STATE OF GLOBAL AIR /2018

A SPECIAL REPORT ON GLOBAL EXPOSURE TO AIR POLLUTION AND ITS DISEASE BURDEN

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The State of Global Air is a collaboration between the Health Effects Institute and the Institute for Health Metrics and Evaluation's Global Burden of Disease Project.

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What is the State of Global Air?

The State of Global Air report brings into one place the most recent information available on levels and trends in air quality and health for countries around the globe. This year we focus not only on ambient (outdoor) air pollution but also, for the first time, on household air pollution from the burning of solid fuels for cooking and heating, a major contributor to pollution both inside and outside the home.

Who is it for?

The report is designed to introduce citizens, journalists, policy makers, and scientists to efforts to estimate and track human exposure to outdoor and household air pollution and their impacts on health as part of the comprehensive Global Burden of Disease project.

How can I explore the data?

This report has a companion interactive website, which provides the tools to explore, compare, and download data tables and graphics with the latest outdoor and household air pollution levels and associated burden of disease. These data are available for individual countries and geographic and economic regions, as well as for highlighting trends from 1990 to 2016.

Where will I find information on:

INTRODUCTION

Studies from across the world have documented the many ways in which air pollution can affect people's health, including making it difficult to breathe for those with asthma or other respiratory diseases, sending the young and old to hospital or causing them to miss school or work, and contributing to early death from heart and lung disease. New studies continue to broaden our understanding of the wide range of effects that air pollution can have on human health.

This State of Global Air 2018 report presents the latest analysis of worldwide air pollution exposures and health impacts. It draws from the most recent evidence (produced in 2016) as part of the Global Burden of Disease (GBD) project of the Institute for Health Metrics and Evaluation (IHME) (published in 2017; see Additional Resources at the end of this report).

As it did last year, the report offers a global update on outdoor, or *ambient*, air pollution. The most recent GBD analysis has continued to identify ambient air pollution as one of the most important risk factors contributing to death and disability (see "Defining Ambient Air Pollution" textbox). Ambient particulate matter (particulate matter less than or equal to 2.5 micrometers in aerodynamic diameter, or $PM_{2.5}$), one component of air pollution, ranked as the 6th-highest risk factor for early death (see Figure 1). Worldwide exposure to $PM_{2.5}$ contributed to 4.1 million deaths from heart disease and stroke, lung cancer, chronic lung disease, and respiratory infections in 2016. $PM_{2.5}$ was responsible for a substantially larger number of attributable deaths than other more well-known risk factors (such as alcohol use, physical inactivity, or high sodium intake) and for an equivalent number of attributable deaths as high cholesterol and high body mass index. Ozone, another important component of outdoor air pollution, whose levels are on the rise around the world, contributed to 234,000 deaths from chronic lung disease.

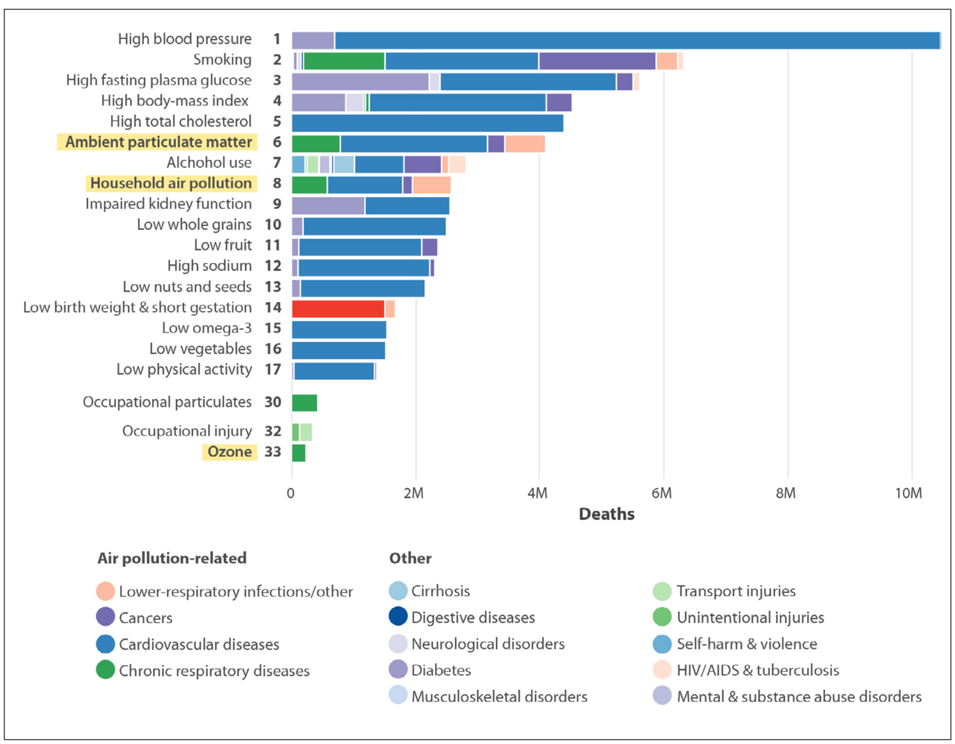
Fine particle air pollution is the largest environmental risk factor worldwide, responsible for a substantially larger number of attributable deaths than other more well-known behavioral risk factors such as alcohol use, physical inactivity, or high sodium intake.

However, the GBD initiative has also documented that millions of people around the world are exposed to air pollution in their homes arising from the use of solid fuels (e.g., coal, wood, and dung) for cooking and heating. The GBD 2016 analysis estimates that exposure to "household air pollution" also has a substantial impact on health and is ranked 8th in risk factors for early death, with 2.6 million attributable deaths in 2016. Both individually and collectively, ambient air pollution and household air pollution impose a substantial burden on public health.

To offer a more comprehensive perspective on air pollution, this year's State of Global Air 2018 provides additional data on:

- Household air pollution — global, regional, and country-level estimates of the proportion of populations exposed to household air pollution and of the public health burden attributable to these exposures, and

Figure 1. Global ranking of risk factors by total number of deaths from all causes for all ages and both sexes in 2016.



Explore the rankings further at the IHME/GBD Compare site.

- Total air pollution — global, regional, and country-level estimates of the total public health burden attributable to ambient air pollution ($PM_{2.5}$ and ozone) and to household air pollution.

This year's report also adds a discussion on the identification of the major sources of air pollution, focusing on recent work in both India and China, and the implications these sources have for the actions necessary to reduce emissions and ultimately public health burden from air pollution.

The State of Global Air website offers interactive features to explore and compare visually ambient, household, and total air pollution levels and their health impacts in individual countries and at the regional level around the world.

Defining Ambient Air Pollution

Air pollution is a complex mixture of gases and particles whose sources and composition vary spatially and temporally. While hundreds of different chemical compounds can be measured in air, governments typically measure only a small subset of gases and particles as indicators of the different types of air pollution and the different types of major sources contributing to the pollution. *$PM_{2.5}$* and *tropospheric ozone* (i.e., ozone found in the atmosphere nearest the earth, where we live and breathe) are the two indicators used to quantify exposure to outdoor, or *ambient*, air pollution in the GBD project.

$PM_{2.5}$, defined as fine particles with aerodynamic diameters less than or equal to 2.5 micrometers, is the most consistent and robust predictor of mortality from cardiovascular, respiratory, and other diseases in studies of long-term exposure to air pollution. *Long term* is defined by annual average exposures over several years. PM exposure is measured in micrograms per cubic meter (μg/m^3). Ozone, a harmful gas produced via the atmospheric reactions of precursor emissions, has itself been implicated in increases in mortality from respiratory disease. When describing exposures to ozone, scientists focus on seasonal, rather than annual, average concentrations because ozone levels are higher in the warm season in the mid-latitudes where most epidemiological studies have been conducted. Ozone exposure is measured in parts per billion (ppb). Exposure to each pollutant is represented by *population-weighted averages*, which take into account the proportions of the population living in areas with different levels of pollution.

How Are Ambient Air Pollution Levels Estimated Around the World?

Although many high-income countries around the world operate extensive networks of air quality monitoring stations in urban areas, providing continuous hourly measurements of pollution levels each day, this is not the case for most countries. These ground-level measurements of air quality have been the basis for most studies of the potential health effects of air pollution and air quality management. However, other approaches are needed to provide a consistent view of air pollution levels throughout the world, including in the many rapidly developing urban areas of low- and middle-income countries and in the large rural and suburban areas that lack any air quality monitoring stations. For these areas, scientists rely on air quality observations from satellites, combined with information from global chemical transport models and available ground measurements, to estimate global annual average exposure to $PM_{2.5}$ systematically, beginning in blocks, or grid cells, covering 0.1° × 0.1° of longitude and latitude (approximately 11 km × 11 km at the equator). Taking into account the population in each block within a country, scientists then aggregate the estimated exposure concentrations to national-level population-weighted averages for a given year. The GBD analysis was conducted in 2016 using data from 1990 to 2016, the most recent year for which the necessary data were available. For ozone, a global chemical transport model was used to calculate a seasonal (summer) average for each grid cell, while accounting for variation in the timing of the ozone season in different parts of the world. The process for estimating national-level population-weighted average ozone exposures was the same.

EXPOSURE TO AMBIENT AIR POLLUTION: LEVELS AND TRENDS

AMBIENT $PM_{2.5}$ CONCENTRATIONS AROUND THE WORLD

Ninety-five percent of the world's population lives in areas exceeding WHO Guideline for healthy air. Nearly 60% lives in areas that do not meet even the least-stringent air quality target from WHO.

Around the world, ambient levels of $PM_{2.5}$ continue to exceed the Air Quality Guideline established by the World Health Organization (WHO). WHO set the Air Quality Guideline for annual average $PM_{2.5}$ concentration at 10 µg/m^3 based on evidence of health effects of long-term exposure to $PM_{2.5}$ but acknowledged that it could not rule out health effects below that level. For regions of the world where air pollution is highest, WHO suggested three interim targets set at progressively lower concentrations: 35 µg/m^3, 25 µg/m^3, and 15 µg/m^3. Figure 2 shows where these guidelines were still exceeded in 2016.

Based on these data and knowledge of the populations in each country for 2016, 95% of the world's population lived in areas that exceeded the WHO Guideline for $PM_{2.5}$. Fifty-eight percent of the global population resided in areas with $PM_{2.5}$ concentrations above the WHO Interim Target 1 (IT-1, 35 µg/m^3); 69% lived in areas exceeding IT-2 (25 µg/m^3), and 85% lived in areas exceeding IT-3 (15 µg/m^3).

The highest concentrations of population-weighted annual average $PM_{2.5}$ (see "Defining Ambient Air Pollution" textbox) in 2016 were in countries in North Africa (e.g., Niger at 204 µg/m^3 and Egypt at 126 µg/m^3), West Africa (e.g., Cameroon at 140 µg/m^3 and Nigeria at 122 µg/m^3), and in the Middle East (e.g., Saudi Arabia at 188 µg/m^3 and Qatar at 148 µg/m^3). The high outdoor concentrations in these regions were due mainly to windblown mineral dust. However, in some of these countries (Niger, Nigeria, and Cameroon), high proportions of the population burn solid fuels in the home and may also engage in open burning of agricultural lands or forests, both of which can also contribute substantially to outdoor air pollution.

The next-highest concentrations appeared in South Asia where combustion emissions from multiple sources, including household solid fuel use, coal-fired power plants, agricultural and other open burning, and industrial and transportation-related sources, are the main contributors. The population-weighted annual average $PM_{2.5}$ concentrations were 101 µg/m^3 in Bangladesh, 78 µg/m^3 in Nepal, and 76 µg/m^3 in both India and Pakistan. The population-weighted annual average concentration in China was 56 µg/m^3. Estimates for population-weighted annual average $PM_{2.5}$ concentrations were lowest (≤ 8 µg/m^3) in Australia, Brunei, Canada, Estonia, Finland, Greenland, Iceland, New Zealand, Sweden, and several Pacific island nations.

