The population attributable fraction (PAF) was used to quantify the burden of disease (BoD) associated with household air pollution in 2016. The PAF is the proportional reduction in population disease or mortality that would occur if exposure to a risk factor (i.e. household air pollution) were reduced to an alternative ideal exposure scenario (e.g. no exposure to household air pollution). The health risk estimates used in the PAF calculations were based on methods developed by the Institute for Health Metrics and Evaluation (IHME), in consultation with expert groups of IHME’s Global Burden of Disease (GBD) project (1-4).

For each risk factor, the population attributable fraction (PAF) was estimated by comparing current exposure distributions to a counterfactual distribution, for each exposure level, sex and age group:

\[
(A) \quad \text{Population attributable fraction (PAF)} = \frac{P_e(RR - 1)}{P_e(RR - 1) + 1}
\]

Where \( P_e \) is the percentage of the population exposed to household air pollution, i.e. the percentage of the population using polluting fuels and technologies for cooking.

Household air pollution attributable burden is obtained by calculating and applying the PAFs to each individual diseases (Figure 1) using sex and age specific disease risk estimates.

**Source of the data**

**Demographic data**
Exposure data

The proportion of households in a country relying mainly on polluting fuels and technologies for cooking is used as a proxy indicator for estimating population exposure to household air pollution. Currently, households using mainly coal, wood, charcoal, dung, crop residues and kerosene are considered “exposed”.

Information on the types of fuels and technologies used by households for cooking is regularly collected on household surveys or census, and compiled in the WHO Household energy database (6). The data housed in the WHO Household energy databases are then used as inputs into a statistical model (7) to derive point estimates for a particular country in a particular year, and then reported for the national, urban and rural levels.

To translate the proxy of the ‘polluting fuel and technology’ used for cooking into personal-level exposure, an average of exposure levels of particulate matter of a diameter of less than 2.5 µg/m³ (PM$_{2.5}$) were derived from the systematic reviews of the epidemiological literature for women, men and children (3) and assumed in the BoD calculations. Below are the PM$_{2.5}$ exposure-level values assumed for households relying mainly on polluting fuels and technologies for cooking (3, 4):

<table>
<thead>
<tr>
<th>Category</th>
<th>Exposure Level (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>337 for women</td>
</tr>
<tr>
<td>Men</td>
<td>204 for men</td>
</tr>
<tr>
<td>Children (&lt;5 yrs)</td>
<td>285 children</td>
</tr>
</tbody>
</table>

Health data

The total number of deaths, years of life lost (YLL), years of life lived with disability (YLD) and DALYs (disability-adjusted life years) by country, sex and age group for acute lower respiratory infections (ALRI), chronic obstructive pulmonary diseases (COPD), lung cancer, ischaemic heart diseases (IHD), and stroke have been developed by the World Health Organization (8).

Exposure-risk relationships

To estimate the relative risk for a disease caused by air pollution exposure from PM$_{2.5}$, an integrated exposure response function (IER) is used. The IER was originally developed for the Global Burden of Disease Study (2, 9-11) and has also been used by WHO (12,13). The IER combines the epidemiological evidence for outdoor air pollution, second-hand smoke, household air pollution and active smoking to estimate the level of disease risk (e.g. stroke) at different levels of PM$_{2.5}$ concentrations (aka dose). In other words, the same mathematical relationship or measure is used to estimate the risk of heart disease from outdoor air pollution as that of second-hand smoke or household air pollution.

An updated version of the IER functions is used for ALRI, lung cancer, IHD and stroke, as in GBD 2016 (14, 15). For chronic obstructive pulmonary disease (COPD), the relative risks from the systematic review / meta-analysis study were used (4). Personal exposure values for women, men and children derived by Balakrishnan et al. (3) resulted in relative risks presented in Table 1. In addition, for the disability-adjusted life years (DALY) calculations attributable to household air pollution, cataract was included as health outcome, for women over 25 years (4).
Table 1. Relative risks

