Outdoor Plus Indoor Air Pollution From Fossil Fuels, Biofuels, Bioenergy, and Biomass Burning is the Second Leading Cause of Death Worldwide, and a 100 Percent WWS World Will Eliminate Most of These Deaths

In
100% Clean, Renewable Energy and Storage for Everything
Textbook in Preparation
https://web.stanford.edu/group/efmh/jacobson/WWSBook/WWSBook.html

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7.7.2. Avoided Health Costs From Air Pollution
Transitioning homes, towns, cities, states, provinces, and countries to WWS immediately reduces air pollution health problems. Fewer health problems result in cost savings due to lower hospitalization rates, fewer emergency room visits, fewer lost work days, fewer lost school days, lower insurance rates, lower taxes, lower workman’s compensation rates, and less loss of companionship, among other impacts.

Air pollution causes premature mortality in several ways. It contributes to death from heart disease, stroke, chronic obstruction pulmonary disease (COPD), lower respiratory tract infection, lung cancer, and asthma. Common types of COPD are chronic bronchitis and emphysema. Common types of lower respiratory tract infections are the flu, bronchitis, and pneumonia.

In 2016, 56.9 million people died from all causes worldwide (WHO, 2017a). Table 7.13 shows that air pollution caused between 24 and 45 percent of the deaths for each of five out of the six leading causes of death. About 4.5 million people died prematurely from outdoor air pollution and 7.1 million, from indoor plus outdoor pollution in 2016 (WHO, 2017b). Thus, about 12.5 percent of all deaths worldwide in 2016 were due to indoor plus outdoor air pollution, making it the second leading cause of death after heart disease. Twenty percent of premature air pollution deaths are of children age five and younger.

GBD (2015) similarly estimated that about 5.5 (5.1 to 5.9) million deaths worldwide in 2013 were caused by outdoor plus indoor air pollution. Of these, 2.8 to 3.1 million were from outdoor PM2.5, 0.16 to 0.27 million were from outdoor ozone, and 2.5 to 3.3 million were from indoor air pollution from solid fuel burning.

Burnett et al. (2018) calculated 8.9 (7.5 to 10.3) million deaths per year worldwide in 2015 due to outdoor plus indoor air pollution. They hypothesized that the additional deaths from air pollution they found may have been due to the fact that previous studies considered only a limited number of categories of death that air pollution contributes to.

Table 7.13. Leading causes of death worldwide in 2016. Also shown are the percent and number of deaths in each category due to outdoor plus indoor air pollution and, separately, outdoor air pollution alone.

<table>
<thead>
<tr>
<th>Cause of death</th>
<th>Total all-cause 4 Number of deaths/y (millions)</th>
<th>Indoor plus outdoor air pollution</th>
<th>Outdoor air pollution only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent of all-cause 4</td>
<td>Number of deaths/y (millions)</td>
<td>Percent of all-cause 4</td>
</tr>
<tr>
<td>1. Ischemic heart disease (coronary artery disease)</td>
<td>9.43</td>
<td>25</td>
<td>2.36</td>
</tr>
<tr>
<td>2. Stroke</td>
<td>5.78</td>
<td>24</td>
<td>1.39</td>
</tr>
</tbody>
</table>
The premature mortality rate in a country in target year $Y$ is projected from a base year ($BYD$) during which death rates from air pollution are available, with

$$D_{C,Y} = D_{C,BYD} \left( e^{\Delta A_C[Y-BYD]} \right) \left( \frac{P_{C,Y}}{P_{C,BYD}} \right)^{\kappa}$$ (7.6)

where $\Delta A_C$ (Table 7.14) is the fractional rate of change per year in the air pollution death rate in country $C$ due to emission controls, $P$ is population, and $\kappa$ is the change in exposed population per unit change in population (Table 7.14).
The value of statistical life is the value economists calculate that a life is worth monetarily, based on what people are willing to pay to avoid health risks. It is determined from how much more employers pay their workers who have a higher risk of dying on the job. The VOSL varies with time and in each country. An estimate of the variation of VOSL (USD $million per death in 2013 USD) in country $C$ during year $Y$ is

$$VOSL_{C,Y} = VOSL_{US,Y} \left( T + \left[ \frac{1 - T}{G_{US,Y}} \right] \frac{G_{C,Y}^{\text{GDP,US,BYV}}}{G_{US,Y}^{\text{GDP,US,BYV}}} \right)^{\gamma_{\text{GDP}}}$$  \hspace{1cm} (7.7)

where

$VOSL_{US,Y}$ is the VOSL in the U.S. in year $Y$ (given in Table 7.14 for $Y=2050$);

$T$ is the fraction of the country’s VOSL that is held constant at the U.S. VOSL for that year;

$G_{C,Y}$ is the gross domestic product (GDP) per capita in the country in year $Y$;

$G_{US,Y}$ is the U.S. GDP per capita in year $Y$ (estimated in Table 7.14 for $Y=2050$);

$G_{US,BYV}$ is the U.S. GDP per capita in base year $BYV$ for calculating VOSL (Table 7.14 for BYV=2006);

$\gamma_{\text{GDP,US,BYV}}$ is the elasticity of the GDP per capita in base year $BYV$ (Table 7.14 for BYV=2006); and

$\gamma_{\text{GDP}}$ is the elasticity of the GDP per capita for all years (Table 7.14).