Figure 2. Comparison of 2016 annual average $PM_{2.5}$ concentrations to the WHO Air Quality Guideline.

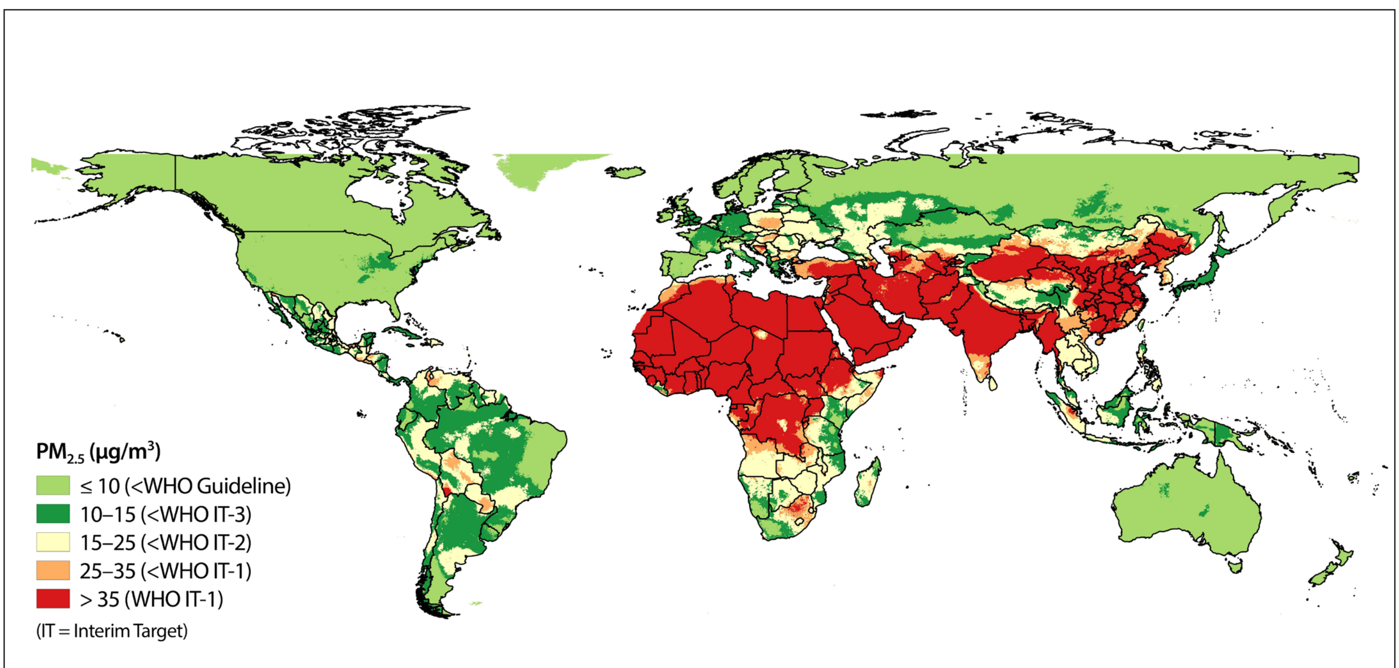
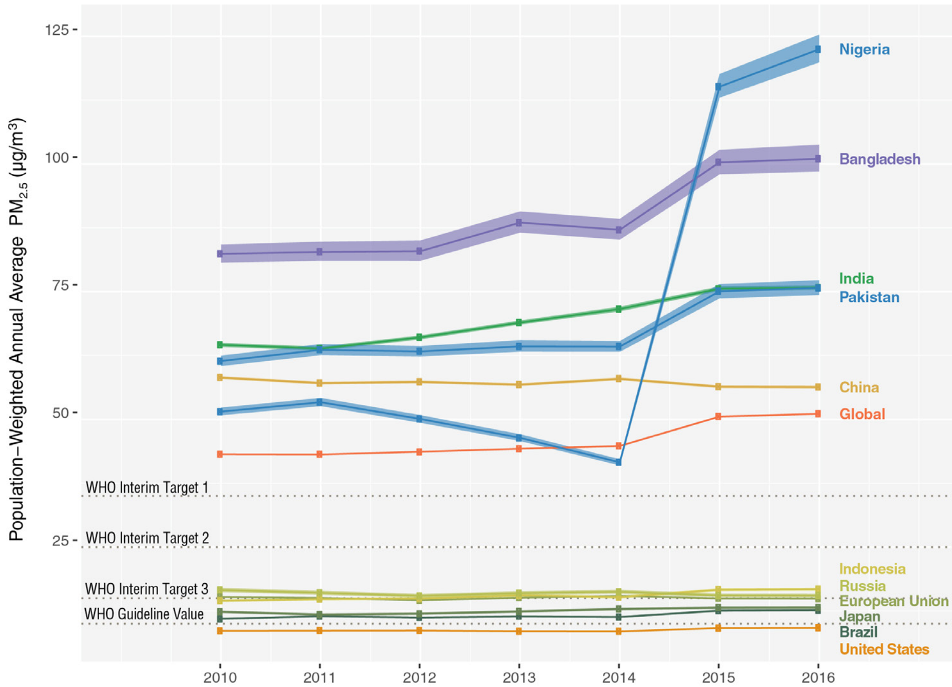


Figure 3. Trends in population-weighted annual average $PM_{2.5}$ concentrations in the 10 most populous countries plus the European Union, 2010–2016.



Explore the trends in other countries and regions at the State of Global Air interactive site.

MAIN TRENDS IN $PM_{2.5}$ CONCENTRATIONS

Global population-weighted $PM_{2.5}$ concentrations increased by 18% from 2010 (43.2 μg/m³) to 2016 (51.1 μg/m³). As the previous discussion on the most recent country data suggests, the global level of population-weighted $PM_{2.5}$ is influenced strongly by the levels of air pollution in populous regions and countries.

China's air pollution exposures have stabilized and even begun to decline slightly; Pakistan, Bangladesh, and India, in contrast, have experienced the steepest increases in air pollution levels since 2010.

Figure 3 illustrates the trends in population-weighted $PM_{2.5}$ concentrations for the 10 most highly populated countries in the world along with the European Union from 2010 to 2016 (see the interactive site for all years 1990 to 2016). India, Bangladesh, Pakistan, and China have all experienced both high concentrations and increasing trends in $PM_{2.5}$ exposure, but there are noteworthy distinctions. Although China experienced substantial increases in population-weighted exposures before 2010 — reflecting in part the dramatic scale of economic development in recent decades — since then the exposures have stabilized and even begun to decline slightly. Pakistan, Bangladesh, and India, on the other hand, have experienced the steepest increases in air pollution levels since 2010 and now present the highest sustained $PM_{2.5}$ concentrations among the countries shown here.

While Saharan Desert dust events are common and annually affect North Africa, between 2015 and 2016 anomalous wind patterns led to major dust events that also affected highly populated regions of West Africa. Nigeria, in particular, saw dramatic increases in $PM_{2.5}$ concentrations resulting from an extensive dust storm in late 2015 and early 2016. However, longer-term trends suggest declines in $PM_{2.5}$ exposures in Nigeria over the last 26 years, with limited evidence pointing to general declines in mineral dust emissions and open burning. Concentrations in the other highly populated countries (Russia, Indonesia, Japan, Brazil, and the United States, as well as the European Union) declined since 1990, yet, with the exception of the United States, remain above the WHO Guideline value.

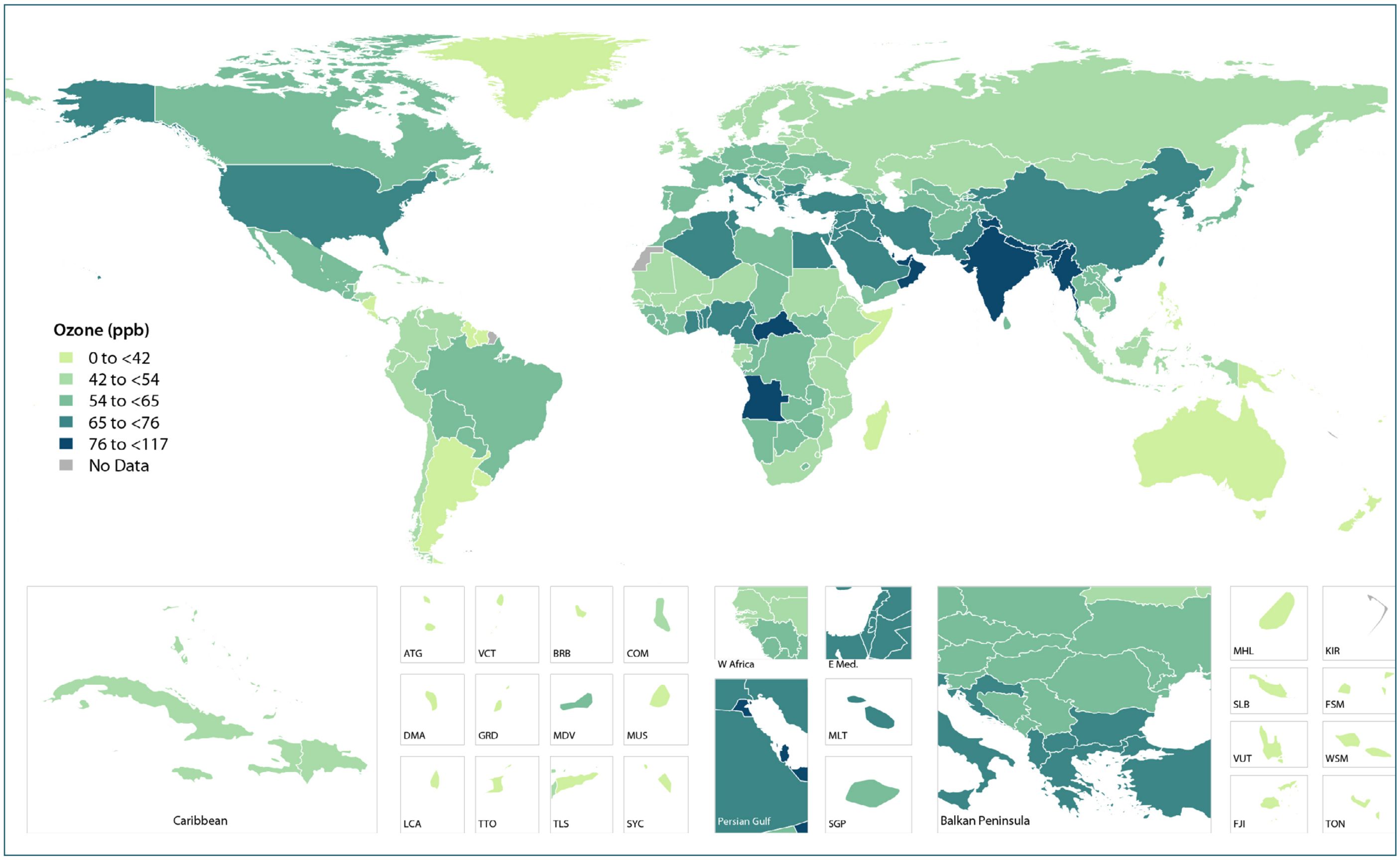
Excluding the recent evidence of stabilization and slight declines in population-weighted concentrations in China, the disparities among these large countries have grown substantially over time. Less-polluted locations have become cleaner, while $PM_{2.5}$ concentrations have increased in the more polluted locations, especially in South Asia. As a result, what was a 6-fold range in 1990 in population-weighted average concentrations among these countries (excluding Nigeria, given the likelihood of the 2015–2016 increase being transient) increased to an 11-fold range in 2016.

HOW AMBIENT OZONE CONCENTRATIONS VARY AROUND THE WORLD

The global ozone map (Figure 4) indicates that seasonal population-weighted average ambient ozone concentrations generally vary less around the world compared with $PM_{2.5}$. Ozone concentrations were relatively higher in the United States, West and Central sub-Saharan Africa, and throughout the Mediterranean, the Middle East, South Asia, and China. Globally, population-weighted ozone concentrations have increased, which reflects a combination of factors, including increased emissions of ozone precursors (such as nitrogen oxides) coupled with warmer temperatures, especially at mid-latitudes in rapidly developing economies. Ozone concentrations are led by ongoing increases experienced in China, India, Pakistan, Bangladesh, and Brazil.