<table>
<thead>
<tr>
<th>Disease</th>
<th>RR (95% CI) women</th>
<th>RR (95% CI) men</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALRI</td>
<td>2.3 (1.8-2.8)</td>
<td>(11, 14, 15)</td>
<td></td>
</tr>
<tr>
<td>COPD</td>
<td>2.3 (1.7-3.1)</td>
<td>1.9 (1.2-3.1)</td>
<td>(4)</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>2.4 (2.0-2.8)</td>
<td>1.9 (1.6-2.3)</td>
<td>(11, 14, 15)</td>
</tr>
<tr>
<td>IHD</td>
<td>(1.3-1.9)</td>
<td>(1.2-1.8)</td>
<td>(11, 14, 15)</td>
</tr>
<tr>
<td>Stroke</td>
<td>(1.2-1.8)</td>
<td>(1.2-1.6)</td>
<td>(11, 14, 16)</td>
</tr>
</tbody>
</table>

RR: Relative risks; CI: Confidence interval; ALRI: Acute lower respiratory disease; COPD: Chronic obstructive pulmonary disease; IHD: Ischaemic heart disease. Women, resp. men, refer to adult women, resp. men aged ≥25 years except for ALRI (all ages). For stroke and IHD, there is an age-gradient for the relative risks, but presented here are the 95% confidence interval over their predicted values from the integrated exposure response functions for age 70 years.

Methods

Estimation of disease burden

The percentage of the population exposed to PM$_{2.5}$ was provided by country and by increment of 1 μg/m$^3$; relative risks were calculated for each PM$_{2.5}$ increment, based on the integrated exposure-response functions (IER). The counterfactual concentration for ambient air pollution was selected to be between 2.4 and 5.9 μg/m$^3$, as described in (9). The country population attributable fractions for ALRI, COPD, lung cancer, IHD and stroke were calculated according to formula (A) above. Currently, the IER is used to estimate the BoD (e.g. the number of deaths) for five causes:

- Acute lower respiratory infections (ALRI), in all ages
- Chronic obstructive pulmonary disease (COPD), in adults over 25 years
- Lung cancer, in adults over 25 years
- Ischaemic heart disease (IHD), in adults over 25 years
- Stroke, in adults over 25 years

DALYs are calculated by adding the YLDs and the YLLs. The relative risks (RRs) for YLDs were adjusted for IHD and stroke (14).

Uncertainty analysis

The model is implemented using Markov chain Monte Carlo (MCMC) and, as with any Bayesian analysis, results in not just point estimates of the proportions (of the usage of each fuel type, by country and by year), but a set of full posterior distributions for those estimates. Summaries of these distributions can be taken to provide both point estimates (e.g. means) and measures of uncertainty (e.g. 95% credible and 95% prediction intervals).

Limitations and outlook

Exposure

- The exposure assessment for household air pollution only considers cooking fuels use, which is mainly a low and middle income problem and reported as such so far. Both lighting and heating fuels are therefore not yet included, mainly due to data availability issues, but the methodology is currently under revision for their inclusion.
- The parallel use of different fuels and technologies (aka also known as fuels and stoves stacking) by the households is currently not fully captured by country data collection efforts,
thus likely leading to an underestimate of the exposure to household air pollution and contribution to ambient levels.

- Personal-level exposure to PM$_{2.5}$ used in the estimates calculation for household air pollution will be revised as more and more data on indoor household air pollution PM2.5 measurements is available.
- Data on the contribution of household air pollution to ambient air pollution is getting more and more available and more thorough assessments will be available in the future.

**Exposure-risk relationship**

- Although the Integrated exposure response (IER) functions present clear improvements in terms of coherence and comprehensiveness, allowing to derive risks at high level of PM$_{2.5}$, they contained several important assumptions, including that the toxicity of PM$_{2.5}$ from ambient air pollution, household air pollution, second-hand smoke and active smoking is roughly the same.
- The IER functions have been developed for the GBD project (2,11) and have been further updated (14). Methodological developments of the IERs over time and various applications have resulted in different estimates of the burden of disease due to household air pollution, which created some misunderstanding.
- WHO has convened a consultation meeting in January 2017 to discuss the issues and challenges of these functions and one of the recommendations was that as the evidence base increases over time it is imperative that a consented approach of adaptation and improvement of the exposure-response functions over time is performed (13). This work is currently ongoing.

**References**


GBD 2016 IER estimates : https://cloud.ihme.washington.edu/index.php/s/puzbu28QteEHTmS


WHO/PHE events http://www.who.int/airpollution/events/

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