Quantifying the Economic Costs of Air Pollution from Fossil Fuels

Lauri Myllyvirta, Lead Analyst | 02/2020

Centre for Research on Energy and Clean Air

CREA is an independent research organisation focused on revealing the trends, causes, and health impacts, as well as the solutions to air pollution.

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Key messages

- First-of-a-kind assessment of the global economic cost of air pollution from fossil fuels, building on recent advances in research on the contribution of fossil fuel burning to air pollutant levels around the world and the health impacts of air pollution.
- The economic costs of air pollution from fossil fuels are estimated at US$2.9 trillion in 2018, or 3.3% of global GDP, far exceeding the likely costs of rapid reductions in fossil fuel use.
- An estimated 4.5 million people died in 2018 due to exposure to air pollution from fossil fuels. On average, each death was associated with a loss of 19 years of life.
- Fossil fuel PM2.5 pollution was responsible for 1.8 billion days of work absence, 4 million new cases of child asthma and 2 million preterm births, among other health impacts that affect healthcare costs, economic productivity and welfare.

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Results

This paper is the first to assess the global economic burden caused by air pollution from fossil fuels. It incorporates many recent first-of-a-kind findings, including the first study to assess the contribution of fossil fuels to global air pollution levels and health impacts, as well as novel research on the burden of asthma and diabetes linked to air pollution.

Air pollution affects the economy in a multitude of ways:

- Increased risk of diseases such as asthma, diabetes, stroke and chronic respiratory diseases causes reduced ability to work, lowers labor participation and increases health care costs. Air pollution also increases the risk of complications from these diseases for people with existing conditions.
- For children, increased asthma attacks and sickness days affect learning results at school, increase healthcare costs and often force their caretakers to take time off work.
- Preterm births linked to air pollution exposure increase healthcare costs and risks of numerous health conditions throughout the lives of the affected babies.
- Increased risk of respiratory infections and other minor illnesses in adults increases work absence.

Both the magnitude of these health impacts and their economic costs are assessed globally for the first time in this paper, building on pioneering studies done in recent years.

Key results on the health impacts of fossil fuel pollution:

- An estimated 4.5 million people died in 2018 due to exposure to air pollution from fossil fuels (confidence range 3.2 to 6.2 million). Some 3.0 million deaths are attributed to PM2.5 pollution, 990,000 to ozone pollution and 500,000 to NO2 pollution. On average, each death was associated with a loss of 19 years of life.
- Approximately 40,000 children died before their 5th birthday because of exposure to PM2.5 pollution from fossil fuels.
- NO2 pollution from fossil fuels is linked to roughly 4 million new cases of asthma in children each year, with approximately 16 million children worldwide living with asthma as a result. Exposure to PM2.5 and ozone from fossil fuels is attributed to roughly 7.7 million asthma-related trips to the emergency room each year.
- Fossil fuel PM2.5 pollution was responsible for 1.8 billion days of work absence.

- Exposure of pregnant women to PM2.5 increases the risk of preterm birth, resulting in an estimated 2.0 million premature deaths per year attributed to fossil fuel pollution.
- Tens of millions of people are living with disabilities related to diabetes, stroke and chronic respiratory diseases due to exposure to air pollution from fossil fuels. Besides serious impacts on the quality of life of the affected people, these disabilities impose costs on healthcare systems and reduce labor participation and labor productivity.

Key results on economic costs:

- Disability from chronic diseases: US$200 billion
- Asthma: $17 billion
- Preterm births: $90 billion
- Sick leaves: $100 billion
- Child deaths: $50 billion
- Adult deaths: $2,400 billion

Total costs are estimated at 2.9 trillion USD, or 3.3% of global GDP, in 2018.

The costs as a percentage of GDP are highest in countries with high levels of air pollution and high incidence of and death rates from chronic diseases - this is the reason that several countries in Central and Eastern Europe and Balkans have even higher costs than India and Bangladesh, with higher pollution levels.

Highest costs in dollars per capita are registered in countries that, in addition, have a high level of income.

These costs show the increase in economic productivity and welfare that can be achieved by eliminating air pollutant emissions from fossil fuel use - gains that are likely to far exceed the costs of such a transition, given the increasing cost competitiveness of clean energy.