Ozone levels remain high across both higher-income and lower/middle income regions of the world.

Figure 4. Population-weighted seasonal average ozone concentrations in 2016.



Explore the data on the State of Global Air interactive site. For country abbreviations, see ISO3 website.

EXPOSURE TO HOUSEHOLD AIR POLLUTION FROM BURNING OF SOLID FUELS: LEVELS AND TRENDS

Household air pollution from the use of solid fuels for cooking and heating is the 8th leading global risk factor contributing to disease burden (see Figure 1). Systematic measurements of $PM_{2.5}$ in households using solid fuels around the world are not available, but numerous individual studies indicate that household air pollution concentrations often far exceed those observed in ambient air. For example, a recent review of such studies reported that, in homes where no interventions had been undertaken to reduce exposures from the burning of solid fuels (e.g., by providing improved biomass stoves with and without chimneys or cleaner fuels such as LPG or ethanol), average exposures were as high as 220 µg/m^3 — approximately 6 times higher than the WHO Level 1 Interim Target of 35 µg/m^3. Even after efforts to reduce exposures using a range of interventions, this review reported that average in-home exposures were still approximately 100 µg/m^3, or 2.8 times higher than the same WHO interim target (see Additional Resources).

The GBD project estimates exposure to household air pollution by combining information from various surveys (including approximately 680 studies from 150 countries for the period 1980 to 2016), primarily at the national or regional level, to calculate the proportion of households using solid fuels. These data are then modeled to provide complete trends and estimates for all countries. Combining this information with population data for each location allows for estimation of the proportion of the population (grouped by age and sex) that is using solid fuels and that is assumed to be exposed to household air pollution (see textbox "Estimating Global Exposures to Household Air Pollution"). The State of Global Air presents these proportions of populations using solid fuels (all ages and both sexes combined) for the world as a whole, for different geographic regions, and for individual countries. The map in Figure 5 displays the proportion of population exposed to household air pollution from burning solid fuels for each country across the globe. Details for individual countries can be explored on the interactive website.

People living in homes using solid fuels can face $PM_{2.5}$ levels 6 times higher than even the least-stringent WHO Interim Air Quality Target for $PM_{2.5}$ and as much as 20 times higher than the full WHO Air Quality Guideline of 10 µg/m^3.

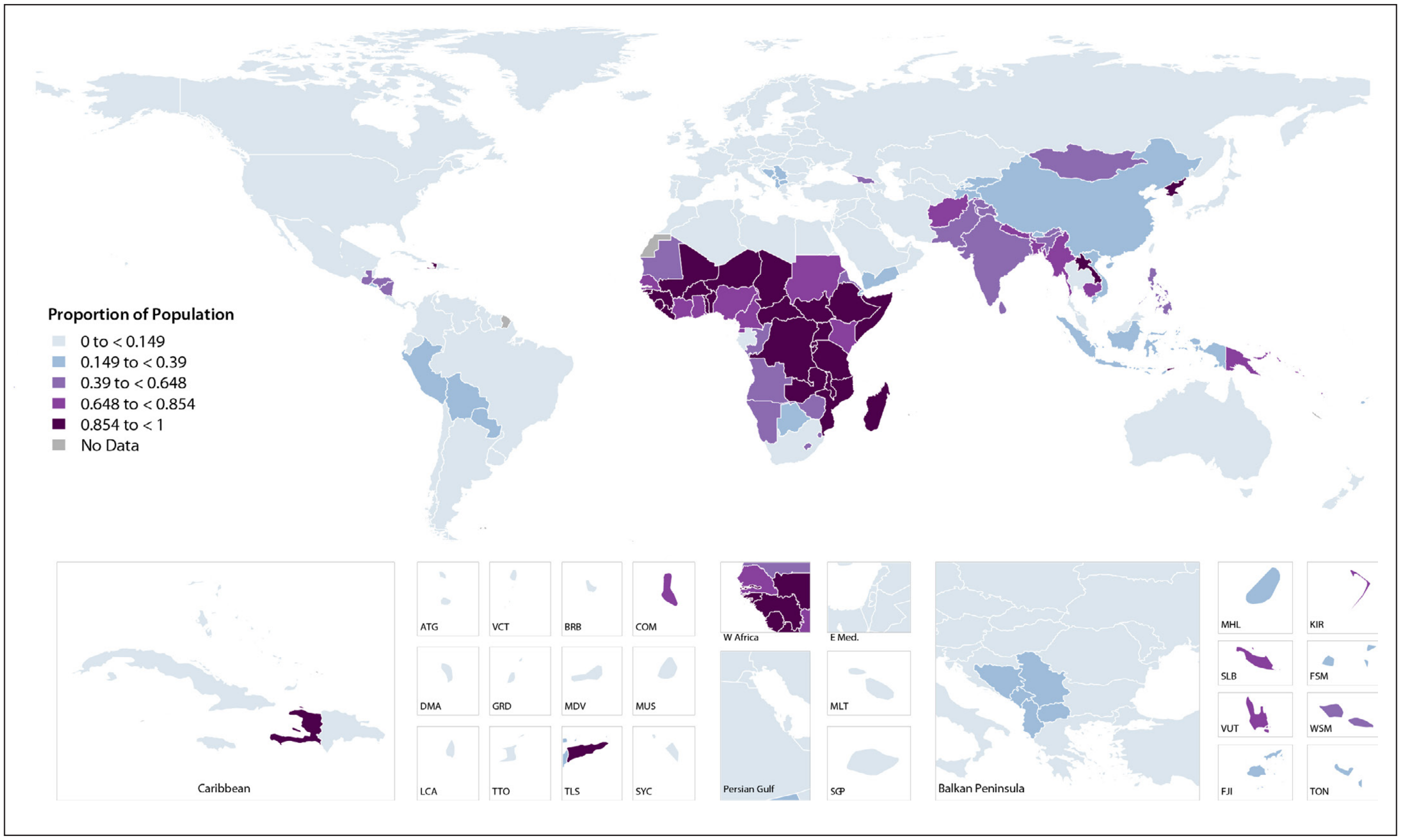
Estimating Global Exposures to Household Air Pollution

Estimation of exposure to household air pollution for the IHME GBD initiative begins by determining the proportion of households using solid fuels of any kind rather than gas or electric sources for cooking. Data on fuel use were extracted from numerous surveys (demographic and health surveys, living standards measurement surveys, multiple indicator cluster surveys, and world health surveys, as well as country-specific sources and the WHO household energy database). In 2016, IHME extracted 680 data points from 150 countries from these resources. These data are used together with demographic data to estimate the proportions of the population (stratified by age and sex) exposed to emissions from household use of solid fuel for each national and, where available, subnational geographic area in the GBD. The proportion of the total population exposed to household solid fuels is used in this report as an estimate of household air pollution exposure.

Subsequently, in order to apply the integrated exposure–response functions to estimate disease burden, the use of solid fuels is translated into indoor $PM_{2.5}$ concentrations and then into exposures for men, women, and children. This mapping relies on indoor measurements of household-air-pollution–related $PM_{2.5}$ from 90 studies in 16 countries. For the GBD 2016 analysis, a linear model was used to estimate the indoor $PM_{2.5}$ concentrations based on IHME's sociodemographic index (a metric assigned to every country in the world based on average income per person, educational attainment, and total fertility rate). Covariates were included in the model to indicate whether measured concentrations were made in the kitchen (or elsewhere in the home) or were measurements of personal exposure, as well as the measurement duration. The relationship described by the linear model was then used to predict indoor concentrations for all geographic locations and years. Finally, these indoor concentrations were translated to exposures by applying the ratio of personal exposures to indoor concentrations based on a subset of seven studies from six countries that included paired personal and indoor measurements. These ratios were modeled separately for men, women, and children based on available differences in the time spent in household activities that would involve exposure to household air pollution.

For more details on these methods, see references in the Additional Resources section.

Figure 5. Proportion of population exposed to household air pollution from burning of solid fuels in 2016.



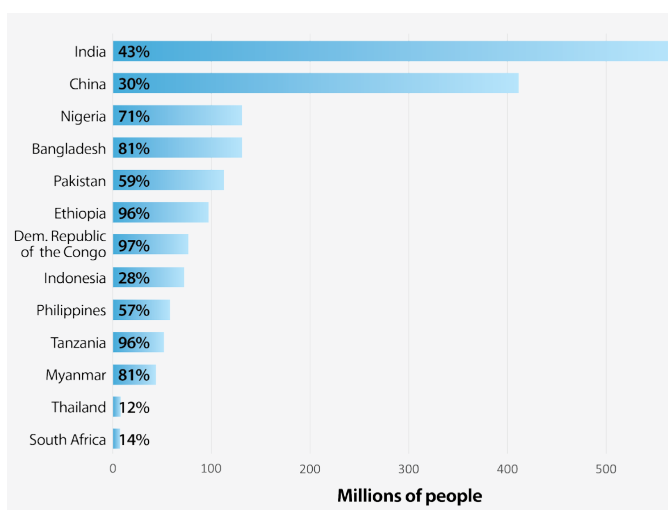
Explore the data on the [State of Global Air interactive site.](#) For country abbreviations, see [ISO3 website](#).

In 2016, a total of 2.45 billion people — one in three global citizens — were exposed to household air pollution from the use of solid fuels.

In 2016, a total of 2.45 billion people (33.7% of the global population) were exposed to household air pollution. Figure 5 illustrates wide disparities in the exposures to household air pollution around the world, with a clustering of two dozen countries in Africa that had over 90% of their populations exposed to household air pollution from the use of solid fuels. Ethiopia, Democratic Republic of the Congo, and Tanzania each had 96% or more of their populations exposed to household air pollution. Figure 6 ranks the 13 countries with populations of over 50 million that also have more than 10% of their populations exposed to solid fuels. Even where the percentage of population exposed to household solid fuel use is lower, the numbers of people potentially exposed can be substantial. India and China — with 43% and 30%, respectively, of their populations using solid fuels — had the largest numbers of people exposed to household air pollution in 2016: 560 million in India and 416 million in China.

The GBD project treats household use of solid fuels as a separate risk factor from outdoor air pollution. However, household air pollution can be an important contributor to outdoor air pollution, although the extent of this contribution varies by location and time and has not been estimated for most countries. The HEI Global Burden of Disease from Major Air Pollution Sources (GBD MAPS) project has quantified the contribution of household burning of solid fuels to ambient $PM_{2.5}$ levels and the associated disease burden in China and India. In China, household burning of biomass and coal contributed

Figure 6. Number of people and percentage of population exposed to household air pollution from solid fuel burning in countries with populations over 50 million and at least 10% solid fuel use in 2016. Countries listed in order of absolute number of people exposed.



Explore the data on the [State of Global Air interactive site.](#)

about 19% of total population-weighted $PM_{2.5}$ concentrations; in India, household burning of biomass was responsible for about 24% of $PM_{2.5}$ levels (see "The Key to Air Quality Progress: Understanding the Major Sources of Air Pollution" later in this report).

