacts the health and lives of billions of people, especially women and children. The energy sector is the primary source of outdoor and indoor anthropogenic air pollutants. In addition to combustion related air pollution sources, there are also other sources, usually related to mechanical action, such as abrasion and friction.

Whilst air pollution and climate change are mostly caused by the same sources, they have different causal pathways to impacting upon human health. Furthermore, they have different timescales of action, with the impacts of air pollution manifesting over days to decades, whereas climate change manifests over longer timescales. These different timescales have led to different political approaches. For climate change the high inertia in the Earth's climate system leads to the problem of time inconsistency, where solutions to climate change take longer than the typical political

timescale, especially within elected governments where leadership typically changes over a relatively short (typically 4-5 year) timescale.

At a global scale, the most effective intervention to reduce both climate change and air pollution is to phase out the most polluting fossil fuels from energy generation. In particular, the phase out of coal power stations will have huge benefits. However, at an individual scale, the exposure to air pollution can most effectively be achieved by reducing indoor air pollution from fossil fuel and biomass burning for cooking and heating, which approximately 40% of the world's population is still reliant upon. In addition to the reduction in energy production from coal, various other win-win situations are identified including preventing crop burning and preventing forest fires.

Discussing climate change without air pollution can lead to risks. For example, strategies that focus on electrification and transition to renewable energy achieve maximum health and air quality benefits compared to strategies that focus mainly on combustible renewable fuels (biofuel and biomass) with some electrification. The review discusses five strategies to decarbonise the energy sector:

- Clean renewable energy,
- Combustible renewable energy,
- Nuclear energy,
- Clean Coal and Carbon capture utilization and storage,
- Efficiency improvements (mainly in the industrial sector).

Clean renewables are the most promising in health and air quality benefits yet have challenges in accessibility and reliability. Nuclear energy is the cleanest and cheapest form of energy albeit raising issues of safety and resource limitation. Although combustible renewable energy might be ideal for rural areas and low-income countries, it can contribute dramatically to local air pollution. Carbon capture and storage can reduce emissions but can cause higher climate and pollutant emissions elsewhere in the production chain. Improving the efficiency of industrial production is a quick solution for reducing immediate emissions in resource and energy-intensive industries. Long term solutions need sustainable strategies that completely decarbonise the power supply by shifting to renewable clean energy.

Addressing climate change necessitates a shift towards a new low carbon era. This involves stringent and innovative changes in behaviour, technology, and policy. There are distinct benefits of considering climate change and air pollution together. Many of the processes that cause climate change also cause air pollution, and hence reductions in these processes will generate cleaner air and less global warming. Politically, the consideration of the two issues in tandem can be beneficial because of the time inconsistency problems of climate change. Air pollution improvements can offer politicians victories, on a useful timescale, to help in their aims of reversing climate change. By coupling air pollution and air pollution agendas together, it will increase the media and political attention both environmental causes receive.

Policies should involve the integration of climate change, air quality, and health benefits to create win-win situations. The success of the strategies requires financial and technical capacity building, commitment, transparency, and multidisciplinary collaboration, including governance stakeholders at multiple levels, in both a top down and bottom up manner.

The United Nations Climate Change Conference UK 2021 (COP26) will be held in Glasgow, UK on the 1-12 November 2021. This provides a key opportunity for the alignment of the climate change and air pollution agendas. Climate change negotiations are already complex, see Figure 1 generated in preparation for COP21 held in Paris in 2015. Adding air pollution considerations to the COP26 agenda will further complicate the situation, but the benefits of tackling air pollution and climate change together will outweigh this additional burden.

Figure 1 Cartoon highlighting the complexity of climate change negotiations, Image from the DiploFoundation, under CC BY-NC-ND 4.0 International.

2. Introduction

Both climate change and air pollution occur because of anthropogenic emissions into the atmosphere. The sources of these emissions are varied, but the majority of emissions derive from the burning of hydrocarbon fuels for the production of energy for heating, cooling, lighting and powering buildings and transportation. Other non-burning sources of pollution exist, typically occurring where mechanical action such as abrasion and friction type processes are present. For example, petrol and diesel vehicles release air pollutants via both exhaust emissions associated with the burning of hydrocarbons, and non-exhaust emissions associated with resuspension of dust from the road surface, and tyre and brake wear.

Emissions associated with climate change are able to interact with the Earth's climate. There are two broad categories for these emissions: greenhouse gases (GHGs) and particulate matter (PM).

- Greenhouse gases (GHGs) warm the atmosphere by absorbing radiation, thereby trapping energy in the atmosphere and increasing average temperature at the surface of the Earth.
- Particulate matter (PM) is composed of small solid and liquid particles, in the size range of tens of nanometres to hundreds of micrometres (1×10^{-8} – 1×10^{-4} metres). Depending on the composition and size of the PM, it can absorb radiation in a manner similar to GHGs, it can also reflect incoming solar radiation back out to space and therefore cool the climate.

In this review, we consider emissions that cause harm to human health as air pollutants, these include both gas emissions such as nitrogen dioxide (NO_2) and PM. A wider definition of air pollutants would also consider the effect upon environmental health but is beyond the scope of this review.

If all atmospheric emissions caused both climate change and air pollution, then the emission reductions would always be beneficial in reducing climate change and improving air quality for human health. Indeed, air pollution and climate change are closely coupled and many interventions benefit both the climate and human health. However, not all air pollutants affect the climate, and not all climate change agents are air pollutants. For example, carbon dioxide (CO_2) is the most important greenhouse gas, but at the concentrations observed in the current ambient atmosphere, and at those projected over the next hundreds of years, it does not present a direct threat to human mortality or morbidity. Therefore, reducing CO_2 on its own will not reduce air pollution.

In this document, we will review in Section 3 how increasing global energy demand is driving climate change and air pollution. In Section 4, the role of emissions in climate and air pollution will be defined. Also, the overlaps, commonalities and divergences between climate change agents and air pollutants will be highlighted. In Section 5, the likely impacts of future energy transitions upon both air pollution and climate change will be considered. In section 6, the differing vulnerabilities to the effects of climate change and air pollution and hence the health inequalities will be explored. Finally in Section 7, other potential approaches for reducing air pollution and climate change in tandem are highlighted, including a brief case study on the recently enacted Graded Response Action Plan (GRAP) in Delhi’s NCR, which primarily aims to reduce air pollution but also assesses the impact on emissions of climate change agents.

