

MORTALITY, MORBIDITY AND WELFARE COST FROM EXPOSURE TO ENVIRONMENT-RELATED RISKS

Dataset documentation

Data on mortality and DALYs from exposure to environment-related risks are taken from GBD (2019), *Global Burden of Disease Study 2019 Results*.¹ Welfare costs are calculated using a methodology adapted from OECD (2017b), *The Rising Cost of Ambient Air Pollution thus far in the 21st Century: Results from the BRIICS and the OECD Countries*.

For further details, please consult:

Dataset documentation

GBD (2019), “Global Burden of Disease Study 2019 Results”, Institute for Health Metrics and Evaluation, Seattle, United States, <http://ghdx.healthdata.org/gbd-results-tool>

GBD 2019 Risk Factor Collaborators (2020). “Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019”, *The Lancet*, Volume 396, Issue 10258, Pages 1223-1249. [https://doi.org/10.1016/S0140-6736\(20\)30752-2](https://doi.org/10.1016/S0140-6736(20)30752-2)
Online appendix 1 <https://ars.els-cdn.com/content/image/1-s2.0-S0140673620307522-mmc1.pdf>

OECD (2017a), *Green Growth Indicators 2017*, OECD Publishing, Paris. <http://dx.doi.org/10.1787/9789264268586-en>; See also <http://oe.cd/ggi2017>

OECD (2017b), *The Rising Cost of Ambient Air Pollution thus far in the 21st Century: Results from the BRIICS and the OECD Countries*, OECD Publishing, Paris. <http://dx.doi.org/10.1787/d1b2b844-en>

OECD (2012), *Mortality Risk Valuation in Environment, Health and Transport Policies*, OECD Publishing, Paris, <https://doi.org/10.1787/9789264130807-en>.

Last update: December 2020.

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¹ Data on mortalities are downloaded directly from the GHDx (<http://ghdx.healthdata.org/gbd-results-tool>). As indicated by the source database, these can be used, shared, modified, or built upon by non-commercial users via the Open Data Commons Attribution License. For more information, visit [IHME Terms and Conditions](#).

ENVIRONMENT-RELATED RISKS

Air pollution

Ambient particulate matter (PM_{2.5})

According to the World Health Organisation (WHO), exposure to fine particulate matter (PM_{2.5}) has potentially the most significant adverse effects on health compared to other air pollutants. Particulate matter (PM_{2.5}) can be inhaled and cause serious health problems including both respiratory and cardiovascular disease, having its most severe effects on children and elderly people. Exposure to PM_{2.5} has been shown to considerably increase the risk of heart disease and stroke in particular.

Exposure to **ambient particulate matter** is estimated by the GBD team by combining satellite data with a chemical transport model, land use information, and calibrated using ground measurements. An integrated exposure-response curve is used to calculate a relative risk for exposure to particulate matter from both ambient and residential (household) sources, and these are then weighted by the proportion of individuals exposed to each source. The method is described in detail in the technical appendix 1 of GBD 2019 Risk Factor Collaborators (2020).

Household air pollution from solid fuels

According to the World Health Organization (WHO), around 3 billion people still cook using solid fuels (such as wood, crop waste, charcoal, coal and dung) and kerosene in open fires and inefficient stoves. These cooking practices are inefficient, and use fuels and technologies that produce high levels of household air pollution with a range of health-damaging pollutants, including small soot particles that penetrate deep into the lungs. In poorly ventilated dwellings, indoor smoke can be 100 times higher than acceptable levels for fine particles.

Exposure to **household air pollution from solid fuels** is estimated based on the proportion of households using solid cooking fuels. The definition of solid fuel includes coal, wood, charcoal, dung, and agricultural residues. Data were extracted from multi-country survey series as well as country-specific survey series, covering more than 195 countries. Each nationally or sub-nationally representative data point provided an estimate for the percentage of households using solid cooking fuels. Estimates for the usage of solid fuels for non-cooking purpose were excluded, i.e. primary fuels for lighting. An integrated exposure-response curve is used to calculate a relative risk for exposure to particulate matter from both ambient and residential (household) sources.

Ozone (O₃)

Ambient (or ground-level) ozone (O₃) has serious consequences for human health, contributing to, or triggering, respiratory diseases. These include breathing problems, asthma and reduced lung function (WHO). Ozone exposure is highest in emission-dense countries with warm and sunny summers. The most important determinants are background atmospheric chemistry, climate, anthropogenic and biogenic emissions of ozone precursors such as volatile organic compounds, and the ratios between different emitted chemicals.