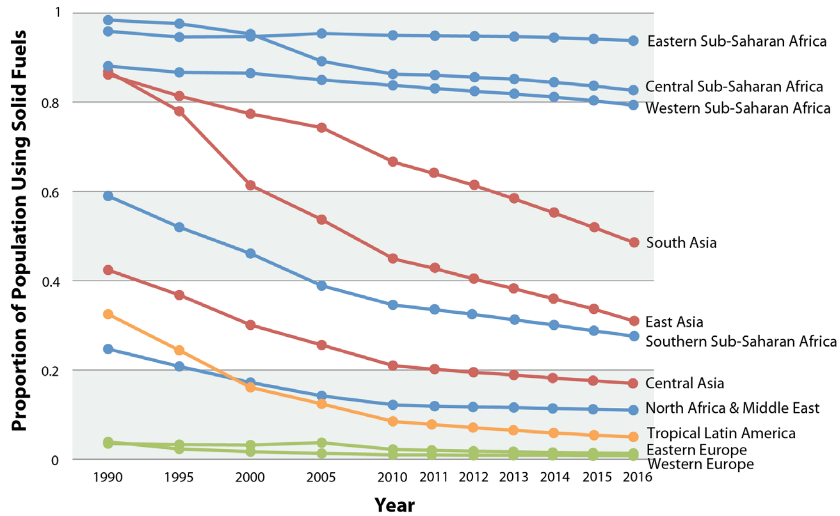
MAIN TRENDS IN HOUSEHOLD AIR POLLUTION EXPOSURE

Trends in population exposure to household air pollution are estimated in the GBD project by evaluating trends in the proportion of the households using solid fuels. Currently there are insufficient data to estimate accurately changes in exposure directly, given differences in types of fuels and appliances, house design, and cooking practices between and within countries. Trends show that the proportion of the population using solid fuels in major world regions (Figure 7) has been declining in many regions of the world over the last 26 years (1990–2016). Some of the most dramatic declines have occurred in Asia and southern Africa and throughout most of South America. However, in East, Central, and West sub-Saharan Africa, where the percentages of population exposed to household air pollution have been the highest, there has been little change in exposure.

Progress toward reductions in reliance on burning solid fuels in the home has been fastest in middle- and high-income countries, and slowest in the rural areas of low- and middle-income regions of the world. These trends are illustrated in Figure 8, which groups populations in the geographic regions in the previous figure according to where they fall on the development spectrum, using the GBD's sociodemographic index (SDI)*, with the low SDI group comprised primarily of African countries. (See GBD Socio-Demographic Income Regions.)

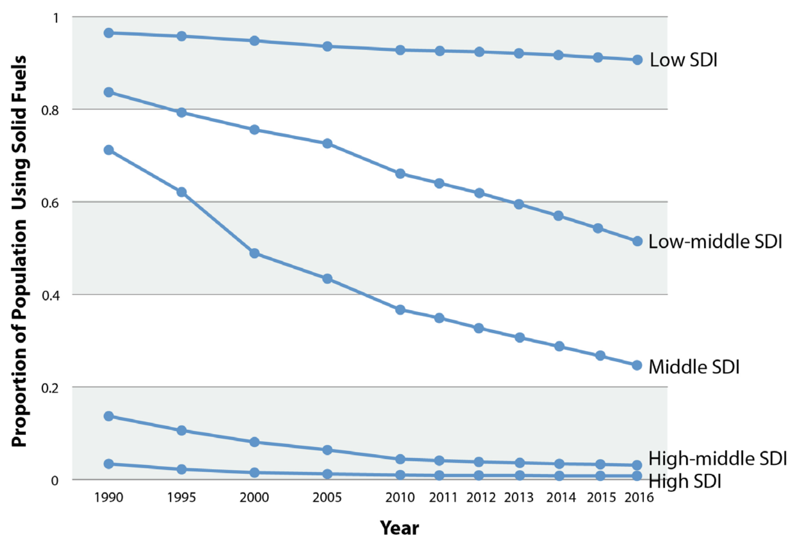
Despite global population growth over the past 26 years, there has been a net decline in the total numbers of people relying on solid fuels from just over 3 billion in 1990 to about 2.4 billion in 2016. Decline or stabilization of these numbers is evident even in many of the largest countries (>50 million population) with substantial proportions of households relying on solid fuels. China, for example, has reduced the estimated population relying on solid fuels to about 416 million in 2016, down from 996 million in 1990. Given the combination of population growth and limited changes in the percentages of their populations using solid fuels, Nigeria, Ethiopia, the Democratic Republic of Congo, and Tanzania have all seen net increases in populations exposed to household air pollution.

Figure 7. Trends in proportion of population exposed to household air pollution from burning of solid fuels for selected regions of the world.



Explore the data on the State of Global Air interactive site.

Figure 8. Trends in proportion of population exposed to household air pollution from burning of solid fuels by selected GBD sociodemographic index (SDI) regions.



Explore the data on the State of Global Air interactive site.

* The sociodemographic index (SDI) is the GBD's numerical index of development that reflects underlying social, demographic, and economic differences among populations in countries or in other geographic areas.

BURDEN OF DISEASE ATTRIBUTABLE TO AIR POLLUTION

What do we mean by "burden of disease" and how is it measured in the GBD project? The GBD initiative measures the burden of disease in terms of (1) the numbers and age-standardized rates of deaths in a given year and (2) the numbers of healthy years of life lost from death or disability, represented by "disability-adjusted life-years" (DALYs) (see textbox "Understanding the Burden of Disease: Deaths and DALYs"). For each risk factor considered by GBD, such as air pollution, these measures of disease burden are estimated for each country or subnational area from 1990 to 2016.

Estimating the burden of disease attributable to air pollution in geographic regions over time requires three major components: (1) estimates of population-weighted average annual exposure to $PM_{2.5}$, ozone, and household air pollution, as described earlier in this report (which are compared against a "minimum risk exposure level," an exposure level below which there is no evidence of additional risk of mortality or disease); (2) mathematical functions, derived from epidemiological studies, that relate the different levels of exposure to the age, sex, and cause-specific health impacts (e.g., mortality from heart disease and stroke, and incidence of lung cancer); and (3) spatially and temporally resolved estimates of the underlying number of deaths and DALYs for each of the causes of death or disability linked to air pollution. Sources for more information on these methods are listed in "Additional Resources" at the end of this report.

An extensive scientific literature has documented a wide range of air pollution health effects, including asthma, increased hospitalizations, illness, and reduced life expectancy from heart and lung disease.

What are air pollution's effects on health? An extensive scientific literature has documented a wide range of health effects: short-term effects such as worsening of asthma and increased hospitalizations for various cardiovascular and respiratory diseases on high-pollution days, as well as increased mortality and illness from cardiovascular

Understanding the Burden of Disease: Deaths and DALYs

The burden of disease due to exposure to a pollutant is calculated using an estimation of the number of deaths and disability-adjusted life-years (DALYs). The number of deaths attributable to air pollution in a given year includes deaths that have likely occurred months or even years earlier than might be expected in the absence of air pollution (as in the case of a child dying from a lower-respiratory infection [LRI]). DALYs provide an overall measure of the loss of healthy life expectancy and are calculated as the sum of the years of life lost from a premature death and the years lived with disability (e.g., blindness caused by the disease diabetes). An important insight gained by using DALYs rather than just the numbers of deaths is that DALYs account for the age at which disease or death occurs. For example, air pollution contributes to LRIs in children, but the number of deaths is small relative to the numbers of air pollution–related deaths from heart disease, which tend to occur in older adults. However, because children who die from LRIs have lost many more years of healthy life, this burden is appropriately reflected in a larger number of DALYs.

Burden is also measured in terms of age-standardized death rates and DALY rates (i.e., the number of deaths or DALYs per 100,000 people). Age-standardized rates are important because they adjust for population size and the age structure of each country's population. This means that the rates in two countries can be compared as if the countries had the same population characteristics. Otherwise, in a country with a large and older population, the total number of deaths attributable to air pollution would be larger than that in a country with a smaller or younger population, even if exposure levels were the same.

The Growing Burden of Disease Due to Ambient Air Pollution Exposure in an Aging World

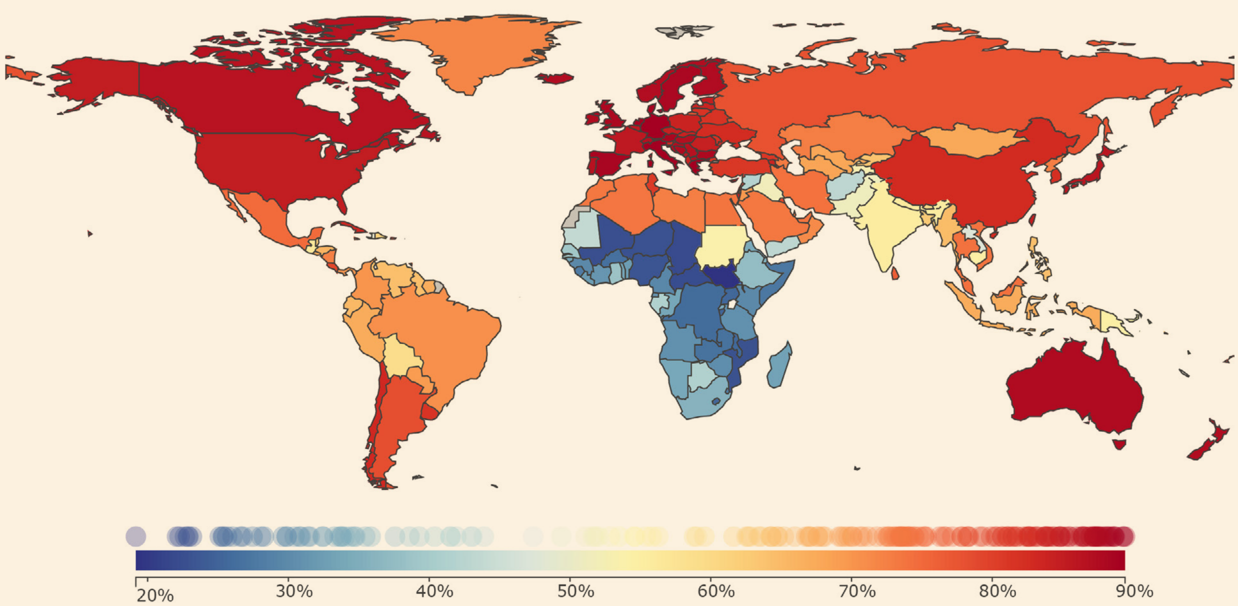
The latest estimates for the global burden of disease due to ambient $PM_{2.5}$ air pollution make clear that it takes its greatest toll in the elderly and middle-aged, in particular from *non-communicable diseases* (cardiovascular disease, stroke, lung cancer, and COPD). All told, in 2016, ambient $PM_{2.5}$ air pollution contributed to 1.8 million deaths and 22 million DALYs in those older than 70 years and 1.3 million deaths and 37 million DALYs in those between 50 and 69 years old from these diseases.

The growing importance of these non-communicable diseases in the burden of disease for air pollution exposure reflects worldwide increases in life expectancy at birth over the last 50 years and improvements in prevention and treatment for communicable diseases (malaria, pneumonia, etc.). The result has been an *epidemiological transition* from historical patterns in which the burden of disease was dominated by communicable diseases that resulted in deaths and disability in the very young to patterns in which the burden is dominated by non-communicable diseases in those over age 50. The textbox figure shows that in much of the world non-communicable diseases dominate the burden of disease: of some 1.5 billion DALYs in 2016, comprising 39 million deaths and 648 million years lived with disability, more than 80% were in those 50 to 70 years or older.

The elderly in low- and middle-income countries experience the greatest loss of healthy life-years due to the non-communicable diseases affected by $PM_{2.5}$. Among those 70 years or older, for example, $PM_{2.5}$-attributable ischemic heart disease alone accounted for 16.2% of DALYs in China, 17.8% in India, and more than 20% in parts of sub-Saharan Africa and of North Africa and the Middle East in 2016**.** And the air pollution-attributable burden from non-communicable diseases is rising, driven by high levels of air pollution and populations that are growing and aging. Over the past 25 years, this burden in low- and middle-income countries has increased for those ages 50 to 69 years — in India, for example, increasing by 24%, from 9.1 million to 11.3 million DALYs.

These numbers have far reaching implications. Reducing the burden of non-communicable disease in the aging populations of low- and middle-income countries is among the major challenges facing national governments and public health officials. In 2014 the Council on Foreign Relations noted that cardiovascular disease and other non-communicable diseases "…killed eight million people before their sixtieth birthdays in [low- and middle-income countries].…The economic costs in terms of both healthcare costs and lost productivity…[threaten] their continued economic development and prosperity." Improvements in treatment for those already suffering from cardiovascular disease and other non-communicable diseases will play a key role, but a strategy of prevention of new cases of non-communicable diseases by reducing exposure to major risk factors such as air pollution, high blood pressure, and tobacco smoking will need to be aggressively pursued.