3. Increasing Global Energy demand

There is a clear and strong link between economic development and demand for energy. Variations in per capita energy consumption are observed both between and within countries. For example, using 2019 values, the average per capita energy usage for the United States of America (USA), United Kingdom (UK), China, India and Sub-Saharan Africa (SSA) was approximately 80,000; 32,000; 27,000; 7,000 and less than 2,000 kWh, respectively (Our World in Data, 2020). Within country variations are striking, with the difference in energy consumption between the richest 10% and poorest 10% of a country observed to be as high as 5 fold(Chancel, 2020). These inter and intra country inequalities are discussed further in Section 5.

Global energy is not equally consumed; currently China, USA, and India are the biggest total energy consumers globally (Fig. 2), while the energy use per capita in the global north is much greater than in the global south (Fig. 2) . Energy consumption is typically subset into the following categories: residential, commercial, transportation and industrial. Decarbonisation of each of these sectors requires different approaches.

Projections for the next 30 years suggest that energy consumption will stay relatively static for OECD (Organisation for Economic Co-operation and Development) countries. Whilst the energy consumption of non-OECD countries will increase significantly (Figs. 2). The major growth in energy consumption will be due to the rise in industrial and transportation sectors in non-OECD countries.

Globally, available energy resources are still dominated by those that need combustion to release their energy. In particular, the combustion of fossil fuels. In 2019, the total global energy production was estimated to be 173,340 TWh. Combined together, the percentage of energy generated by oil, gas and coal was 78.9%, which increases to 85.3% when traditional biomass burning is also considered. The final category of fuels which require combustion to release their energy are modern biofuels. In 2019, modern biofuels only represented 0.7% of the total energy resource, but the percentage is rapidly increasing albeit from a near zero baseline before 1990.

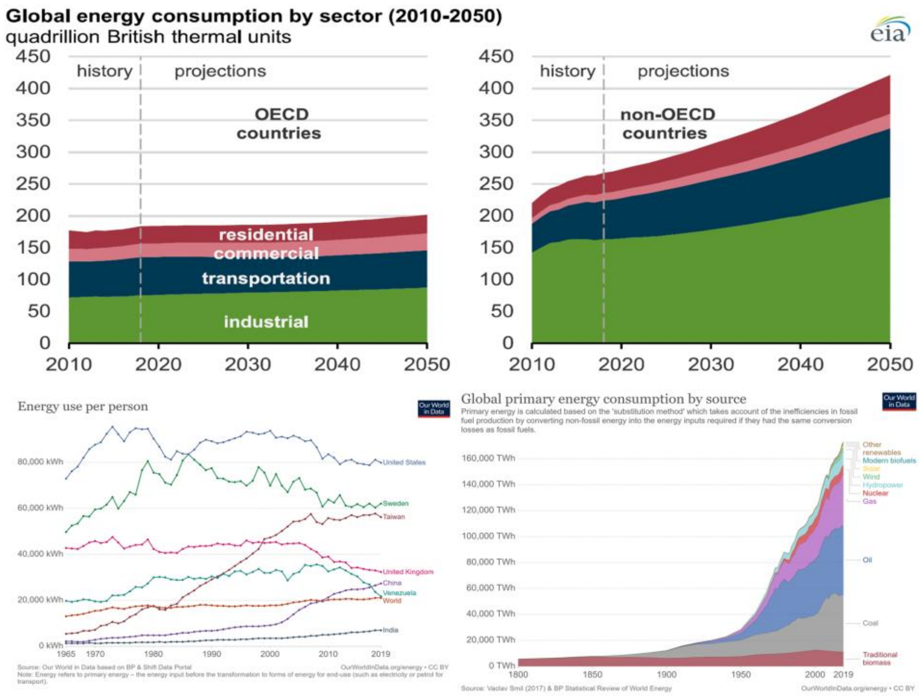


Figure 2. Global energy use statistics. Top: Global energy consumption subset by OECD and non-OECD countries, by sector 2010-2050. Bottom left: Energy use by a person in seven countries in 2019. Bottom right: Global energy consumption, TWH, by source: U.S. Energy Information Administration, http://www.eia.gov. Reproduced with permission

4. Climate change, air pollution and human health

Climate change and air pollution are closely coupled because the sources of air pollutants are also often the sources of climate change agents. As discussed above, not all air pollutants are climate change agents, and vice versa. Whilst the sources are often similar, the impacts upon human health are distinct. The combined impacts of climate change and air pollution is currently understudied and it is not clear whether the effects of these two environmental health risks are additive or multiplicative. Further research into the combined effects of the twin threats is required.

Climate change

Climate change is caused by the release of anthropogenic GHGs into the atmosphere. Once in the atmosphere, these gases absorb infrared radiation released by the Earth, thereby causing the planet to warm up. Multiple different types of gases act as GHGs and each chemical species has a distinct contribution to global warming. The ability of a specific GHG to cause global warming is a function of the lifetime of the GHG of interest in the atmosphere, the intrinsic ability of the GHG of interest to absorb radiation, and the concentration of the species in the atmosphere. The GHGs that are most responsible for causing climate change are three relatively long lived gases with high atmospheric concentrations: CO_2, methane (CH_4) and nitrous oxide (N_2O). None of these gases are considered to be air pollutants that affect human health. CO_2 is predominantly produced by fossil fuel combustion and is typically co-emitted with air pollutants. CH_4 is mostly released from agricultural activities, and N_2O is typically released from industrial and agricultural activities.

CO_2 is responsible for approximately two thirds of global warming and hence is the most important GHG. Globally, CO_2 emissions have increased by over 200 fold in the last two centuries (Fig. 1e). In the last decade the yearly increase in CO_2 has been approximately 0.6% per year.

The increase in GHGs has led to increases in global average temperatures (Fig. 4). Human activities are estimated to have caused approximately 0.8-1.2°C global warming above preindustrial levels and are estimated to rise to beyond 1.5°C if no action is taken to combat the rising temperatures due to the growing impact of development and industrialisation (IPCC). This average hides wide differences between regions. It also hides the variation in extreme temperature events. Climate change does not just effect temperature, it also has knock on effects upon other hydrometeorological processes, leading to greater variability in the climate system resulting in greater likelihoods of natural disasters such as flooding, storms and droughts. For example, in late July 2010, over one-fifth of Pakistan's land area was affected by floods caused by heavy global-warming-related rains. Flood disaster caused over 2000 deaths and more than US $40 bn damage to the national economy (Memon and Sharjeel, 2016).