Exposure to **ambient ozone** is defined as the seasonal (6-month period with highest mean) 8-hour daily maximum ozone concentrations, measured in ppb. Exposure estimates by the GBD team

incorporate a comprehensive ozone measurement database enabling a continent-specific weighted blend of six chemical transport models, and the calibration with ground measurements.

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Climate

High and low temperature

Ambient temperature affects human health in various ways. There is substantial epidemiologic evidence of increased risk of mortality from high or low non-optimal ambient temperatures or extreme temperature events. Non-optimal temperatures have been associated, among other causes, with ischaemic heart disease, stroke, hypertensive heart disease, diabetes, respiratory infections and obstructive pulmonary diseases. In addition, extreme weather events such as heat waves, droughts or polar vortex are expected to be more frequent and intense under climate change, with significant associated health impacts.

Exposure to **high and low temperature** is estimated by the GBD team combining *ERA5 climate reanalysis* data with gridded population data. An integrated exposure-response meta-analysis model is used to calculate a relative mortality risk for exposure to average daily temperatures and temperature zones. The GBD study performs a systematic assessment of risk across the whole temperature range (i.e. including moderate non-optimal temperatures) in populations exposed to different climates. The method is described in detail in the technical appendix 1 of GBD 2019 Risk Factor Collaborators (2020).

Other environmental risks

Lead (Pb)

Lead (Pb) is a toxic metal found in the Earth's crust. Its widespread use has resulted in extensive environmental contamination, human exposure and significant public health problems in many parts of the world. Important sources of environmental contamination include mining, smelting, manufacturing, recycling activities and the continued use of leaded paint, gasoline, and aviation fuel in some countries. More than three quarters of global lead consumption is for the manufacture of lead-acid batteries for motor vehicles however lead is also used in many other products like pigments, paints, solder, stained glass, lead crystal glassware, ammunition, ceramic glazes, jewellery, toys and in

some cosmetics and traditional medicines. Drinking water delivered through lead pipes or pipes joined with lead solder may contain lead. Much of the lead in global commerce is now obtained from recycling.

Young children are particularly vulnerable to the toxic effects of lead and can suffer profound and permanent adverse health effects, particularly affecting the development of the brain and nervous system. Lead also causes long-term harm in adults, including increased risk of high blood pressure and kidney damage. Exposure of pregnant women to high levels of lead can cause miscarriage, stillbirth, premature birth and low birth weight.

Exposure to **lead** is defined in two different ways according to the currently known pathways of health loss. Acute lead exposure, relevant to disease burden through IQ loss in children, is measured as the micrograms of lead per decilitre of blood ($\mu\text{g}/\text{dL}$). Long-term lead exposure, relevant to disease burden in adults given the manifestation of health impact through increased systolic blood pressure and hence a decline of cardiovascular health, is measured as the accumulation of lead in the bone as micrograms of lead per gram of bone ($\mu\text{g}/\text{g}$). GBD's input data for lead exposure is primarily extracted from literature regarding blood lead, in addition to a few blood lead surveys. Blood lead values are derived from a literature review. The pathway of burden related to bone lead exposure was estimated by calculating a cumulative blood lead index using estimated blood lead over their lifetime. Relative risk estimates for blood lead and bone lead are taken from pooled and meta-analysis.

Radon (Rn)

Radon (Rn) is a radioactive gas that is produced as a by-product of the decay chain of uranium, occurring naturally within the Earth's crust. Some fraction of this natural radon production escapes into the atmosphere, where it forms at low concentration unless build-up is caused by enclosed spaces like homes, mines, or caves. Soil gas infiltration is recognized as the most important source of residential radon. Other sources, including building materials and water extracted from wells, are of less importance in most circumstances. Radon is a major contributor to the ionizing radiation dose received by the general population, and is the second cause of lung cancer, after smoking. Epidemiological studies have provided convincing evidence of an association between indoor radon exposure and lung cancer, even at the relatively low radon levels commonly found in residential buildings.

Exposure to **residential radon** is expressed as average daily exposure to indoor air radon gas levels measured in Becquerels (disintegrations per second) per cubic meter (Bq/m^3). Exposure to radon is then determined using values validated by an expert group of the GBD team. These values are taken from the literature, government agencies, and monitoring stations. The relative risk of radon is extracted from a meta-analysis of case-control studies showing the association of residential radon with lung cancer.