Percentage of total DALYs resulting from non-communicable diseases by country for both sexes and all ages in 2016.



and respiratory disease and lung cancer and reduced life expectancy from long-term exposure to ambient air pollution. Systematic reviews of this literature have been undertaken by organizations such as the U.S. Environmental Protection Agency (U.S. EPA), the WHO, and the International Agency for Research on Cancer (IARC), among others (see "Additional Resources" at the end of this report). The GBD project determined that the body of evidence was sufficient to conclude that causal relationships exist between several diseases or causes of death and exposure to ambient $PM_{2.5}$, namely:

- ischemic heart disease,
- cerebrovascular disease (ischemic stroke and hemorrhagic stroke),
- lung cancer,
- chronic-obstructive pulmonary disease (COPD), and
- lower-respiratory infections (LRIs).

Based on the current literature, for health effects attributable to ozone, the GBD analysis includes only COPD (see "Additional Resources").

Our current estimates do not include causes of death and disability for which evidence for a causal relationship with exposure to ambient $PM_{2.5}$ is growing. These effects include the development of asthma in children, low birth weight and pre-term birth, type 2 diabetes, and neurological disorders. Type 2 diabetes is currently the 5th-ranked cause of death and the 3rd-ranked cause of *years lived with disability,* a component in estimating DALYs (see textbox, "Understanding the Burden of Disease: Deaths and DALYs") in those aged 50 to 69 years. Multiple studies have reported that exposure to $PM_{2.5}$ air pollution is a contributor to increased risk of type 2 diabetes. Recent studies also suggest an association between air pollution exposure and increased risk of Alzheimers disease, the 3rd-ranked global cause of death in those 70 years and older. To date, the evidence for these other health effects has not been judged conclusive enough to justify their inclusion in the GBD health burden estimates, but it will continue to be evaluated for future GBD estimates.

To estimate the potential effects of exposure to household air pollution from the use of solid fuels for cooking or heating, scientists rely on evidence both from studies of household air pollution and from the broader air pollution and smoking literature. Studies of exposure to household air pollution have documented impacts on acute LRIs, COPD, cataracts, and lung cancer. Some of the strongest evidence is for cancer; IARC has classified indoor burning of coal as a "known human carcinogen" (IARC Group 1) and indoor burning of biomass as a "probable human carcinogen" (IARC Group 2A). Very few studies have evaluated household air pollution in direct relation to ischemic heart disease or stroke, both of which are major contributors to disease burden from ambient air pollution, although a few studies have evaluated the relation between household air pollution exposure and potential indicators (e.g., blood pressure) of cardiovascular disease. However, under the assumption that particles from all combustion sources (ambient air pollution, household air pollution, secondhand smoking, and tobacco smoking) are harmful, the GBD project does estimate the disease burden attributable to household air pollution exposure from ischemic heart disease and stroke using the same integrated exposure–response relationships that it developed for ambient air pollution (see "Additional Resources").

LEVELS AND TRENDS IN THE BURDEN OF DISEASE FROM AMBIENT $PM_{2.5}$ FOR 2016

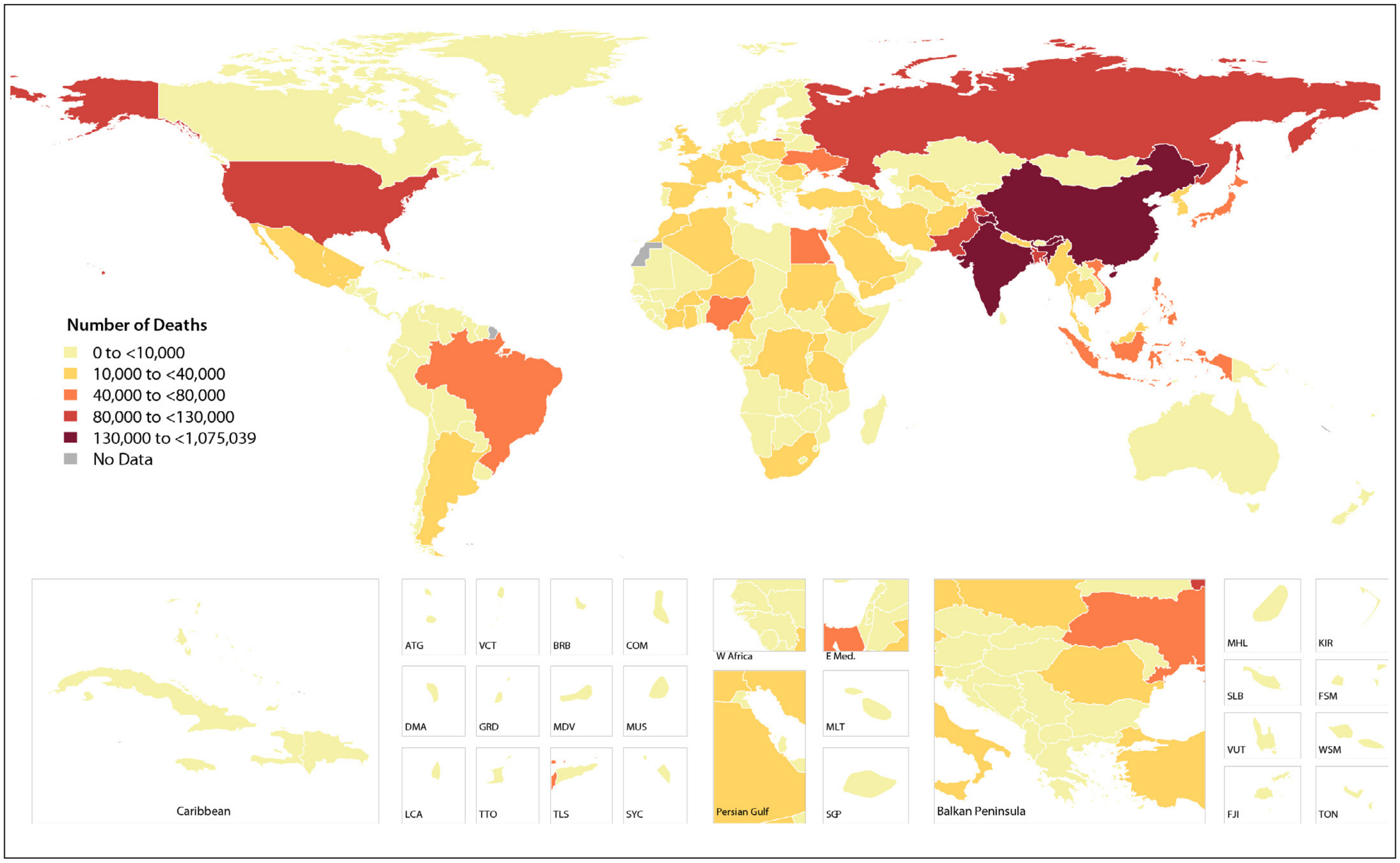
In 2016, long-term exposure to ambient $PM_{2.5}$ contributed to 4.1 million deaths and to a loss of 106 million DALYs worldwide. China (26%) and India (25%) together continue to bear most (51%) of the mortality burden attributable to $PM_{2.5}$.

In 2016, long-term exposure to ambient $PM_{2.5}$ contributed to 4.1 million deaths and to a loss of 106 million DALYs, making $PM_{2.5}$ exposure responsible for 7.5% of all global deaths and 4.4% of all global DALYs. The highest mortality burden was concentrated in Asia (Figure 9). China and India had the highest numbers of deaths attributable to $PM_{2.5}$. Together, these two countries accounted for 51% of the total global $PM_{2.5}$-attributable deaths and 50% of the DALYs. While long-term exposure to ambient $PM_{2.5}$ was linked to 7.5% of all deaths globally in 2016, it was linked to even higher percentages of global deaths from COPD, ischemic heart disease, stroke, lung cancer, and LRIs (see left panel of Figure 10). Of the 4.1 million deaths attributable to $PM_{2.5}$, most (58%) were caused by ischemic heart disease and stroke (data not shown).

Overall, while the absolute numbers of deaths attributable to $PM_{2.5}$ increased by over 20% from 1990 to 2016 and by 9% from 2010 to 2016 globally, there was a 12% decrease in the rate of deaths attributable to $PM_{2.5}$ from 1990 to 2016, indicating that the increase in total deaths during this period is largely due to changes in population characteristics. From 2010 to 2016 there was a 2.6% increase in the number of global deaths, reflecting a greater impact of population aging and increased global exposure than of decreases in the rates for diseases affected by air pollution. The global trend in $PM_{2.5}$-attributable deaths broadly reflects a balance between different trends in high-income and in low- and middle-income countries.

The global numbers and trends in $PM_{2.5}$-attributable mortality, while intriguing, can obscure important regional and country-level patterns in individual countries that are likely to be more relevant to local scientists and policy makers interested in understanding and addressing the health burden attributable to poor air quality.

Figure 9. Numbers of deaths attributable to ambient $PM_{2.5}$ in 2016.



Explore the data on the State of Global Air interactive site. For country abbreviations, see ISO3 website.

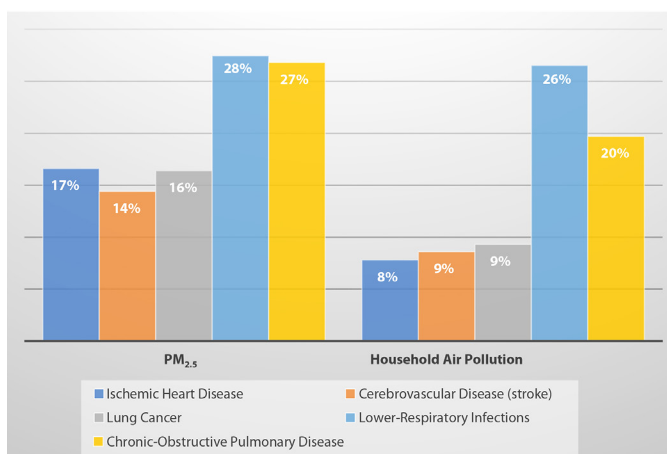
LEVELS AND TRENDS IN BURDEN OF DISEASE FROM HOUSEHOLD AIR POLLUTION FOR 2016

Exposure to household air pollution from burning of solid fuels was responsible for 2.6 million deaths and 77 million DALYs (4.7 % and 3.2% of the global totals, respectively) in 2016, with the highest burdens in Asia and sub-Saharan Africa.

Household air pollution was responsible for 2.6 million deaths (4.7% of the global total) and 77 million DALYs (3.2% of the global total) in 2016. The regional patterns of mortality burden reflect the size of populations as well as the proportions of households using solid fuels. China, India and its neighbors Pakistan and Bangladesh, Indonesia, and the African nations of Nigeria, the Democratic Republic of Congo, Ethiopia, and Tanzania are among those countries bearing the heaviest burden (Figure 11).