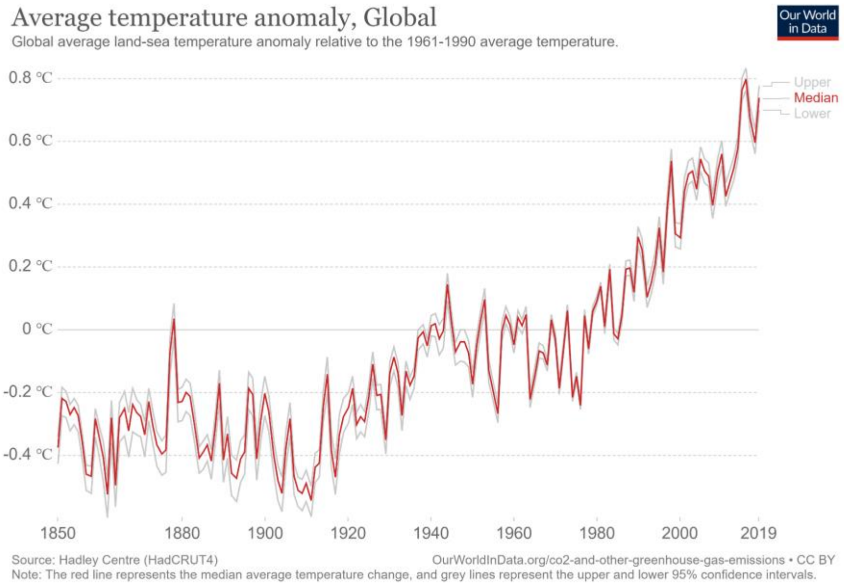


Figure 3. Global average land-sea temperature rise from 1850-2019 relative to 1961-1990 average temperature, source: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions, licensed under CC BY 4.0.

In addition to GHGs, the other major atmospheric species that can affect the climate is particulate matter (PM), which can either heat or cool the climate depending on the size and composition of the PM. The composition of PM is not fixed and depends on sources, atmospheric processing and loss processes. The dominant components of PM composition are sulphates, nitrates, ammonia, sodium chloride, black carbon (BC), mineral dust and water. In broad terms, the darker the PM material, the greater its atmospheric warming potential. Black carbon (BC) is the major atmospheric warming component of PM; it is a soot like substance, which is generated from combustion. Sulphate, nitrates, ammonia, sodium chloride and mineral dust aerosols tend to cool the climate by reflecting light. Hence PM that cools the climate can mask some of the effects of global warming.

Burning coal produces more CO_2 per unit than any other fuel due to it high carbon content. Despite a modest recent drop in demand, coal is still the fastest growing fuel in the market and contributes to around 40% of total global GHG emissions in 2019 (Our World in Data). Around 14.6 billion tons of CO_2 are produced from coal, following by oil and gas at 12.4 billion and 7.6 billion tons respectively. Most global CO_2 from coal is produced in the US, Australia and China, with China leading the show with more than 7 billion tons of CO2 release from coal in 2019, followed by Indian and the US at 1.67 and 1.09 billion tons CO_2 respectively. Wang et al. (2018) performed a life-cycle assessment to determine the environmental impacts of coal-fired power generation in China and found that smoke and dust were the key environmental impacts, in addition to the release of environmental pollutants like CO, SO_2, and PM with high environmental cost (Wang et al., 2018).

According to the IPCC 5th assessment report, currently, the direct effect of global warming upon human health is relatively small compared with the effects of other environmental stressors. The review of Crimmins et al. (2016) highlights that the global warming aspects of climate change affects human health in two main ways:

- first, by changing the severity or frequency of health problems that are affected by climate or weather factors; and
- second, by creating unprecedented or unanticipated health problems or health threats in places where they have not previously occurred (Crimmins, 2016).

As average temperatures increase due to additional global warming, this additional heat burden will become greater. In 2018, the IPCC released a Special Report to highlight the importance of limiting global temperature rise to less than 1.5°C. Detrimental climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are expected beyond the 1.5 °C limits and even more abruptly towards the 2°C limits (IPCC). Significantly lower risks are projected at 1.5°C compared to 2°C for heat-related morbidity and mortality (IPCC). A major worry is the increasing frequency of heat waves.

Other risks from climate change are shown in Fig. 4. Risks from some vector-borne diseases, such as malaria and dengue fever, are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range (IPCC). Moreover, amplification of heatwaves in cities as a result of the urban heat island effect, the additional warming observed in urban areas because of more energy absorbing land surfaces, is associated with further health risks on the urban population.

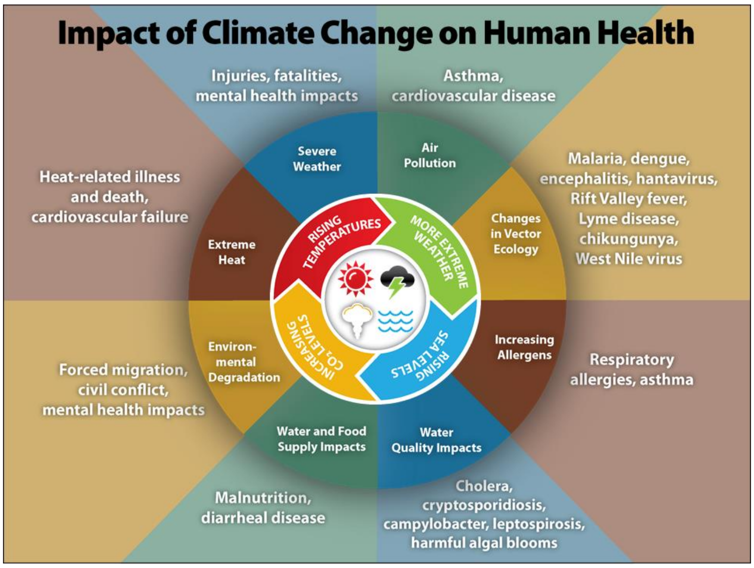


Figure 4 Impacts of climate change upon human health, https://www.cdc.gov/climateandhealth/effects/default.htm. Reproduced with permission.

Air Pollution

Air pollution is the leading environmental risk factor for premature death globally. There are a multitude of air pollutants, which differ in their chemical composition, reaction properties, emissions, persistence in the environment, ability to be transported, and their eventual impacts on human health. The World Health Organization (WHO) has identified the main pollutants that adversely impact human health as particulate matter (PM), in the PM_{10} and $PM_{2.5}$ size fractions, nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), and tropospheric/ground-level ozone (O_3).