Unsafe water, sanitation and handwashing

Safe and readily available water is important for public health, whether it is used for drinking, domestic use, food production or recreational purposes. Improved water supply and sanitation and better management of water resources can result in better health, particularly for children, resulting in better long-term consequences for their lives, it can also boost countries' economic growth and can contribute greatly to poverty reduction. Contaminated water and poor sanitation are linked to transmission of diseases such as cholera, diarrhoea, dysentery, hepatitis A, typhoid, and polio. Absent, inadequate, or inappropriately managed water and sanitation services expose individuals to preventable health risks.

Unsafe water source

Unsafe water source is defined based on reported primary water source used by the household and use of household water treatment to improve the quality of drinking water before consumption. Water sources are defined as improved based on the *WHO-UNICEF joint monitoring programme of improved and unimproved water sources and sanitation facilities*, which includes piped water as improved water, and households with access to piped water connection to the house, yard, or plot were defined as having access to piped water supply. Solar treatment, chlorine treatment, boiling, or the use of filters are all established by the *joint monitoring programme* as effective point-of-use household water treatments based on effect sizes calculated from network meta-analysis.

Exposure to **unsafe water sources** is expressed as the proportion of individuals with unimproved water source prevalence or household water treatment. Water source data and household water treatment data include country-specific demographic health surveys and malaria indicator survey series, validated by the GBD team of experts.

Unsafe sanitation

Unsafe sanitation is defined based on the primary toilet type used by households. Improved facilities are defined based on the *WHO-UNICEF joint monitoring programme of improved and unimproved water sources and sanitation facilities*, which includes flush toilets or any toilet with connection to the sewer or septic tank.

Exposure to **unsafe sanitation** is expressed as the proportion of individuals without sewer connection or improved sanitation. Improved sanitation facilities and sewer connection data is obtained from censuses and nationally representative surveys, validated by the GBD team of experts.

No access to handwashing facility

Unsafe handwashing facility is defined based on the availability of a handwashing station with soap and water. **No access to handwashing facility** is expressed as the proportion of individuals without sewer connection or improved sanitation. Improved sanitation facilities and sewer connection data is obtained from country-specific censuses, demographic health surveys and malaria indicator survey series, validated by the GBD team of experts.

Environment-related occupational risks

Occupational carcinogens

Occupational carcinogens include arsenic, benzene, beryllium, cadmium, chromium, diesel engine exhaust, formaldehyde, nickel, polycyclic aromatic hydrocarbons, silica, sulphuric acid, and trichloroethylene. Exposure to these agents causes a wide range of cancers; cancers of the lung and other respiratory sites, followed by skin, account for the largest proportion. The dominant routes of exposure are inhalation and dermal contact.

Exposure to **occupational carcinogens** is expressed as the proportion of the population that is occupationally exposed to carcinogens at high or low exposure levels, based on distributions of occupation across economic activities. Data on economic activity proportions, occupation proportions, employment to population ratio estimates are obtained from the International Labour Organization. Exposure rates are provided by expert group recommendations, literature, and a modelling of prevalence of exposure developed by the GBD team.

Occupational particulate matter, gases and fumes

Exposure to particulate matter, gases and fumes has significant adverse effects on health. Particulate matter can be inhaled and cause serious health problems including both respiratory and cardiovascular disease. Exposure to these occupational risks has been shown to considerably increase the risk of heart disease and stroke in particular.

Exposure to **occupational particulate matter, gases and fumes** is expressed as the proportion of the population that is occupationally exposed to particulates, based on distributions of occupation across economic activities. Data on economic activity proportions, occupation proportions, employment to population ratio estimates are obtained from the International Labour Organization. Exposure rates are provided by expert group recommendations, literature, and a modelling of prevalence of exposure developed by the GBD team.

Occupational noise

Excessive noise seriously harms human health. It can disturb sleep, cause cardiovascular and psychophysiological effects, reduce performance, and provoke annoyance responses and changes in social behaviour.

Exposure to **occupational noise** is expressed as the proportion of the population occupationally exposed to 85+ decibels of noise, based on population distributions across seventeen economic activities. Data on economic activity proportions, occupation proportions, employment to population ratio estimates are obtained from the International Labour Organization. Exposure rates are provided by expert group recommendations, literature, and a modelling of prevalence of exposure developed by the GBD team.