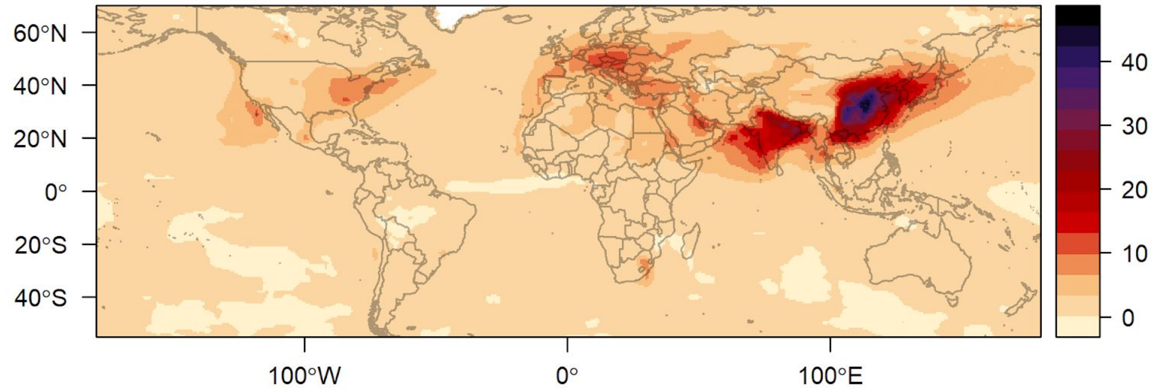
Highest costs per capita by country/region (US$)

Luxembourg	2600
United States	1900
Switzerland	1900
Austria	1700
Germany	1700
Netherlands	1200
Denmark	1200
Norway	1100
Belgium	1100
South Korea	1100
Canada	1100
Czech Republic	1000
Italy	1000
United Kingdom	1000
Japan	1000
Hungary	1000
Slovak Republic	900
Slovenia	900
France	800
Lithuania	800
Ireland	800

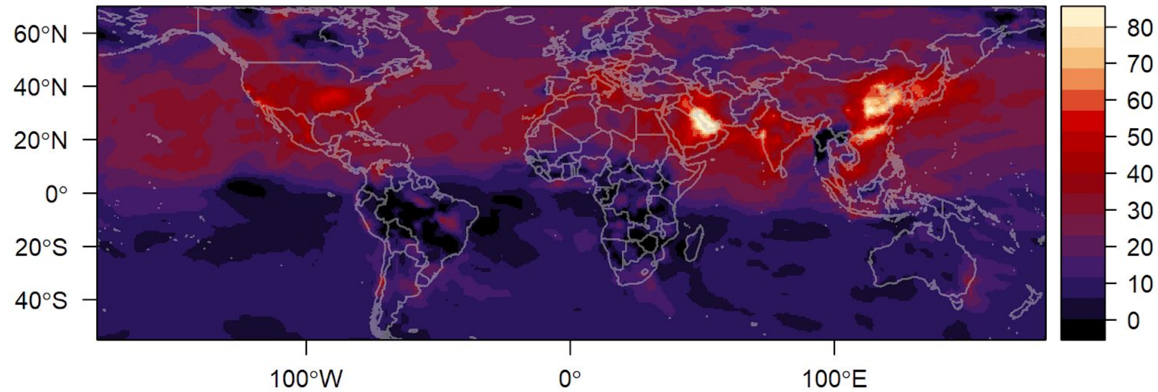
Highest cost as % of GDP by country/region

China Mainland	6.6%
Bulgaria	6.0%
Hungary	6.0%
Ukraine	5.8%
Serbia	5.8%
Belarus	5.4%
India	5.4%
Romania	5.3%
Bangladesh	5.1%
Moldova	5.0%
Poland	4.9%
Slovak Republic	4.8%
Bosnia and Herzegovina	4.6%
Czech Republic	4.5%
Croatia	4.4%
Lithuania	4.2%
Russian Federation	4.1%
North Macedonia	4.1%
Georgia	4.0%
Montenegro	3.8%
Latvia	3.6%
Germany	3.5%
Kosovo	3.4%
Slovenia	3.4%
South Korea	3.4%