Air pollution has both natural and anthropogenic sources. Predominantly, anthropogenic air pollutants come from combustion related processes. PM has multiple natural sources, such as desert dust, sea spray, volcanic emissions and forest fires.

CO is predominantly produced from the inefficient combustion of hydrocarbons including biomass burning for cooking/heating and vehicle exhausts. NO_2 is associated with high temperature combustion and hence is mainly emitted by power plants, industrial and traffic sources. SO_2 is also predominantly formed by the burning of fossil fuels, in particular oil and coal which have high sulphur content. The sources of O_3 in the troposphere, the lowest part of the atmosphere where air pollution is most important, are more complicated. They are formed by chemical interactions between nitrogen oxides (including NO_2) and volatile organic compounds (VOCs).

PM has multiple sources, the smaller size fractions ($PM_{2.5}$) has combustion as a major source, whereas the coarser particles (PM_{10} – $PM_{2.5}$) typically have a greater contribution from non-combustion sources such as mechanical sources, for example brake and tyre wear in vehicles and resuspension of dust. At present, the WHO or other regulatory authorities do not consider the composition of PM as a determinant of its toxicity, put simply, all PM is considered bad. It is noted from a climate perspective the majority of PM compositions cool the climate. Hence, the removal of PM can have the perverse effect of heating the climate whilst removing the air pollution burden.

The relative benefits upon health of this positive air quality effect and negative climatic effects needs to be carefully considered.

Ambient (outdoor) air pollution accounts for an estimated 4.2 million deaths per year due to stroke, heart disease, lung cancer, acute and chronic respiratory diseases and has been widely classified as the leading cause of death and disability worldwide (WHO). The global distribution of air pollution related deaths from fossil fuels is shown in Fig. 5.

As a comparison, it is highlighted, that over 1.7 million died prematurely due to air pollution in Asia in 2015, while the global number of deaths due to the ongoing Covid-19 pandemic is 2.1 million at the date of the present report.

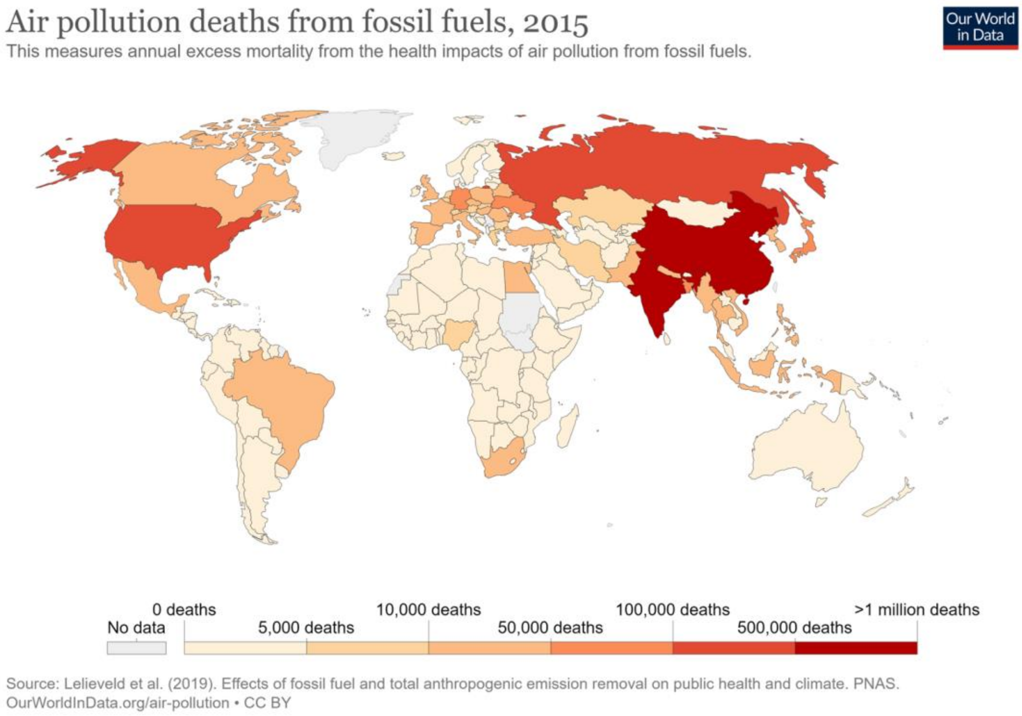


Figure 5. Global distribution of death from fossil fuels, 2015, source: https://ourworldindata.org/air-pollution, licensed under CC BY 4.0

Evidence regarding the linkage of air pollution to specific diseases, such as cardiovascular, respiratory diseases, and cancers have been produced at country, regional and global levels. A wide body of research, including environmental and epidemiological studies, have studied the relationships between outdoor air pollution and prevalence of cancer, results confirming a direct connection between harmful air pollutants, precisely PM pollution to lung cancer and cancer of the urinary tract (WHO, 2016). Serious risks were also associated with exposure to O_3, NO_2, and SO_2. O_3 has been found as a major cause of asthma-related morbidity and mortality, while NO_2 and SO_2 also can play a role in asthma, bronchial symptoms, lung inflammation, and reduced lung function.

Indoor air pollution causes noncommunicable diseases including stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD), and lung cancer. In poorly ventilated households, indoor smoke from biomass burning can be up to 100 times higher than acceptable levels for fine particles. In low and middle income countries (LMICs), exposure is particularly high among women and young children, who spend a disproportionate time close to combustion sources indoors. Close to 4 million people die prematurely every year from illness attributable to household air pollution from inefficient cooking practices using polluting stoves paired with solid fuels and kerosene (WHO, 2018).

Recently, a growing body of work is highlighting the importance of PM air pollution upon cognition and mental health. It suggests that citizens of more polluted cities and countries will have, on average, worse cognitive ability than they would have if air quality was better. This observation is potentially far reaching for the ability of countries to effectively enter the high tech job markets (Shehab and Pope, 2019).

Interaction between air pollution and climate change

Climate change influences air pollution by altering the frequency, severity, and duration of heatwaves, air stagnation events, and other meteorology conducive to the accumulation of heatwaves. Climate change can also impact local and regional meteorology which can alter the source, transfer and loss of air pollutants. Climate change can also impact upon natural sources of air pollution. For example, increasing aridity can cause desertification and hence greater production of desert dust PM. Despite these intricate connections, policies that benefit air pollution do not necessarily benefit the climate change and vice versa.