Environment-related behavioural risks

Second-hand smoke

Second-hand smoke is one of the most important and most widespread exposures in the indoor environment. The link between second-hand smoke and several health outcomes, such as respiratory infections, ischaemic heart disease, lung cancer and asthma, have long been established. Smoke-free health regulations in public places, including all indoor workplaces, protects people from the harms of second-hand smoke, helps smokers quit and reduces youth smoking.

Exposure to **second-hand smoke** is expressed as the proportion of the population exposed to second-hand smoke at home, work or in other public places. Household surveys are used to study the household composition as a proxy for non-occupational second-hand smoke exposure; all persons living with a daily smoker are assumed to be exposed to tobacco smoke. Surveys are used to estimate the proportion of individuals exposed to second-hand smoke at work. Only non-smokers are considered to be exposed to second-hand smoke. Non-smokers are defined as all persons who are not daily smokers (ex-smokers and occasional smokers are considered non-smokers) in the analysis done by the GBD team. Input survey data includes country-specific demographic health surveys, the multiple indicator cluster surveys, the living Standards Measurement Surveys, Global Adult Tobacco Surveys, Eurobarometer Surveys, and the World Health Organisation stepwise approach to surveillance survey.

Diet high in red meat

Eating meat has many known health benefits, however the WHO advise people to limit intake of processed meat and red meat, which are linked to increased risks of death from heart disease, diabetes, and other illnesses. In the case of red meat, according to the WHO's meta-analysis of epidemiological studies, there exist positive associations between eating red meat and developing colorectal cancer. There is also evidence of links with pancreatic cancer and prostate cancer. The lowest level of consumption of red meat at which the risks of mortality have been observed is of 18-27 gr/day.

In addition to the impact that a diet high in red meat has on human health, meat consumption has an important burden for the environment. The production, processing and distribution of meat leads to land use changes, increased freshwater use, water pollution, air pollution and emissions of greenhouse gases. Among the range of animal products, red meat has potentially the highest impact on the environment, however, even the lowest-level impact animal products typically exceed those of vegetable substitutes, raising the importance of a dietary change (Poore, J. and Nemecek, T., 2018²).

Exposure to **diet high in red meat** is defined as average daily consumption of greater than 22.5 grams per day of red meat (beef, veal, pork, lamb, mutton, horse, and goat but excluding poultry, fish, eggs, and all processed meats). Dietary data used to calculate exposure includes nationally and sub-

² Poore, J. and Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. *Science*, 360(6392), pp.987-992.

nationally representative nutrition surveys, household budget surveys, accounts of national sales, and United Nations FAO Food Balance Sheets and Supply and Utilization Accounts.

Diet high in processed meat

Eating meat has many known health benefits, however the WHO advise people to limit intake of processed meat and red meat, which are linked to increased risks of death from heart disease, diabetes, and other illnesses. In the case of processed meat³, according to the WHO, there is sufficient evidence from epidemiological studies that eating processed meat causes colorectal cancer. An association with stomach cancer was also seen, but the evidence is not conclusive. The lowest level of consumption of processed meat at which the risks of mortality have been observed is of 0-4 gr/day.

In addition to the impact that a diet high in red meat has on human health, meat consumption has an important burden for the environment. The production, processing and distribution of meat leads to land use changes, increased freshwater use, water pollution, air pollution and emissions of greenhouse gases. Among the range of animal products, red meat (used in most processed meats) has potentially the highest impact on the environment, however, even the lowest-level impact animal products typically exceed those of vegetable substitutes, raising the importance of a dietary change (Poore, J. and Nemecek, T., 2018).

Exposure to **diet high in processed meat** is defined as average daily consumption of greater than 2 grams of meat preserved by smoking, curing, salting, or addition of chemical preservatives. Dietary data used to calculate exposure includes nationally and sub-nationally representative nutrition surveys, household budget surveys, accounts of national sales, and United Nations FAO Food Balance Sheets and Supply and Utilization Accounts.

³ Processed meat refers to meat that has been transformed through salting, curing, fermentation, smoking, or other processes to enhance flavour or improve preservation. Most processed meats contain pork or beef, but processed meats may also contain other red meats, poultry, offal, or meat by-products such as blood. Examples of processed meat include hot dogs (frankfurters), ham, sausages, corned beef, and biltong or beef jerky as well as canned meat and meat-based preparations and sauces.

MORTALITY, MORBIDITY AND WELFARE COSTS

Health impacts and welfare costs from exposure to environment-related risks are reported separately for each risk, and split by sex (female, male) and age groups (less than 15, 15-64 and more than 64 years old) as:

Premature deaths: calculated as the number of premature deaths attributed to exposure to environment-related risks, expressed in absolute value, per million inhabitants of the same age group and sex (mortality), and as a percentage of total attributable premature deaths. Total attributable premature deaths include premature deaths due to environmental and occupational risks, behavioural risks and metabolic risks.