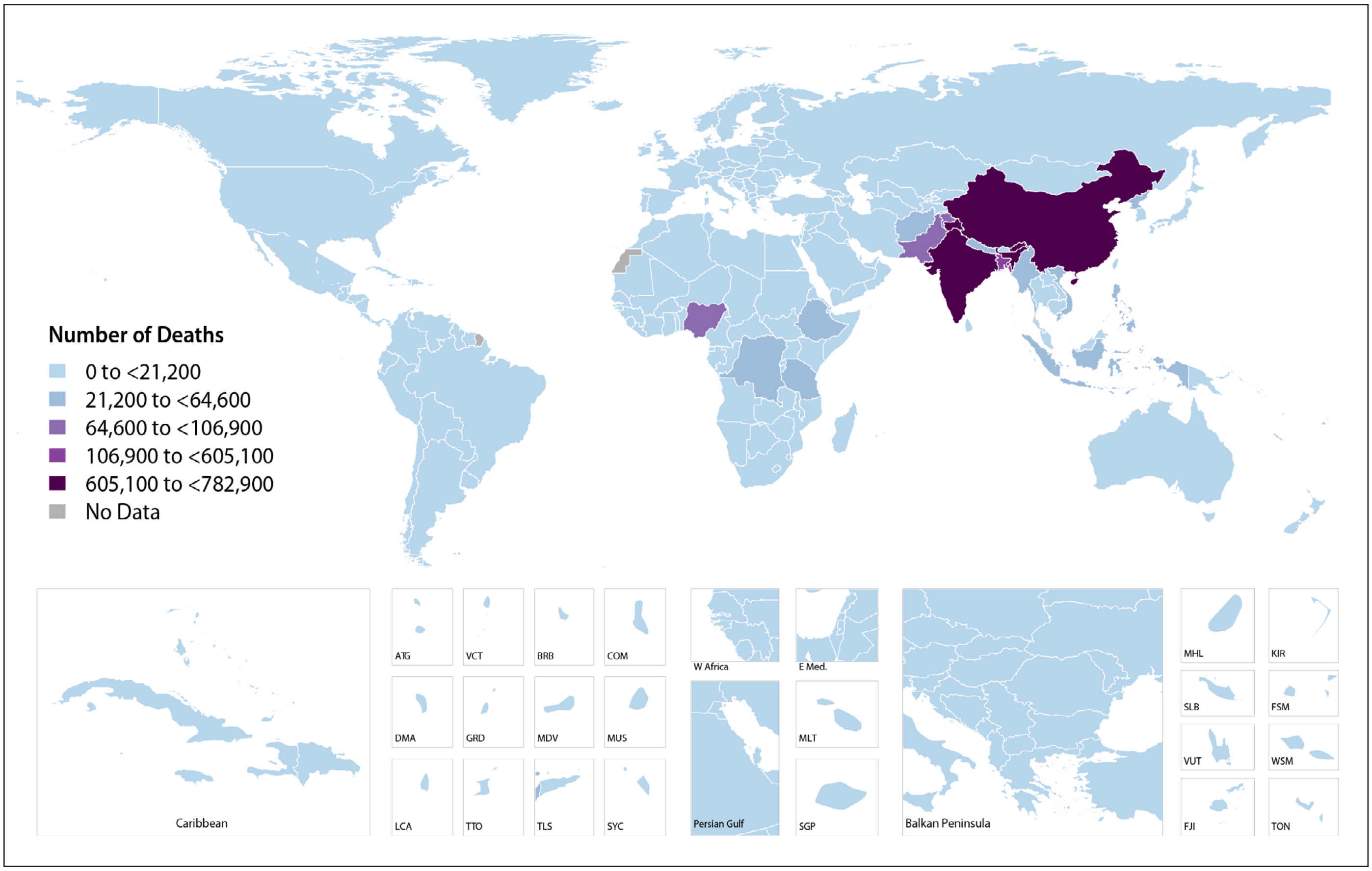
Although representing 4.7% of all deaths globally, household air pollution exposure accounts for substantially greater percentages of the worldwide mortality due to ischemic heart disease, stroke, lung cancer, LRIs, and COPD (see right panel of Figure 10). Of the 2.6 million deaths attributable specifically to household air pollution, 46% were linked to ischemic heart disease and stroke (data not shown).

Figure 10. Percentage of global deaths by cause attributable to ambient particulate matter and to household air pollution.



The declining proportion of households using solid fuels in many countries, discussed earlier, has been reflected in decreases in global mortality attributable to household air pollution — a 30% decrease from 1990 (3.7 million deaths) to 2016 (2.6 million deaths). A 16% decrease occurred in just the last 6 years. Declining death rates from LRIs, COPD, and stroke — in part, from other factors such as improved medical care — also contribute to these trends. With

Figure 11. Numbers of deaths attributable to household burning of solid fuels in 2016.

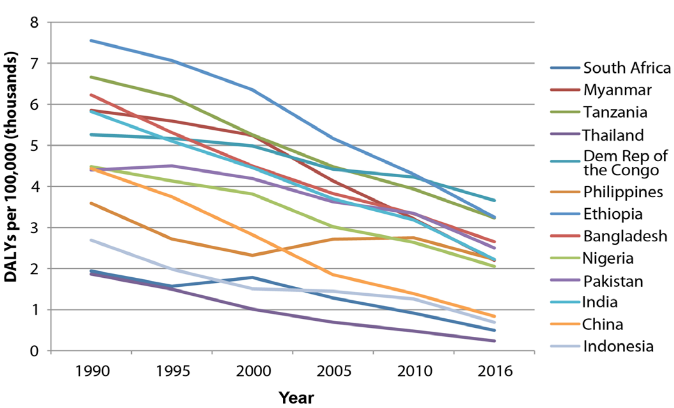


Explore the data on the State of interactive site. For country abbreviations, see ISO3 website.

few exceptions, these decreases in deaths attributable to household air pollution were experienced throughout the world, with the largest reductions in the rate of attributable deaths in North Africa, the Middle East, and parts of Asia (e.g., South Korea, Japan, and Malaysia).

Age-standardized DALY rates (DALYs/100,000 people) allow direct comparisons between populations of different sizes and age

Figure 12. Trends in the DALY rates (DALYs per 100,000 population) attributable to household air pollution in countries with greater than 50 million population and at least 10% of their population using solid fuels.

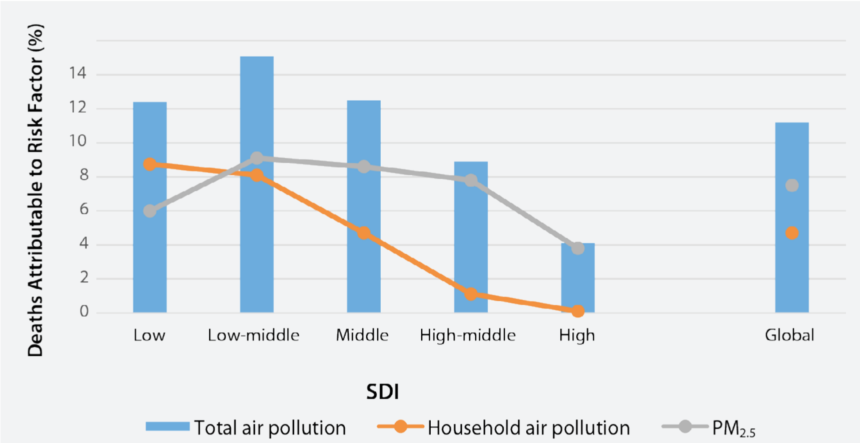


structures. And, as the trends in Figure 12 of DALY rates attributable to household air pollution indicate, in all of the countries shown there were sharp declines, reflecting the combination of decreasing exposure and decreases in age-standardized rates of diseases affected by household air pollution, especially acute LRIs in children.

WHO BEARS MOST OF THE BURDEN FROM EXPOSURES TO AIR POLLUTION?

Mainly because of age-related differences in mortality from chronic diseases, exposures to ambient and household air pollution can particularly affect the very old and the very young. Of the total burden from years of healthy life lost (DALYs), 24% was accounted for by those over 70 years old, and 18% was associated with those less than 5 years old. Sixty-two percent of the overall burden attributable to ambient $PM_{2.5}$ falls on those aged 50 and older. In contrast to the findings for ambient air pollution, the burden of disease attributable to household air pollution falls somewhat more on the young, who already experience higher rates of lower-respiratory disease, particularly in regions were household burning of solid fuels is more prevalent. Nearly 28% of total DALYs for those under 5 years is attributable to household air pollution exposures, compared with about 19%

Figure 13. Comparison of the percentages of deaths attributable to $PM_{2.5}$, household, and total air pollution by sociodemographic (SDI) index.



for the population older than 70 years. (For more details, see textbox, "The Growing Burden of Disease Due to Ambient Air Pollution Exposure in an Aging World" on page 10.)

COMBINED BURDEN OF EXPOSURE TO AIR POLLUTION

Since many populations may be exposed to both household and ambient air pollution ($PM_{2.5}$ and ozone), the GBD project estimates a "total" air pollution health burden that takes them all into account. Within the GBD analysis, the effects of exposure to household and ambient air pollution are assumed to be largely independent, given the absence of empirical studies of their joint effects. However, because the exposures overlap to some degree (e.g., household pollution contributes to ambient pollution), the number of deaths attributable to both exposures combined is less than the sum of the deaths due to each exposure (see Additional Resources).

Taken together, air pollution from ambient particulate matter, ambient ozone, and household burning of solid fuels was estimated to contribute to 6.1 million deaths — about 11% of the total global deaths in 2016.

The estimated combined toll from all forms of air pollution ($PM_{2.5}$, ozone, and household) can be substantial. On a global basis, total air pollution was responsible for 6.1 million deaths (11.2% of the global total) and for 163 million DALYs (6.8% of the global total). Of the number of global deaths in specific disease categories, 22.6% of ischemic heart disease deaths, 21.4% of stroke deaths, 23.5% of lung cancer deaths, 45.1% of deaths from acute LRIs, and 44.7% of COPD deaths were attributed to air pollution in 2016.

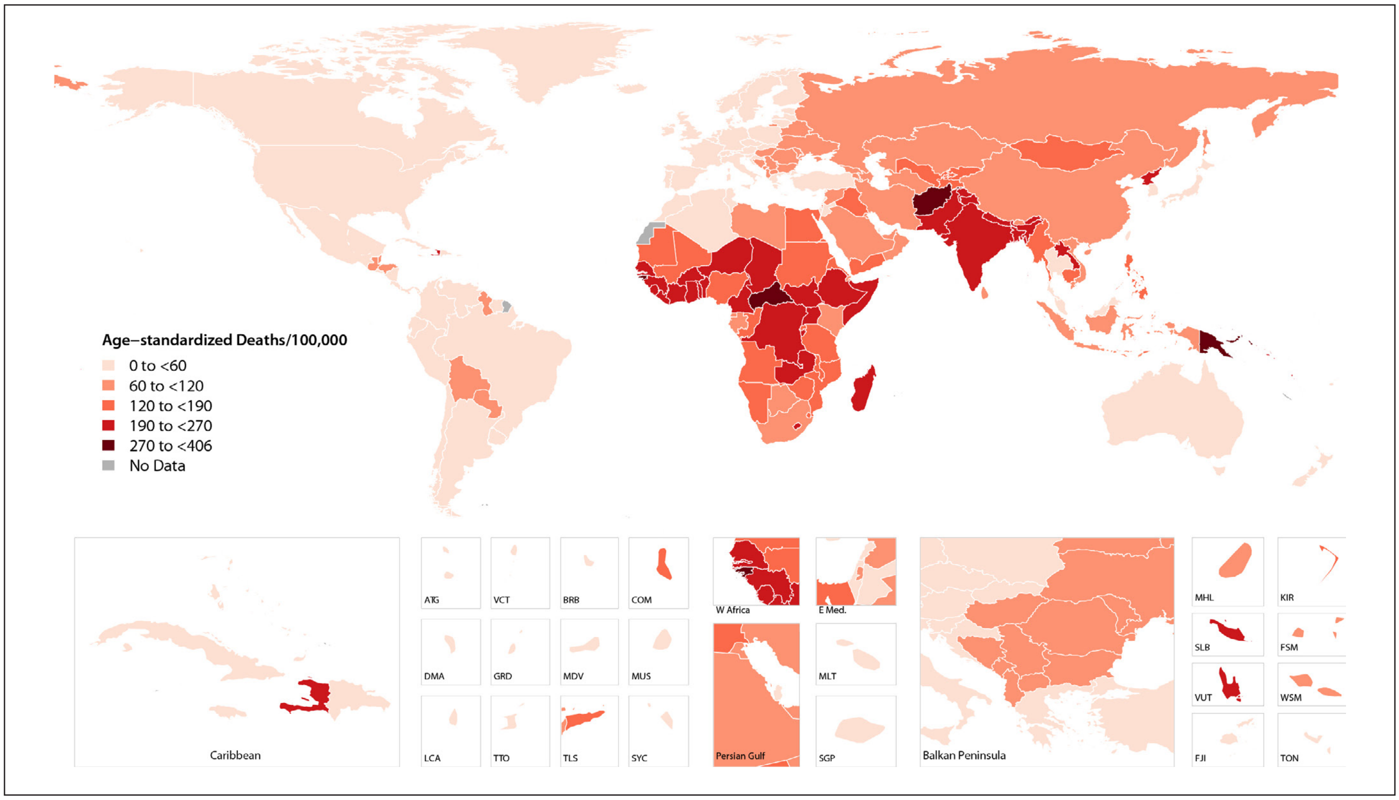
Strong relationships exist between the degree of development in and demographic standing of a country (as measured by the SDI) and exposure to household air pollution: countries at the lower end of the SDI scale experience higher exposures to household air pollution. The relation between ambient $PM_{2.5}$ exposure and sociodemographic standing is more complex, with the highest exposures found in low- and mid-SDI locations (Figure 13). Consequently, the combined impact of air pollution is highest in those countries at "low/middle" SDI where there is high exposure to both risk factors — household and ambient air pollution. These countries face a "double burden" from household air pollution on the one hand, and from ambient $PM_{2.5}$ and ozone on the other.