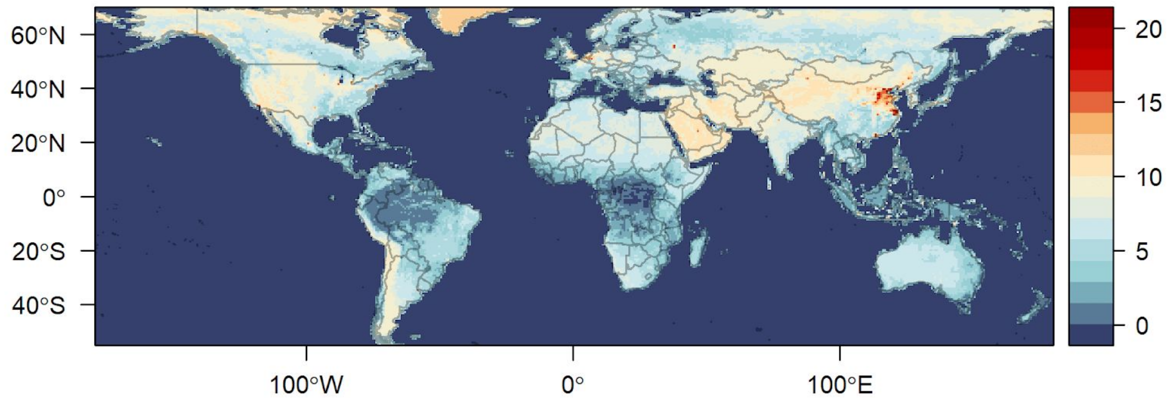
Annual average PM2.5 levels attributed to fossil fuels (ug/m3)



Summertime average ozone levels attributed to fossil fuels (ppb)



Annual average NO2 levels attributed to fossil fuels (ppb)



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Methodology

Exposure to air pollution from fossil fuels

The concentrations of PM2.5 and ozone linked to fossil fuel emissions in 2015 were estimated globally by Lelieveld et al (2019). Larkin et al (2017) built the first high-resolution global map of NO2 pollution levels, for the year 2011. These datasets are adjusted to 2018 situation using satellite-based aerosol measurements from NASA MODIS and NO2 measurements from the NASA OMI instrument; ozone levels are not adjusted. All concentration data was validated against measurements in official air quality stations in China, India, European Union and the U.S.

Importantly, these adjustments capture the avoided health costs due to dramatic air quality improvements in China; our estimate of premature deaths from fossil fuel PM2.5 in China in 2018 is approximately 1/4 lower than Lelieveld et al estimated for 2015. Population, health and economic datasets used for the research are updated to the latest available data, generally 2017-2018.

For NO2, it is assumed that concentrations above the no-harm thresholds used in different studies are linked to fossil fuels, as NOx emissions are heavily dominated by fossil fuels globally, and particularly in cities where the majority of the exposure above the thresholds takes place.

Health impacts and costs

Adult deaths and years of life lost from PM2.5 exposure were estimated using the same risk functions as Lelieveld et al (2019), developed by Burnett et al (2018). For deaths from chronic obstructive pulmonary diseases linked to ozone exposure, the updated risk function used in Malley et al (2017) was used. Deaths from long-term NO2 exposure were quantified following the recommendations from the WHO HRAPIE project (WHO 2013).

Deaths of small children from lower respiratory infections linked to PM2.5 pollution from fossil fuels was assessed using the PM2.5 concentration results from Lelieveld et al (2019) and the Global Burden of Disease risk function for lower respiratory diseases (GBD 2017).

For all mortality results, the required country-specific data on baseline death rates and years of life lost was taken from the Global Burden of Disease project results for 2017 (GBD 2017).

The economic losses from these air pollution related deaths were assessed based on the resulting reduction in life expectancy, with one year of life lost valued at EUR56,000 ($69,400 at 2005 exchange rate) in the European Union, following the EEA (2014) cost-benefit methodology, and adjusted by purchasing power adjusted Gross National Income (GNI PPP) for other countries, with an elasticity of 0.9 as recommended by OECD (2012).