Air pollutants interact with solar and terrestrial radiation and perturb the planetary energy balance, leading to changes in climate. Climate is expected to degrade air quality in many regions by changing air pollution meteorology (dilution and ventilation), precipitation and by triggering amplifying responses in atmospheric chemistry and anthropogenic and natural sources (Fiore et al., 2015). This will mainly impact the distribution and extreme episodes of tropospheric ozone and $PM_{2.5}$, which are influenced by changes in precipitation and ventilation due to changes in weather patterns (mainly temperature, humidity and windspeed).

For all the air pollutants highlighted for attention by the WHO, the lifetime of the pollutants in the atmosphere is typically less than a few weeks. This means that all directly emitted anthropogenic air pollution would disappear after a few weeks if the sources of the air pollution were all (magically) turned off at the same time. This is not the case for the most important long lived climate forcing agents (CO_2, CH_4, N_2O and halocarbons) and hence distinct strategies are required for combatting climate change compared to air pollution because of the greater inertia within the climate system.

The longer lifetimes of GHGs also mean that the emission location is not of primary importance for the implications for climate change. One molecule of CO_2 released in China has the same climate change impact as one molecule released in the UK.

The relatively rapid loss of air pollution, often makes air pollution largely dependent on proximity to air pollution sources. This is why urban roadside locations tend to have poorer air quality than urban background locations, which in turn, are more polluted than rural locations. Hence, urban areas are typically pollution hotspots. However, this is not true for all pollutants. For secondary pollutants, those which are not emitted directly but form in the atmosphere, like ozone are typically regional in scope. This brings the spotlight on the concept of ‘transboundary air pollution’.

Regional air pollution and climate change do not stop at national borders and therefore to be successfully addressed need to be considered as international issues that require international collaboration. Transboundary air pollution has been identified as one of the most serious environmental challenges in many regions around the world, due to range of factors such as geographical proximity of countries, increase of energy consumption, lack of sufficient technology, rapid urbanization and inadequacy of existing regional frameworks that address the problem (NEASPEC). Moreover, international trade is contributing to the globalization of emissions and pollution as a result of the production of goods (and their associated emissions including transport) in one region for consumption in another region. In his study, Zhang et al. concludes that the transboundary health impacts of $PM_{2.5}$ pollution associated with international trade are greater than those associated with long-distance transport of atmospheric pollutants (Zhang et al., 2017). International organization like US Environment Protection Agency (EPA) and North-East Asia Clean Air Partnership (NEACAP) are working to address the issue of transboundary air pollution by connecting subregional experts and existing collaborative mechanisms to generate a coordinated and integrated approach to policymaking and problem-solving (NEASPEC).

Recently, a new comprehensive report from the Global Alliance on Health and Pollution (GAHP), AirQualityAsia and The Schiller Institute for Integrated Science and Society at Boston College assessed interventions with respect to the air quality and climate change impacts. The assessment was performed by expert solicitation, in which researchers evaluated 22 possible interventions. The outcome from this assessment is shown in Fig. 6, which provides a graphic summary of the estimated climate change and health benefits of air pollution interventions (GAHP et al., 2020). The report highlights that the following air pollution interventions will likely have benefits for both human health and reducing CO_2:

- Replacement of coal fired power stations with renewables
- Vehicle fleet penetration by electric vehicles
- Prevention of crop residue burning
- Prevention of forest fires
- Controlling Diesel emissions
- Replacement of coal fired power stations with gas
- Energy efficiency improvements for industries.

See: Figure 6. Benefits of air pollution interventions. KEY: Cost effectiveness is represented by the size of the bubble – larger bubbles are more cost effective. A rough indication of the difficulty of implementing interventions is represented by bubble colour. Darker coloured interventions are often more complex to put in place. Source: GAHP et al. (2020), https://gahp.net/intervention-benefits/

5. Inequalities and differing vulnerabilities to climate change and air pollution

There are clear global inequalities in both climate change and air pollution. These inequalities vary both within and beyond country borders. These inequalities at a country level are shown in Figures 5 and 7. For example, the United States contains 4.3% of the global population, but emitted nearly 18% of global CO_2 in 2018. As highlighted in section 3.3, air pollution is predominantly an urban problem and so urban-rural inequalities easily occur.

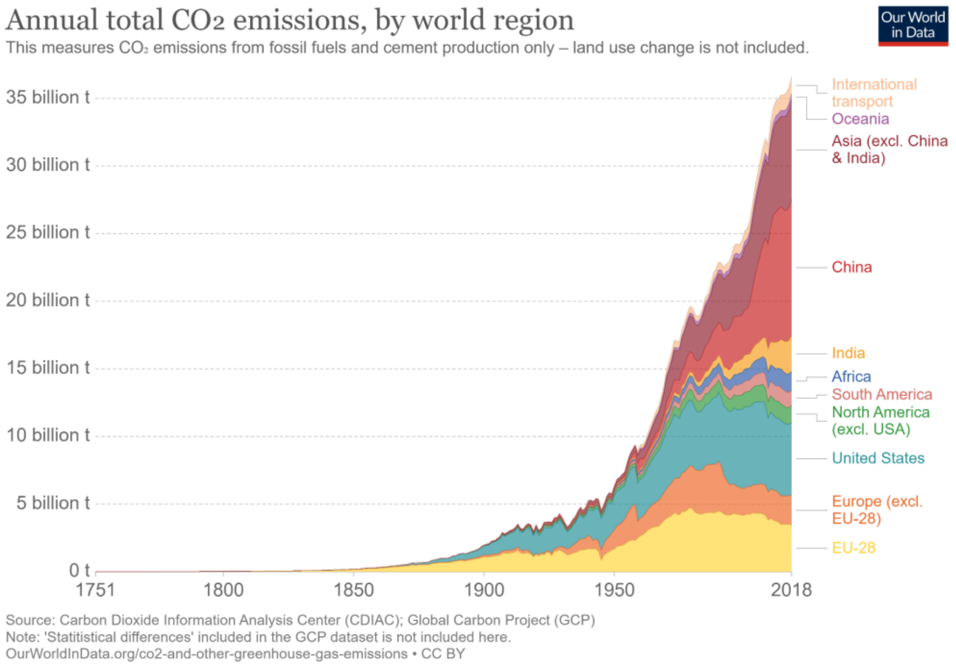


Figure 7. Annual total CO_2 emissions by world region, source: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions, licensed under CC BY 4.0.