The GDP per capita in Equation 7.7 is the GDP at purchasing power parity (PPP). The GDP at PPP means that the GDP is determined by equalizing the value of a basket of goods in one country versus another, taking into account the currency exchange rate. For example, suppose countries A and B have a normal GDP per capita of $20 and $40, respectively, but a cup of coffee costs $5 in country A and $20 in country B. In that case, a consumer in country B can purchase only one-fourth the goods that a consumer in country A can for the same amount of money. If we make country A the reference country, then its GDP at PPP is still $20 per person, but the GDP at PPP of the second country is $40 per capita × ($5 per cup in country A / $20 per cup in country B) = $10 per person. So, although the normal GDP per capita is higher in Country B, the GDP at PPP is higher in Country A.

Equation 7.7 and the corresponding values of $T$ in Table 7.14 indicate that a small portion of the VOSL is assumed to be constant across all countries. This constant portion is the fraction of the VOSL that is independent of relative wealth, productivity or consumption. The equation also indicates that the VOSL is a function of change in income. In addition, the elasticity of the GDP per capita is itself a function of the GDP per capita ratio between the country and the U.S.

**Example 7.4.** Estimating the value of statistical life.

Estimate the medium number of premature air pollution deaths in Country $C$ in 2050 if the number of deaths in base year 2018 is 10,000/y, the population in the base year is 30 million, and that in 2050 is estimated to be 50 million. Also, estimate the VOSL and cost of air pollution in 2050 in the country assuming the GDP per capita in 2050 in the country is USD $40,000/person.

**Solution**

From Equation 7.6, the number of premature deaths in the country is estimated to increase to about 10,909/y. Thus, the impact of the increase in population was offset partly by the impact of better emission controls. From Equation 7.7, the value of statistical life in the country in 2050 is estimated to be $6.59 million in 2013 USD. Finally, from Equation 7.5, the air pollution mortality, morbidity, and non-health effects cost is $90.9 billion/y.


<table>
<thead>
<tr>
<th>Parameter</th>
<th>LCHB</th>
<th>Middle</th>
<th>HCLB</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. VOSL in base year 2006 ($VOSL_{US,BYV}$)</td>
<td>9.00</td>
<td>7.00</td>
<td>5.00</td>
</tr>
<tr>
<td>U.S. VOSL in target year 2050 ($VOSL_{US,Y}$)</td>
<td>15.37</td>
<td>10.40</td>
<td>6.47</td>
</tr>
<tr>
<td>Approximate global average VOSL ($\text{VOSL/USD 2006}$)</td>
<td>4.00</td>
<td>3.48</td>
<td>3.43</td>
</tr>
<tr>
<td>U.S. GDP per capita in 2006 ($G_{US,BYV}$) (USD $/person 2006)</td>
<td>52.275</td>
<td>52.275</td>
<td>52.275</td>
</tr>
<tr>
<td>U.S. GDP per capita target year 2050 ($G_{US,Y}$) (USD $/person 2013)</td>
<td>96.093</td>
<td>96.093</td>
<td>96.093</td>
</tr>
<tr>
<td>Multiplier for morbidity impacts ($F_1$)</td>
<td>1.25</td>
<td>1.15</td>
<td>1.05</td>
</tr>
</tbody>
</table>
Table 7.15. Relative risks ($\beta$) of premature mortality due to PM$_{2.5}$ and O$_3$, and of cancers over 70 years for various carcinogens.

<table>
<thead>
<tr>
<th>Long-term PM$_{2.5}$ exposure$^a$</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause mortality</td>
<td>0.0035</td>
<td>0.0055</td>
<td>0.0076</td>
</tr>
<tr>
<td>Cardiopulmonary mortality</td>
<td>0.0100</td>
<td>0.0129</td>
<td>0.0159</td>
</tr>
<tr>
<td>Ischemic heart disease mortality</td>
<td>0.0175</td>
<td>0.0217</td>
<td>0.0259</td>
</tr>
<tr>
<td>Lung Cancer mortality</td>
<td>0.0055</td>
<td>0.0129</td>
<td>0.0203</td>
</tr>
</tbody>
</table>

| Short-term O$_3$ exposure$^b$    |         |        |         |
| All-cause mortality (1-h max O$_3$) | 0.0002  | 0.0004 | 0.0006  |
| All-cause mortality (8-h max O$_3$) | 0.00027 | 0.00053 | 0.0008 |
| All-cause mortality (24-h O$_3$)  | 0.0005  | 0.001  | 0.0015  |

| Cancers over 70 years$^c$        | U.S. EPA CURES | OEHHA CURES |

LCHB = low cost, high benefit. HCLB = high cost, low benefit. VOSL = value of statistical life. GDP = gross domestic product at purchasing power parity (PPP).