Millions of people around the world are living with diabetes and chronic respiratory diseases, and disabilities caused by stroke, because of exposure to fossil fuel pollution. Air pollution both increases the risk of developing these diseases, and increases the complications from them. These diseases significantly lower the quality of life and economic productivity of people affected, and cause substantial healthcare costs. The Global Burden of Disease project has quantified the degree of disability caused by each disease into a “disability weight” that can be used to compare the costs of different illnesses. The economic cost of disability and reduced quality of life caused by diabetes and chronic bronchitis is assessed based on these disability weights, combined with the economic valuation of disability used by the UK environmental regulator DEFRA (Birchby et al 2019), and adjusted by GNI PPP for other countries. For example, type 2 diabetes without complications has a disability weight of 4.9%, meaning that the cost of one year lived with diabetes is estimated at 4.9% of the cost of one year lived with disability, or $4000 in the UK and $1600 at world average income level.

The economic cost of asthma related to fossil fuel pollution was assessed based on two indicators: new cases of asthma linked to NO2 exposure and emergency room visits related to PM2.5 and ozone exposure. NO2 pollution is linked to the annual occurrence of 4 million new cases of asthma in children worldwide (Achakulwisut et al 2019). Incidence and prevalence of asthma in children was taken from Global Burden of Disease (2017).

The economic cost of new asthma cases was estimated assuming that an increase there means an equal increase in the prevalence of childhood asthma - logically, each existing case of asthma is the result of a new case of asthma. This resulted in the assumption that a new case of child asthma results in four years lived with childhood asthma, on global average basis. Brandt et al (2012) assessed the direct and indirect cost per year associated with childhood asthma, including medical costs and loss of income to the child’s caregiver, estimating a cost of $3800 and $4000 in two different communities in California. The midpoints of these two valuations is used for the estimates, adjusted by the ratio of California’s Gross Regional Product to U.S. national average, and by GNI PPP for other countries.

Exposure to PM2.5 is very likely linked to an even larger number of new asthma cases globally than exposure to NO2, but uncertainty in the estimates is large (Anenberg et al 2018), so this effect is not included. Instead, we include the economic cost of emergency room visits for asthma linked to PM2.5 and ozone exposure, which is only a small part of the overall cost of the burden of asthma linked to PM2.5. Exposure to PM2.5 from fossil fuels was linked to an estimated 2.7 million emergency room visits due to asthma in 2015, and exposure to ozone linked to fossil fuels to 5.0 million visits, based on CREA analysis of data from Anenberg et al (2018) on asthma emergency room visits per year by country, and Lelieveld et al (2019) concentration results. We estimate the cost of these visits based on costs reported by Brandt et al in California, with the cost per visit for each country in the world adjusted to GDP PPP.

PM2.5 exposure to pregnant women increases the likelihood of preterm birth and low birth weight, which in turn increase the risk of many health and development issues throughout the baby's life. Approximately 2.0 million preterm births per year can be attributed to the exposure of pregnant women to PM2.5 pollution from fossil fuels specifically, based on CREA analysis using the Lelieveld et al (2019) concentration results, the concentration-response relationship in Trasande et al (2016) and a WHO-funded study of the rates of preterm birth in different countries globally (Chawanpaiboon et al 2019).

A U.S. study (Trasande et al 2016) estimated the economic costs of a preterm birth, primarily lower economic productivity and increased health care costs, at $300,000 per birth. This valuation is used globally, adjusted using GDP PPP for each country.

Exposure to PM2.5 air pollution from fossil fuels leads to increased sick leaves (work absence), causing an estimated 500 million days of sick leave annually, estimated based on the WHO HRAPIE (2013) recommendations. The economic cost of these sick leaves is evaluated at EUR130 per day ($160 at 2005 exchange rate) in the European Union, based on EEA (2014). This value is taken to represent the valuation at EU average GDP per capita, and adjusted for each country based on GDP PPP.

Data on total population and population age structure by country was taken from Global Burden of Disease results for 2017 (GBD 2017); data on GDP and GNI per capita in international dollars (PPP-adjusted), current US dollars and in local currency in 2018 was obtained from World Bank (undated). The spatial distribution of population within each country was based on Gridded Population of the World v4 (CIESIN 2018).