DALYs: Disability-adjusted life years (DALYs) are calculated as the number of years lost due to exposure to environment-related risks, expressed in absolute value, per 1000 inhabitants of the same age group and sex, and as a percentage of total attributable DALYs. DALYs are defined as the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability (morbidity). Total attributable DALYs include DALYs due to environmental and occupational risks, behavioural risks and metabolic risks.

Welfare cost: Welfare costs of premature deaths from exposure to environment-related risks are expressed in millions constant 2015 USD using PPP, compared to GDP as percentage points of GDP equivalent, per capita (total population across age groups and sex), and as a percentage of the welfare cost of total attributable premature deaths.

Cost estimates represent only the cost of premature mortalities. They are calculated using estimates of the “Value of a Statistical Life” (VSL) and the number of premature deaths attributable to each environmental risk. They exclude any morbidity impacts (labour productivity losses, treatment costs and willingness to pay to avoid pain and suffering from illness). They also exclude impacts other than those on human health (e.g. on built structures, agricultural productivity, ecosystem health). The social cost of the exposure to these environment-related risks is thus greater than the cost of mortalities presented in this chapter. Yet the available evidence suggests that mortality costs account for the bulk of the total costs to society. Finally, VSL also captures non-market values that are unrelated to expenditures and therefore not an integral part of the calculation of GDP. Consequently, the cost estimates are compared with GDP only for illustration.

Value of a statistical life: VSL is derived from aggregating individuals’ willingness-to-pay (WTP) to secure a marginal reduction in the risk of premature death. Therefore, the welfare cost is evaluated in terms of what the population at large would be “willing to pay” to avoid the mortalities due to exposure to environment-related risks.

OECD (2012) describes the process for deriving the VSL values from willingness-to-pay surveys. Moreover, it conducts a meta-analysis of VSLs with 1095 values from 92 published studies. This meta-analysis recommends a base value for the OECD of 3 million 2005 USD PPP for the year 2005. Country-specific VSL values for countries both within and outside the OECD are calculated using the methodology adapted from OECD (2017b). The OECD formula applied to any given country c , for any given year y , in 2005 USD PPP is calculated as follows:

$$\begin{aligned}
VSL_{c,y,constant\ 2005\ USD\ PPP} &= VSL_{OECD,2005,constant\ 2005\ USD\ PPP} \\
& * \left(\frac{GDP\ per\ capita_{c,2005,constant\ 2005\ USD\ PPP}}{GDP\ per\ capita_{OECD,2005,constant\ 2005\ USD\ PPP}} \right)^{\varepsilon_{c,y}} \\
& * (1 + \% \Delta GDP\ per\ capita_{c,y-2005,constant\ 2005\ USD\ PPP})^{\varepsilon_{c,y}}
\end{aligned}$$

- An OECD base value of USD 3 million in year 2005 as a starting point for the calculation.
- The calculation is in purchasing power parity (PPP)-adjusted USD estimates of per-capita GDP in each country relative to the OECD average per-capita GDP;
- The formula accounts for differences in income levels and income elasticities across countries. The income elasticity ε is 0.8 for high-, 0.9 for middle- and 1 for low-income countries. The classification follows the historical classification of countries by the World Bank.
- The income elasticity adjustment is applied not only to the 2005 level, but also to the real GDP per-capita growth over time.
- This formula allows the calculation of VSLs for groups of countries as a whole. This is done for the World total, assuming an income elasticity of 0.9. The VSLs for the remaining country groups are calculated by dividing the sum of the country welfare costs and the sum of premature mortalities.

The VSLs are converted to national currency, current prices and current dollars using the GDP deflator and PPP rates. They are also converted to millions 2015 USD PPP using the implicit conversion factor between $GDP_{c,y,constant\ 2005\ USD\ PPP}$ and $GDP_{c,y,constant\ 2015\ USD\ PPP}$. The VSL values are not a function of the environment-related risk studied; they are included and repeated across all dimensions (risks, sex and age groups) to facilitate the use of the dataset.

FLAGS

- B: Break in series
- C: Confidential
- E: Estimated
- I: Incomplete
- N: National estimate

NULL VALUES

Null values are either unknown or incalculable from the input data. Zero values are true zeros based on the input data.