The combined burden from both ambient and household air pollution falls most heavily on low- and middle-income countries where exposures to both are high. These countries face a double burden.

These SDI-level differences in numbers of attributable deaths reflect differences among countries in the underlying health of the populations, including in the fraction of total deaths accounted for by diseases affected by air pollution, in their population's age structure, and in exposure levels. Consequently, comparing age-standardized rates of death or DALYs can be more useful in comparing the burden of disease attributable to a particular risk factor across countries or regions, because they factor in population age structure and size. Figure 14 provides a global map of the age-standardized death rates from total air pollution in 2016. It shows that the combined effect of air pollution is highest throughout much of sub-Saharan Africa and South Asia. These patterns reflect an interaction between the levels of exposure to the various forms of air pollution and the high rates of diseases affected by air pollution in these regions. Further comparisons of age-standardized rates for individual risk factors may reveal more information about the relative importance of those risk factors in individual countries.

The interactive website allows for detailed comparisons of both exposures to and burden (deaths, DALYS, and their respective rates) attributable to air pollution between countries and among various regional groupings (e.g., WHO Regions, GBD Regions, and SDI among others) for the years 1990 to 2016.

Figure 14. Comparison of the global patterns of age-standardized death rates for both sexes attributable to total air pollution.



Explore the data on the State of Global Air interactive site. For country abbreviations, see ISO3 website.

THE KEY TO AIR QUALITY PROGRESS: UNDERSTANDING THE MAJOR SOURCES OF AIR POLLUTION

To reduce the disease burden attributable to air pollution in all its forms requires a well-founded understanding of its major contributing sources, both now and in the future. This is the critical first step toward identifying the highest priority actions for air quality emissions control and the most cost-effective solutions to protect public health.

A wide range of industrial, residential, and transportation air pollution sources contribute to PM exposure, all needing to be controlled to reduce health burden.

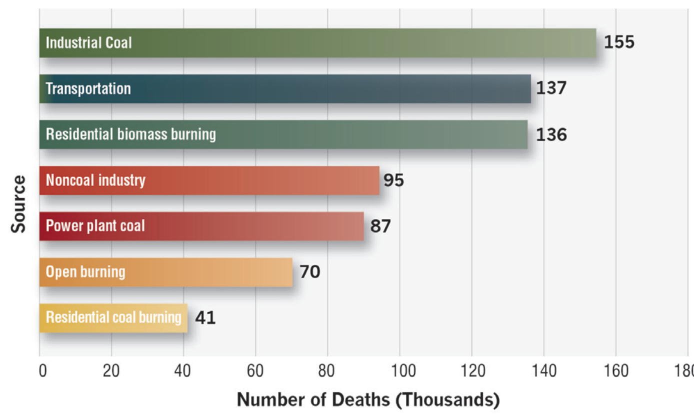
To meet that need for credible estimates of source-specific burdens, HEI launched the Global Burden of Disease from Major Air Pollution Sources (GBD MAPS) project, designed to engage local experts in China and India in (1) producing the most accurate estimates of emissions from each source, (2) using sophisticated air pollution models to estimate the contribution of each source to ambient $PM_{2.5}$ exposure, both today and in future scenarios, and (3) applying the GBD methods to estimate source-specific health burdens. GBD MAPS is a multiyear collaboration among HEI, IHME, Tsinghua University, IIT Bombay, the University of British Columbia, and other leading academic centers.

The first major GBD report was completed in 2016 with publication of *Burden of Disease Attributable to Coal-Burning and Other Major Sources of Air Pollution in China* (GBD MAPS Working Group 2016). That work has now been joined by publication in 2018 of *The Burden of Disease Attributable to Major Air Pollution Sources in India* (GBD MAPS Working Group 2018). For each country, local experts worked with the international team to assess what the sources of air pollution health burden were for a baseline year and what they could be in the future according to different policy pathways ("scenarios").

CHINA

The China study found that coal-burning — by industry, by power plants, and for residential heating — was the most important contributor to ambient air pollution. Coal-burning from these three sectors combined accounted for 40% of population-weighted ambient $PM_{2.5}$ concentrations and an estimated 366,200 deaths** in 2013, the baseline year for this study (see bar graph in Figure 15).

Figure 15. Source contributions to deaths attributable to $PM_{2.5}$ in China in 2013.



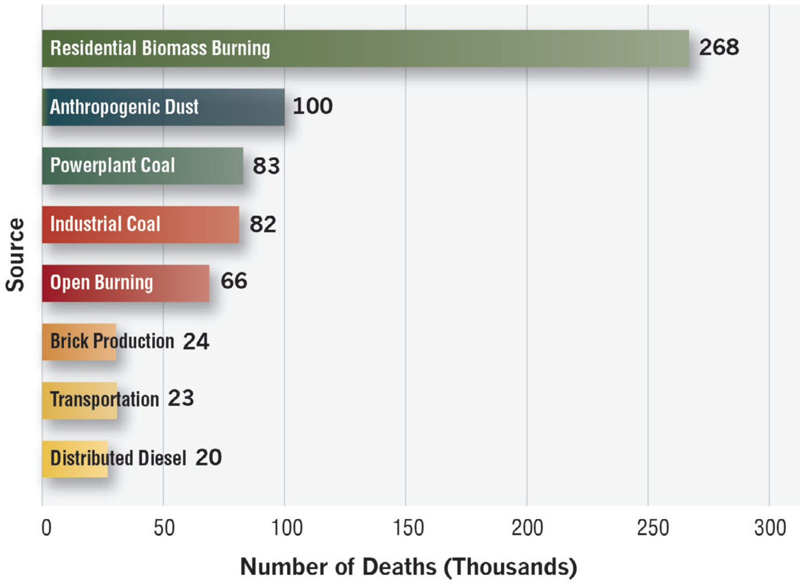
In China, the industrial sector, comprising both coal and noncoal sources (with 155,000 attributable deaths and 95,000 attributable deaths, respectively), was one of the largest contributors to mortality attributable to ambient $PM_{2.5}$, accounting for about 27%. However, household burning of both coal and biomass (e.g., wood and agricultural waste) was also an important contributor to the burden of disease attributable to ambient $PM_{2.5}$. Household combustion of these solid fuels had a combined impact (177,000 deaths) in 2015 that was larger than that from transportation (137,000 deaths) and other sectors. Under four future policy scenarios designed to evaluate the impacts of different levels of energy use and pollution control in China, the analysis indicated that, even under the most stringent policy scenarios, coal was projected to remain the single largest source contributor to ambient $PM_{2.5}$ and health burden in China in 2030. The findings demonstrated the air quality and health benefits associated with continued aggressive strategies to reduce emissions from coal combustion, along with reductions in emissions from other major sources.

INDIA

In India, the GBD MAPS study also found significant burdens from all forms of combustion, albeit with a different mix of the most important sources (Figure 16). In 2015, the baseline year for this study, particulate matter air pollution from a range of major sources was responsible for approximately 1.1 million deaths, 10.6% of the total number of deaths in India.

** Note that the sum of the deaths attributed to each of the coal sources does not add up to the simulated numbers of deaths attributable to all coal sources. This difference results both from the nonlinearities in the relationships between emissions and ambient concentrations and from the sensitivity simulations used to estimate the fractional contribution from each source.

Figure 16. Source contributions to deaths attributable to $PM_{2.5}$ in India in 2015.



- **Residential biomass burning was the largest individual contributor to disease burden.** Residential biomass burning was responsible for 267,700 deaths or nearly 25% of the deaths attributable to $PM_{2.5}$, making it the most important single anthropogenic source related to mortality in 2015. These burden estimates do not include the considerable additional burden from indoor exposure to biomass burning in the home.
- **Coal combustion and open burning also contributed substantially to disease burden.** Coal combustion, roughly evenly split between industrial sources and thermal power plants, was responsible for 169,300 deaths (15.5%) in 2015. The open burning of agricultural residue was responsible for 66,200 (6.1%) $PM_{2.5}$-attributable deaths.
- **Transport, distributed diesel, and brick production were also important contributors to $PM_{2.5}$-attributable disease burden.** In 2015, transportation contributed 23,100 deaths, distributed diesel contributed 20,400 deaths and brick production contributed 24,100 deaths.

The study also reported that if no further action is taken, population exposures to $PM_{2.5}$ are likely to increase by over 40% by 2050. Three different energy efficiency and air pollution control scenarios were evaluated. Only under the most aspirational scenario, in which aggressive emission reductions were assumed, were exposures projected to be reduced in a major way — by nearly 35% from 2015 to 2050, reaching about 48 µg/m^3. Even with the projected exposure decreases, the burden of disease is expected to grow in the future relative to the baseline year as the population ages and grows and leaves more people susceptible to air pollution.

The Indian government has begun taking actions to improve air quality. However, the study reported, the most aggressive action — with all major sectors achieving reductions in air pollution — could avoid up to 1.2 million deaths in 2050 compared with just instituting currently planned policies. Achieving such reductions will require particular attention to reducing emissions from household biomass combustion, coal burning, and dusts related to human activities. Depending on the scenario, coal combustion has the potential to emerge as the leading contributor to the disease burden from air pollution in the future.

SUMMARY

These two studies have demonstrated that the reduction of air pollution exposure and health burden in China and India — and likely many other countries — will require continued and updated source-specific analyses as actions are taken to measure progress and identify continuing challenges. The GBD MAPS initiative is currently putting in place the next generation of such analyses for China and India, with other countries to follow.

CONCLUSIONS

The GBD project has played a key role in identifying the factors that contribute the most to disease and premature mortality — the first step toward determining what can be done to improve public health. Among the 84 risk factors included in its comprehensive analysis, the GBD project reported that ambient air pollution from $PM_{2.5}$ ranked 6th globally in its contribution to mortality in 2016, accounting for 4.1 million deaths. Household air pollution was ranked 8th globally, responsible for 2.6 million deaths. Air pollution from ambient $PM_{2.5}$, ozone, and household burning of solid fuels combined was the 4th-highest global risk factor, accounting for 6.1 million deaths — 11% of the global total. The GBD analysis has also laid out the critical interplay between the trends in population structure, underlying disease, and economic factors and the trends in air pollution levels. Knowledge of these trends is essential to understanding patterns in the burden of disease experienced by different countries and regions and to helping to inform decision makers where policy action to reduce population exposure at the national or regional levels has the most potential to provide large benefits in improved health. Ultimately, reduction in air pollution and its burden on health requires identifying and taking action to control the major sources that contribute to them. Actions to reduce air pollution should address not only the larger-scale burning of coal by power plants and industries, but also the use of coal or different forms of biomass for heating and cooking in millions of small households around the world.