The French economist Lucas Chancel (2020) differentiates between five different forms of environmental inequalities (Chancel, 2020):

1. Unequal access to natural resources
2. Unequal exposure to the risks of environmental disturbance
3. Unequal responsibility for the degradation of natural resources
4. Unequal exposure to the effects of environmental protection policies
5. Unequal say in decisions concerning the management of natural resources

Air pollution and climate change are represented to lesser and greater extents in each of these five forms of environmental inequality. The greater importance of relative location in air pollution, compared to climate change, causes this differential.

Risk and vulnerability can be defined through the three intersecting lenses of exposure, susceptibility and adaptive capacity (Avis, 2018). There are clear overlaps between economic and environmental vulnerability. Exposure is a function of where you live, work and travel between these locations. The most susceptible to the effects of air pollution and climate change are typically the young, the old, and those with pre-existing health conditions. Adaptive capacity defines one's ability to engineer away the environmental risk, for example by installing air filtration and air conditioning in buildings and vehicles.

6. Future Energy Transitions

Co-benefits and possible tensions of decarbonization of the energy sector

Currently energy production globally is primarily from fossil fuels, which are the primary source of GHG emissions and air pollutants. Policies that support decarbonisation, the reduction of carbon emissions, should also provide air quality and health benefits.

A recent literature review in 2020, by Gallagher and Holloway, presents evidence from available studies, highlighting that GHG reduction has synergistic benefits of decreasing air pollution and protecting public health (Gallagher and Holloway, 2020). They note that "*compared to other aspects of climate and energy policy evaluation, however, there are still relatively few of these co-benefits analyses"*. Clearly, more work is needed in this area.

Zhao et al. highlight that the air quality and health benefits are only truly realised by deep decarbonisation pathway implementation (Zhao et al., 2019). Decarbonisation pathways that focus on electrification and transition to clean renewable energy (wind, solar, hydro) achieve the highest health benefits compared to pathways focusing on combustible renewable energy (biofuels) since combustion, even if carbon neutral combustion, still released air pollutants into the atmosphere.

Several factors continue to impact the effectiveness of alternatives to fossil fuels, including relatively low petroleum and fossil fuel prices; uncertainty about future policy, and funding programs to support zero carbon alternatives. Estimates of emissions from all fuels have some level of uncertainty associated with them. Any assessment of new technologies needs to consider the associated uncertainty of the technique.

David Victor in his 2011 'Global Warming Gridlock' highlights three 'myths' which help explain why climate change is such a hard problem to solve, similar arguments can also be made for air pollution.

The Scientist's Myth - Policy does not necessarily follow scientific consensus. Policy follows what governments are willing and able to do.

The Environmentalist's Myth - Climate change is not a typical environmental problem, and hence the environmental policy toolkit is poorly matched to the central regulatory task of slowing global warming.

The Engineer's Myth -Technological innovation does not lead directly to implementation. In many ways imagination and innovation are fast – but the testing and installation of technologies on scales appropriate to tackle climate change take a long time to come to maturity.

Renewable energy production

The contribution of renewable power to global energy has increased by 7-fold in the past five decades (Fig. 4a). The renewables sector is largely composed of hydro, solar and wind energy. It is clear they will continue to play an ever more important role in the decarbonisation of global energy in the coming decades. However in 2019, the renewable energy market only represents around 11% of the global energy production. The bulk of renewable energy production are concentrated in industrial countries such as the US, China, India, UK, and Germany.

Renewable energy production still has several important technical challenges. In particular, they lack the convenience of fossil-fuel plants that provide a sustainable and predictable amount of energy.

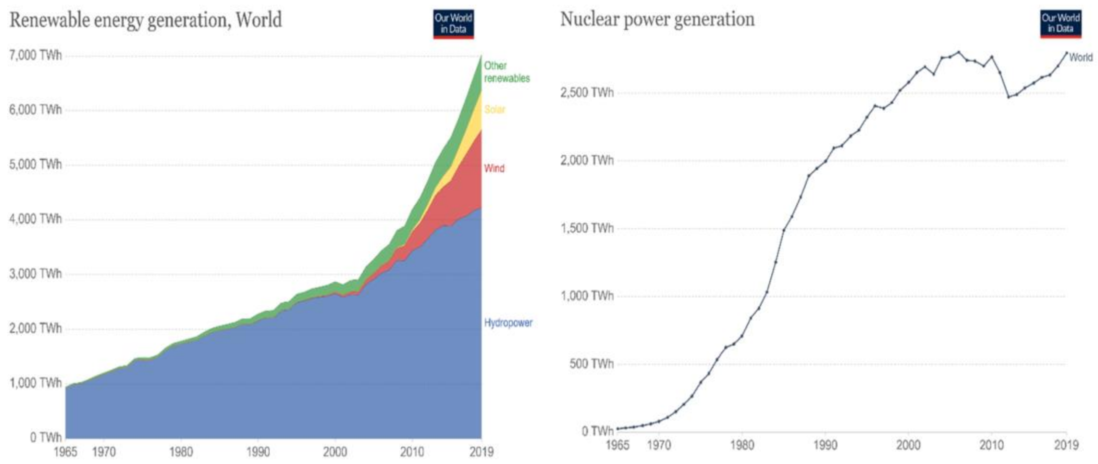
Hydropower is the leading source of renewable energy contributing to up to 70% of the renewable energy supply mix. The development of hydropower started with building thousands dams primarily in North America and Europe but has moved rapidly to developing countries. Despite being a renewable source of energy, nowadays more dams are being removed than built due to the associated negative impacts of disrupting river ecology, deforestation, losing aquatic and terrestrial biodiversity, releasing substantial greenhouse gases, displacing thousands of people, and altering people's livelihoods plus affecting the food systems, water quality, and agriculture near them (Moran et al., 2018). Another issue that deserves important consideration is the impact of climate change scenarios on future water supply which makes increases the technical challenges of hydropower generation.

Another emerging renewable energy market is hydrogen-based energy system, which is a combustion energy source albeit one that has zero-carbon-emissions at the end use. The current colour coding model available in the literature, differentiating hydrogen based on its production, indicates the hydrogen origin, grey or polluting hydrogen is from fossil fuels (steam reforming, partial oxidation of methane or coal gasification), blue hydrogen from fossil fuels coupled with carbon capture and storage, while green hydrogen comes from renewable energy. However, the GHG and air pollution emissions from the production and use of hydrogen fuel need to be considered in a full life cycle to fully evaluate how clean is clean or green hydrogen fuel is versus the other colour types (Dawood et al., 2020).