Equation 7.6 requires a premature mortality rate from air pollution in a base year in each country. Such an estimate can be obtained from data, such as that shown in Table 7.13, but for individual countries. Those data include the number of actual deaths occurring in each country due to a specific cause, as denoted on death certificates, and an approximation of how many deaths of each cause were due to air pollution.

A second way is first to obtain measurements or computer model simulation estimates of the concentrations of PM$_{2.5}$ and O$_3$, throughout each country. The advantage of using measurements is that they are fairly accurate. However, such data are usually scattered sparsely throughout a country, and concentrations measured in one location may not be representative of concentrations nearby. The advantage of using a model is that it has complete horizontal and vertical coverage of a country. The disadvantage is that the model estimates are usually less accurate than the measurements.

Concentrations of PM$_{2.5}$ and O$_3$ over a country are combined with estimates of the population exposed to those concentrations and with relative risk estimates of premature mortality as a function of concentration of PM$_{2.5}$ and O$_3$, in a health-effects equation. The equation estimates premature mortalities due to PM$_{2.5}$ and O$_3$.

The health effects equation gives the death rate (e.g., deaths per year), cancer rate, hospitalization rate, etc., due to exposure to a pollutant as

$$y = y_0 P \left[1 - \exp \left(-\beta \times \max \left(x - x_{th}, 0 \right)\right)\right]$$

(e.g., Jacobson, 2010b), where $x$ is the average concentration or mixing ratio of the pollutant, $x_{th}$ is the threshold concentration or mixing ratio below which no health effect occurs, $\beta$ is the relative risk, or fractional increase in the risk of the health effect occurring per unit concentration $x$, $y_0$ is the baseline health effect rate per unit population (e.g., all-cause deaths per year per 100,000 population), and $P$ is the population. Table 7.15 gives relative risks and threshold values for PM$_{2.5}$, O$_3$, and carcinogens.

Equation 7.8 can be applied over very small regions, such as a neighborhood, or large regions, such as a whole country. When it is applied to each of multiple small regions adjacent to each other, results are summed over all regions to obtain a total number of premature mortalities per year, for example.
The relative risks due to the long-term effects of PM$_{2.5}$ are the fractional increases in the cause of death specified per $\mu$g/m$^3$ increase in annual average outdoor PM$_{2.5}$ concentration (Krewski et al., 2009, based on data for 1999 to 2000; CARB, 2010). The relative risks apply only above a threshold concentration of $x_{th} = 5.8$ $\mu$g/m$^3$, the lowest annual averaged PM$_{2.5}$ concentration measured in Krewski et al. (2009). The relative risks apply only for people older than 30 years. The low threshold due to health problems from PM$_{2.5}$ is 0 $\mu$g/m$^3$, but the relative risk down to zero is uncertain. Jacobson (2010b) estimate the relative risk down to zero as one-fourth that above $x_{th}$. The low and high values in the table represent 95 percent confidence intervals. Ischemic heart disease is a subset of cardiopulmonary causes of death. Those two and lung cancer are a subset of the all-cause death rate.

The relative risks (for all ages) due to the short-term effects of O$_3$ are the fractional increase in all-cause daily mortality that is due to short-term exposure to a 1 ppbv increase in the highest 1-hour average ozone level during a day, the highest 8-hour average ozone level during a day, or the 24-hour average ozone during a day (Ostro et al., 2006). The low threshold for ozone health effects is $x_{th} = 35$ ppbv.

CURES are cancer unit risk estimates. They are 70-year cancer risks per $\mu$g/m$^3$ sustained concentration change of a carcinogen. Thus, divide the CURES by 70 years for use in Equation 7.8 to obtain the number of new cancers (not necessarily cancer deaths) per year due to exposure to the carcinogen. No low thresholds apply. The two sources of CURES are the U.S. Environmental Protection Agency (U.D. EPA) and the California Office of Environmental Health Hazard Assessment (OEHHAA) (Jacobson, 2010b).

Example 7.5. Estimating the number of premature mortalities due to ozone.

Estimate the number of premature mortalities in the United States per year due to short-term ozone exposure if the entire population of 300 million were exposed to 40 ppbv ozone over a year. Assume the all-cause death rate is approximately $y_0 = 833$ deaths per year per 100,000 population.

Solution

Substituting $y_0=0.0083$ deaths per person, $P=300,000,000$ people, $\beta=0.0004$ per ppbv, $x=40$ ppbv, and $x_{th}=35$ ppbv into Equation 7.8 gives $y=5000$ additional premature mortalities per year due to ozone in the U.S.

Table 7.11 estimates the avoided premature mortalities from air pollution by country in 2050 upon a conversion to 100 percent WWS. The table also shows the resulting avoided health cost by country from Equation 7.5 per unit of BAU energy eliminated. The table indicates that transitioning to 100 percent WWS will avoid millions of premature deaths each year and save the equivalent of $0.127$/kWh (USD 2013), which is more than the direct cost of energy.

References