Numbers, Numbers Everywhere

As recognition of the world's air pollution problems has grown, estimates of the numbers of deaths and years of healthy life lost attributable to outdoor air pollution have proliferated. Most of these health burden estimates are from the World Health Organization (WHO) or from the Institute for Health Metrics and Evaluation (IHME) Global Burden of Disease (GBD) project. (This State of Global Air report is based on IHME estimates.)

In its most recent update, released in 2016, the WHO estimated there were 3 million deaths from $PM_{2.5}$ exposure for the year 2012, while the most recent GBD estimate was 4.1 million for the year 2016. Other estimates exist for outdoor air pollution–related deaths in individual countries or regions, alone and at times in combination with estimates for household air pollution. Indeed, the GBD 2016 estimates 6.1 million deaths attributable to all forms of air pollution: 4.1 million from $PM_{2.5}$, 2.6 million from household, and the remainder from ozone. Over time, these or related numbers have been echoed in reports by several leading economic and energy institutions that have sought to put a monetary value on the health burden attributable to outdoor air pollution and its sources — the World Bank, the Organization for Economic Cooperation and Development, and the International Energy Agency, to name a few (see "Additional Resources" section for details).

WHAT CAN WE MAKE OF ALL THESE NUMBERS? DO THEIR DIFFERENCES MATTER?

The most important takeaway message is that they are all large numbers — the burden of disease from air pollution is substantial. And given the complexity of the process for developing them, these estimates are surprisingly consistent. Some variation from this kind of scientific analysis is to be expected. These are estimates made by different analysts at different points in time. They vary primarily because of different data or because of different methods used to assess exposure to pollutants, to characterize exposure–disease relationships, and to quantify the baseline rates of disease and mortality in populations — all of which go into estimates of the numbers of people affected by air pollution.

Increasingly, the methods for estimating the burden of disease are converging. Most of the data and methods have their origins with IHME's GBD project and, particularly, its major update in 2010, which substantially expanded the analyses. WHO and IHME now use essentially the same methodologies for estimating air pollution levels around the world. Their estimates are therefore most sensitive to changes in exposure–response relationships that occur as new evidence is incorporated and, to a lesser degree, to changes in the baseline disease and mortality rates. Differences in the choice of exposure–response relationships largely account for the differences between the most recent mortality estimates from WHO and GBD: WHO relied on exposure–response relationships from GBD 2013 and WHO population mortality rate estimates for 2012, whereas the GBD 2016 report used an updated exposure–response function that predicted higher rates of mortality from $PM_{2.5}$ exposure and 2016 estimates of population mortality rates.

ANNUAL GBD UPDATES

The GBD project now updates its estimates annually and, with each update, provides an analysis of the trends over time (e.g., for the 26 years from 1990 to 2016). Although these updates include improvements in data and methods that themselves contribute to differences from previous GBD estimates (e.g., GBD 2010, GBD 2013, and GBD 2015), each GBD update recalculates the entire temporal sequence so that its trends (based, e.g., on the years 1990–2016) are internally consistent. These are the data that will be featured in future State of Global Air reports.

PUTTING IT ALL TOGETHER — A GLOBAL ESTIMATE OF POLLUTION'S IMPACT

The *Lancet* Commission on Pollution and Health has recently used the GBD methods and data to estimate the disease burden from all forms of pollution — ambient, household air, water, soil, heavy metal, and chemical pollution. The Commission estimated that 9 million premature deaths, about 16% of the total global mortality, could be attributed to pollution-related disease in 2015 (see Additional Resources). The World Health Organization, using additional definitions of pollution-related risk factors, had put the number at 12.6 million in 2012. Again, the size of these numbers is more important than their differences.

<<Return

ADDITIONAL RESOURCES

GBD 2016 METHODS

Details on the methods used to estimate $PM_{2.5}$, ozone, and household air pollution exposures and to estimate the premature deaths and disability-adjusted life-years (DALYs) and their respective rates for the GBD 2016 analyses can be found in these studies and their related references:

Cohen AJ, Brauer M, Burnett R, Anderson HR, Frostad J, Estep K, et al. 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015. Lancet 389:1907–1918; http://dx.doi.org/10.1016/S0140-6736(17)30505-6.

GBD 2016 Risk Factors Collaborators. 2017. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. Lancet 390:1345–1422; doi: 10.1016/S0140-6736(17)32366-8.

Shaddick G, Thomas M, Jobling A, Brauer M, van Donkelaar A, Burnett R, et al. 2016. Data integration model for air quality: A hierarchal approach to the global estimation of exposures to ambient air pollution. Available: https://arxiv.org/abs/1609.00141 [accessed 9 February 2018].

At the IHME GBD Compare website, data on mortality and disease burden for air pollution, as well as other risk factors, may be further explored and downloaded.

HEALTH EFFECTS OF $PM_{2.5}$, OZONE, AND HOUSEHOLD AIR POLLUTION

For comprehensive reviews of the scientific evidence on the health effects associated with exposures to $PM_{2.5}$ and ozone from the U.S. Environmental Protection Agency and the WHO, see the following:

Daniels, ME, Jr, Donilon TE, Bollyky TJ. 2014. The Emerging Global Health Crisis: Noncommunicable Diseases in Low- and Middle-Income Countries. Independent Task Force Report No. 72. New York, NY:Council on Foreign Relations. Available: https://cfrd8-files.cfr.org/sites/default/files/report_pdf/TFR72_NCDs.pdf [accessed 23 February 2018].

Health Effects Institute. In press. Household Air Pollution and Non-Communicable Diseases. Communication 18. Boston, MA: Health Effects Institute.

IARC (International Agency for Research on Cancer). 2013. Air Pollution and Cancer. IARC Scientific Publication No. 161. Lyon, France:World Health Organization. Available: www.iarc.fr/en/publications/books/sp161/AirPollutionandCancer161.pdf [accessed 8 February 2018].

U.S. EPA (United States Environmental Protection Agency). 2013. Final Report: Integrated Science Assessment (ISA) for Ozone and Related Photochemical Oxidants (Final Report, Feb 2013). EPA/600/R-10/076F, 2013. Washington, DC:U.S. Environmental Protection Agency. Available: https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=247492 [accessed 12 February 2018].

U. S. EPA (United States Environmental Protection Agency). 2009. Final Report: Integrated Science Assessment (ISA) for Particulate Matter (Final Report, Dec 2009). EPA/600/R-08/139F, 2009. Washington, DC:U.S. Environmental Protection Agency. Available: http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=216546 [accessed 8 February 2018].

WHO (World Health Organization). 2015. Air Quality Guidelines: Global Update 2005. WHO Reg Off Eur. Available: www.who.int/phe/health_topics/outdoorair/outdoorair_aqg/en/ [accessed 12 February 2018].

WHO (World Health Organization). 2014. Burden of Disease from Household Air Pollution for 2012. Geneva, Switzerland:World Health Organization. Available: www.who.int/phe/health_topics/outdoorair/databases/HAP_BoD_results_March2014.pdf?ua=1 [accessed 21 February 2018].

WHO (World Health Organization). 2016. Burning Opportunity: Clean Household Energy for Health, Sustainable Development, and Wellbeing of Women and Children. Geneva, Switzerland:World Health Organization. Available: http://apps.who.int/iris/bitstream/10665/204717/1/9789241565233_eng.pdf [accessed 21 February 2018].

WHO (World Health Organization). 2014. WHO Guidelines for Indoor Air Quality: Household Fuel Combustion. Executive Summary. Geneva, Switzerland:World Health Organization. Available: http://apps.who.int/iris/bitstream/10665/144309/1/WHO_FWC_IHE_14.01_eng.pdf?ua=1 [accessed 21 February 2018].

GBD MAPS

GBD MAPS Working Group. 2016. Burden of Disease Attributable to Coal-Burning and Other Major Sources of Air Pollution in China. Special Report 20. Boston, MA:Health Effects Institute.

GBD MAPS Working Group. 2016. Executive Summary. Burden of Disease Attributable to Coal-Burning and Other Major Sources of Air Pollution in China. Special Report 20. Boston, MA:Health Effects Institute.

GBD MAPS Working Group. 2018. Burden of Disease Attributable to Major Air Pollution Sources in India. Special Report 21. Boston, MA:Health Effects Institute.

GBD MAPS Working Group. 2018. Summary for Policy Makers. Burden of Disease Attributable to Major Air Pollution Sources in India. Special Report 21. Boston, MA:Health Effects Institute.

HOUSEHOLD AIR POLLUTION

Clark ML, Peel JL, Balakrishnan K, Breysse PN, Chillrud SN, Naeher LP, et al. 2013. Health and household air pollution from solid fuel use: The need for improved exposure assessment. Environ Health Perspect 121:1120–1128; doi: 10.1289/ehp.1206429.

GBD 2016 Risk Factors Collaborators. 2017. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. Lancet 390:1345–1422; doi: 10.1016/S0140-6736(17)32366-8.

GBD 2015 Risk Factors Collaborators. 2016. Global Burden of Disease Study 2015 (GBD 2015) Socio-Demographic Index (SDI) 1980–2015. Available: http://ghdx.healthdata.org/record/global-burden-disease-study-2015-gbd-2015-socio-demographic-index-sdi-1980%E2%80%932015 [accessed 14 February 2018].

World Bank and Institute for Health Metrics and Evaluation. 2016. The Cost of Air Pollution: Strengthening the Economic Case for Action. Washington, D.C.:World Bank Group. Available: http://documents.worldbank.org/curated/en/781521473177013155/The-cost-of-air-pollution-strengthening-the-economic-case-for-action [accessed 16 December 2016].

NUMBERS, NUMBERS EVERYWHERE

Listed below are the reports and papers referred to in the textbox "Numbers, Numbers Everywhere":

IARC (International Energy Agency). 2016. Energy and Air Population: World Energy Outlook Special Report. Paris, France:International Energy Agency. Available: www.iea.org/publications/freepublications/publication/WorldEnergyOutlookSpecialReport-2016EnergyandAirPollution.pdf [accessed 12 February 2018].

Landrigan PJ, Fuller R, Acosta NJR, Adeyi O, Arnold R, Basu N, et al. 2017. The *Lancet* Commission on Pollution and Health. Lancet 391:462–512; https://doi.org/10.1016/S0140-6736(17)32345-0.

Organization of Economic Cooperation and Development. 2014. The Cost of Air Pollution: Health Impacts of Road Transport. Paris:OECD Publishing. Available: http://dx.doi.org/10.1787/9789264210448-en [accessed 12 February 2018].

WHO (World Health Organization). 2016. Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease. Geneva:World Health Organization. Available: http://apps.who.int/iris/bitstream/10665/250141/1/9789241511353-eng. pdf?ua=1 [accessed 12 February 2018].

WHO (World Health Organization). 2016. WHO Global Urban Ambient Air Pollution Database (Update 2016). Available: http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/ [accessed 12 February 2018].

World Bank and Institute for Health Metrics and Evaluation. 2016. The Cost of Air Pollution: Strengthening the Economic Case for Action. Washington, DC:World Bank Group. Available: http://documents.worldbank.org/curated/en/781521473177013155/The-cost-of-air-pollution-strengthening-the-economic-case-for-action [accessed 12 February 2018].

CONTRIBUTORS AND FUNDING

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Health Effects Institute: HEI is an independent global health and air pollution research institute, a leader of the air pollution analysis within the Global Burden of Disease (GBD) project, and the producer, most recently, of the GBD from Major Air Pollution Sources (GBD MAPS) reports on China and India. HEI is the primary developer of the State of Global Air report, host and manager for the related website, coordinator of input from all other members of the team, and facilitator of contact with media partners.

The Institute for Health Metrics and Evaluation: IHME is an independent global health research center at the University of Washington, which provides rigorous and comparable measurement — through the GBD project — of the world's most important health problems and the risk factors that contribute to them, and which evaluates the strategies used to address them. A key collaborator, IHME provides the underlying air pollution and health data and other critical support for this project.

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Glossary

For a glossary of terms, see the State of Global Air website.

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