Renewables have issues of reliability and energy security due to their fluctuating and unpredictable power sources that are reliant on local environmental conditions. Cloudy days and still wind days are the enemies of solar and wind energy, respectively. The continuity of supply problem with renewables can lead to secondary reliance upon back up fossil fuel generators and the consequent impacts on local air quality. The storage of the produced energy is another major technical challenge of renewable systems. Hence, research and investment into new energy storage systems is on the rise to address issues of unreliability and unpredictability and are deemed essential to ensure the growth of the renewable energy markets.

Nuclear power energy

Nuclear power generation has existed for the past six decades but saw massive global growth in the last few decades of the 20th century (Fig. 4b). Although nuclear power plants could provide one of the cheapest, cleanest in terms of atmospheric emissions, and reliable energy. The past nuclear accidents/disasters have exerted an influence on public perception. Despite passing the Chernobyl disaster in 1986 and over twenty years of improved technical experience on the safety issues of operating nuclear power plants, the Fukushima Daiichi nuclear disaster in 2011 reiterated the high risk of nuclear energy. The radioactive particles introduced into the atmosphere during those accidents can still be detected in the atmosphere of EU countries. Meanwhile, nuclear waste is another principal challenge, which has not yet been sufficiently addressed.



(a) (b)

Figure 8 (a) Renewable energy generation, TWh, 1965-2019 ; (b) Nuclear power generation, TWh,1965-2019. Source: https://ourworldindata.org/grapher/renewable-energy-gen?country=~OWID_WRL, licensed under CC BY 4.0.

Biofuels: combustible renewable fuel

Biofuels have been a prominent method of decarbonising the transport sector with global production and consumption increased from over 64 billion litres in 2007 to over 145 billion litres in 2017 (Ebadian et al., 2020). Most of the policies used to promote transport decarbonisation have focused on increasing the use of biofuels in on road mobile sources, while off road mobile sources like aviation, shipping, and rail have received less attention despite being energy-intensive and significant producers of GHGs emissions.

Biogenic residual matter/waste accumulates in many fields of business and society, extending from agriculture and forestry to industrial and municipal waste. An opportunity arises here to improve the efficiency of established utilisation and the use of material that is regarded as waste. This process otherwise referred to as circular economy, where one industry’s waste can be used as a feedstock for other industries, has been receiving attention and international funding due to energy efficiency and environmental benefits (including CO_2 and air pollution reduction) (Hennig et al., 2016).

Burning waste/ waste incineration has been contributing to massive GHGs release and global warming, however, found an essential tool for waste management. Is there a way to slightly relieve the negative impacts and enhance the management of waste incineration?

Burning for energy rather referred to as waste to energy (WTE) coupled with direct electric heating is found to reduce CO_2 emissions as well as reduce the emissions of total suspended particles, NO_x, CO, VOCs, and other toxic pollutants generated from burning wood-based biomass (rural area and mountain in Europe) and coal (low-income countries) in household stoves (Adami et al., 2020). WTE is particularly effective in low-income and rural areas where access to clean sustainable energy is almost impossible. It also serves as a waste management solution and reduces the GHGs emissions from waste transportation to waste management facilities.

Around 3 billion people cook using polluting open fires or simple stoves fuelled by kerosene, biomass (wood, animal dung, and crop waste), and coal

Biofuel and biogenic waste can be an effective strategy to lower the carbon emissions of the energy sector. However, to achieve beneficial synergies to health and air quality, a complete strategy framework that shifts to clean renewable energy will bring on the most effective long-term results.

Technologies in Development [Clean Coal and Carbon Capture Utilization and Storage]

Coal is the world's most abundant and widely distributed fossil fuel source, it supplies around 27% of global energy needs and 38% of global electricity needs. It is also the most carbon intensive fuel. Some regions of the world, particularly China, are working on the development of 'clean coal' technologies to address the climate warming impact of coal to facilitate future utilization of the massive coal resources available.

Carbon capture utilization and storage (CCUS) is a promising method to reduce the emissions of CO_2, particularly from coal-fired power plants (IEA). It is the process of capturing CO_2, storing it at a location where it does not escape to the atmosphere. The most common application is enhanced oil recovery (EOR) at fossil fuel recovery sites and some can be used to make plastics, grow greenhouse plants or make carbonated drinks. Despite reducing CO_2 emissions onsite at power plants, CCS might contribute to worsening other air emissions on and offsite (Sekar et al., 2014), including SO_2, CO_2, PM, and ammonia NH_3, which negatively impact public health. Other issues involve the high cost and lack of political and financial commitment (IEA). Complete study of the life cycle of CCUS is required to properly evaluate the benefits of the technology and is highly dependent on the location of the power plant and efficiency of transport to the storage site.

Efficiency improvement

The industrial sector contributes to a large share of the world's total CO_2 emissions. Improving the efficiency of the production in resource-intensive industries, for example, the iron and steel industries can contribute to a significant reduction in global CO_2 emissions. The iron and Steel industry is a major sector of greenhouse gas emissions accounting for about 7% of total global CO_2 emissions and 14% of China's CO_2 emissions.

Among many other strategies to reduce CO_2 emissions from industry, like phasing out production and switching to clean fuel, transitioning to low-carbon technologies, like developing high efficiency/low emission equipment, implementing green innovation, and promoting new technologies, have been the most effective in reducing the environmental burden of industry (An et al., 2018).

Vehicle fleet electrification

The global transition to electric vehicles has increased dramatically over the last decade. Tesla, one of the most popular electric vehicles in the market, is currently valued to exceed US $800 billions, making it the most valuable car company in the world (Reuters, 2021). This is significant because of the percentage of total global energy consumption is due to the transport sector, see Fig. 1d. This transition has the potential to significantly reduce CO_2 emissions, air pollution, and consequently help public health. However, recent reports argue that the electric vehicle transition can have negative environmental impacts if due consideration is not given to a full life cycle assessment. The location and fuel type of the power plant supplying the electricity, and time of operation are key determinants of the environmental consequences (Lin et al., 2020).

The electrification of the vehicle fleet does not reduce the non-exhaust emissions. Since electric vehicles tend to be heavier than like for petrol and diesel vehicles, there is a worry in the literature that fleet electrification will result in greater resuspension of dust, tyre and brake wear (Beddows and Harrison, 2021).

Finally, the emissions created from the production and scrapping of vehicles should be considered in a full life cycle analysis. Estimates of the emissions from the production of a new car can be equivalent to approximately 50,000 km of driving (Chancel, 2020).