Each cost was converted to purchasing power adjusted international dollars at 2011 prices, and then the unit cost in each country was calculated based on country-specific GDP or GNI as indicated. Results were then converted to current US dollars and to local currency. Impacts related to productivity were adjusted by GDP, while ones related to income or welfare loss were adjusted by GNI.

All analysis was carried out in the R data analysis software, in a global spatial grid with 0.25x0.25 degree resolution (approx. 28km at the equator), with health impacts calculated for each grid cell. All datasets were aggregated or interpolated to this resolution as required. For NO2, the original Larkin et al (2017) dataset is at 100x100 meter resolution and exhibits a lot of variation at fine scale. The dataset was first averaged to a resolution of 800x800 meters, approximately the resolution of the spatial population dataset (CIESIN 2018), and then population-weighted averages above each of the no-risk thresholds shown in Table 1 were calculated for each grid cell - this approach preserves population exposure above the threshold in parts of the grid cells in which the average concentration for the entire grid cell is below the threshold.

Table 1: Input parameters and data used in estimating physical health impacts.

Age group	Effect	Pollutant	Concentration-response function	Concentration change	No-risk threshold	Reference	Incidence data
1-18	New asthma cases	NO2	1.26 (1.10 - 1.37)	10 ppb	2 ppb	Achakulwisut et al 2019	Achakulwisut et al 2019
0-17	Asthma emergency room visits	PM2.5	1.03 (1.01–1.04)	10 ug/m3	6 ug/m3	Zheng 2015	Anenberg et al 2018
0-17	Asthma emergency room visits	O3	1.02 (1.01–1.02)	10 ppb	2 ppb	Zheng 2015	Anenberg et al 2018
18-99	Asthma emergency room visits	PM2.5	1.02 (1.02–1.03)	10 ug/m3	6 ug/m3	Zheng 2015	Anenberg et al 2018
18-99	Asthma emergency room visits	O3	1.02 (1.01–1.02)	10 ppb	2 ppb	Zheng 2015	Anenberg et al 2018
Newborn	Preterm birth	PM2.5	1.15 (1.07, 1.16)	10 ug/m3	8.8 ug/m3	Trasande et al 2016	Chawanpaiboon et al 2019
0-4	Deaths from lower respiratory infections	PM2.5	GBD 2017		5.8 ug/m3	GBD 2017	GBD 2017
25-99	Deaths from non-communicable diseases	PM2.5	Burnett et al 2018		2.4 ug/m3	Burnett et al 2018	GBD 2017
30-99	Deaths from chronic obstructive pulmonary disease	O3	1.12 (1.08, 1.16)	10 ppb	35 ppb	Malley et al 2017	GBD 2017
25-99	Disability caused by diabetes, stroke and chronic respiratory disease	PM2.5	GBD 2017		2.4 ug/m3	Burnett et al 2018	GBD 2017
30-99	Premature deaths	NO2	1.037 (1.021-1.080)	10 ug/m3	20 ug/m3	WHO HRAPIE 2013	GBD 2017

Numeric values in the column "Concentration-response function" refer to relative risk corresponding to the increase in concentrations given in the column "concentration change". Literature references indicate the use of a non-linear concentration-response function. No-harm threshold refers to a concentration below which the health impact is not quantified, generally due to lack of evidence in the studies on which the function is based on.

Table 2. Economic cost of different health outcomes.

Effect	Valuation	Currency	Unit	Year	Source	Adjustment	Reference income level	GDP/GNI Elasticity
Year lived with childhood asthma	3,914	USD	year	2010	Brandt et al 2012	GDP PPP	California	1.0
Asthma emergency room visits	844	USD	visit	2010	Brandt et al 2012	GDP PPP	California	1.0
Preterm birth	321989	USD	birth	2010	Trasande et al 2016	GDP PPP	U.S.	1.0
Disability	62,800	GBP	year lived with disability	2018	Birchby 2019	GNI PPP	UK	1.0
Premature deaths	56,000	EUR	lost life year	2005	EEA 2014	GNI PPP	EU	0.9
Work absence	130	EUR	work day	2005	EEA 2014	GDP PPP	EU	1.0

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