7. References

All of Our World in Data; https://ourworldindata.org/.

ADAMI, L., SCHIAVON, M. & RADA, E. C. 2020. Potential environmental benefits of direct electric heating powered by waste-to-energy processes as a replacement of solid-fuel combustion in semi-rural and remote areas. *Science of The Total Environment,* 740**,** 140078.

AN, R., YU, B., LI, R. & WEI, Y.-M. 2018. Potential of energy savings and CO2 emission reduction in China's iron and steel industry. *Applied Energy,* 226**,** 862-880.

AVIS, W. M., S. & SINGH, A. 2018. Air Pollution Exposure in Low Income Households in Kampala. *ASAPEast Africa Vulnerability Scoping Study no. 6. .* Birmingham, UK: University of Birmingham.

BEDDOWS, D. C. S. & HARRISON, R. M. 2021. PM10 and PM2.5 emission factors for non-exhaust particles from road vehicles: Dependence upon vehicle mass and implications for battery electric vehicles. *Atmospheric Environment,* 244**,** 117886.

CHANCEL, L. 2020. *Unsustainable Inequalities: Social Justice and Environment*, Harvard University Press.

CRIMMINS, A., J. BALBUS, J. L. GAMBLE, C.B. BEARD, J.E. BELL, D. DODGEN, R.J. EISEN, N. FANN, M. HAWKINS, S.C. HERRING, L. JANTARASAMI, D. M. MILLS, S. SAHA, M. C. SAROFIM, J. TRTANJ, AND L. ZISKA 2016. Executive Summary. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, . Washington, DC, .

DAWOOD, F., ANDA, M. & SHAFIULLAH, G. M. 2020. Hydrogen production for energy: An overview. *International Journal of Hydrogen Energy,* 45**,** 3847-3869.

EBADIAN, M., VAN DYK, S., MCMILLAN, J. D. & SADDLER, J. 2020. Biofuels policies that have encouraged their production and use: An international perspective. *Energy Policy,* 147**,** 111906.

FIORE, A. M., NAIK, V. & LEIBENSPERGER, E. M. 2015. Air Quality and Climate Connections. *Journal of the Air & Waste Management Association,* 65**,** 645-685.

GAHP, AIRQUALITYASIA & COLLEGE, T. S. I. F. I. S. A. S. A. B. 2020. Air Pollution Interventions: SEEKING THE INTERSECTION BETWEEN CLIMATE & HEALTH.

GALLAGHER, C. L. & HOLLOWAY, T. 2020. Integrating Air Quality and Public Health Benefits in U.S. Decarbonization Strategies. *Frontiers in Public Health,* 8.

HARJANNE, A. & KORHONEN, J. M. 2019. Abandoning the concept of renewable energy. *Energy policy,* 127**,** 330-340.

HENNIG, C., BROSOWSKI, A. & MAJER, S. 2016. Sustainable feedstock potential – a limitation for the bio-based economy? *Journal of Cleaner Production,* 123**,** 200-202.

IPCC The Intergovernmental Panel on Climate Change; https://www.ipcc.ch/.

LIN, W.-Y., HSIAO, M.-C., WU, P.-C., FU, J. S., LAI, L.-W. & LAI, H.-C. 2020. Analysis of air quality and health co-benefits regarding electric vehicle promotion coupled with power plant emissions. *Journal of Cleaner Production,* 247**,** 119152.

MEMON, F. & SHARJEEL, M. 2016. Catastrophic Effects of Floods on Environment and Health: Evidence from Pakistan. *Pakistan Journal of Engineering, Technology & Science,* 5.

MORAN, E. F., LOPEZ, M. C., MOORE, N., MÜLLER, N. & HYNDMAN, D. W. 2018. Sustainable hydropower in the 21st century. *Proceedings of the National Academy of Sciences,* 115**,** 11891-11898.

NEASPEC. *Transboundary Air Pollution* [Online]. North-East Asian Subregional Programme for Environmental Cooperation. Available: http://neaspec.org/our-work/transboundary-air-pollution [Accessed 10/2/2021 2021].

OUR WORLD IN DATA. 2020. *Energy Use Per Person* [Online]. Available: https://ourworldindata.org/grapher/per-capita-energy-use?tab=chart&time=earliest..latest&country=CHN~IND~KEN~TZA~GBR~USA&region=World [Accessed 2020].

REUTERS. 2021. Available: https://www.reuters.com/article/tesla-stocks-int-idUSKBN29D20B [Accessed].

SEKAR, A., WILLIAMS, E. & CHESTER, M. 2014. Siting Is a Constraint to Realize Environmental Benefits from Carbon Capture and Storage. *Environmental Science & Technology,* 48**,** 11705-11712.

SHEHAB, M. A. & POPE, F. D. 2019. Effects of short-term exposure to particulate matter air pollution on cognitive performance. *Scientific Reports,* 9**,** 8237.

WANG, J., WANG, R., ZHU, Y. & LI, J. 2018. Life cycle assessment and environmental cost accounting of coal-fired power generation in China. *Energy Policy,* 115**,** 374-384.

WHO https://www.who.int/nutrition/publications/reports/en/.

WHO 2016. Ambient air pollution: A global assessment of exposure and burden of disease Geneva, Switzerland: WHO.

WHO. 2018. *Household Air Pollution and Health* [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health [Accessed 24.1.2020 2020].

WORLD ENERGY COUNCIL 2020. World Energy Trilemma Index 2020 – ‘Used by permission of the World Energy Council. *In:* COUNCIL, W. E. (ed.). London, UK: World Energy Council.

ZHANG, Q., JIANG, X., TONG, D., DAVIS, S. J., ZHAO, H., GENG, G., FENG, T., ZHENG, B., LU, Z., STREETS, D. G., NI, R., BRAUER, M., VAN DONKELAAR, A., MARTIN, R. V., HUO, H., LIU, Z., PAN, D., KAN, H., YAN, Y., LIN, J., HE, K. & GUAN, D. 2017. Transboundary health impacts of transported global air pollution and international trade. *Nature,* 543**,** 705-709.

ZHAO, B., WANG, T., JIANG, Z., GU, Y., LIOU, K.-N., KALANDIYUR, N., GAO, Y. & ZHU, Y. 2019. Air Quality and Health Cobenefits of Different Deep Decarbonization Pathways in California. *Environmental Science & Technology,* 53**,** 7163-7171.

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