

Burden of disease from Household Air Pollution for 2012

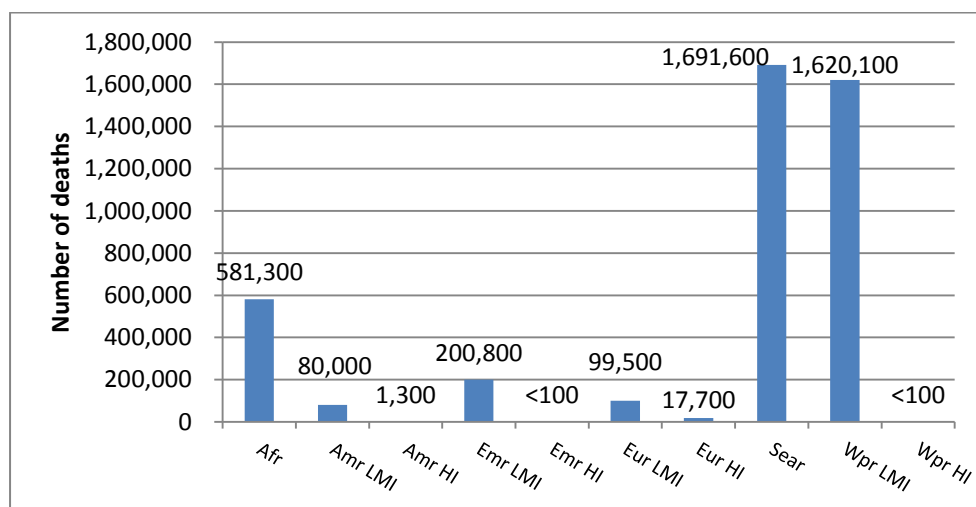
Summary of results

Globally, 4.3 million deaths were attributable to household air pollution (HAP) in 2012, almost all in low and middle income (LMI) countries. The South East Asian and Western Pacific regions bear most of the burden with 1.69 and 1.62 million deaths, respectively. Almost 600'000 deaths occur in Africa, 200'000 in the Eastern Mediterranean region, 99'000 in Europe and 81'000 in the Americas. The remaining 19'000 deaths occur in high income countries.

The large increase in burden compared with the previous estimate of 2 million deaths from HAP from 2004¹ is mainly due to 1) additional health outcomes such as cerebrovascular diseases and ischaemic heart disease included in the analysis²; 2) additional evidence that has become available on the relationship between exposure and health outcomes and the use of integrated exposure-response functions³; and 3) an increase in non-communicable diseases.

Although women experience higher personal exposure levels than men^{2,4} and therefore higher relative risk to develop adverse health outcomes due to their greater involvement in daily cooking activities, the absolute burden is larger in men due to larger underlying disease rates in men.

Figure 1. Total deaths attributable to HAP in 2012, by region



HAP: Household air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: High-income.

¹ *Global Health Risks*, World Health Organization, Geneva 2009.

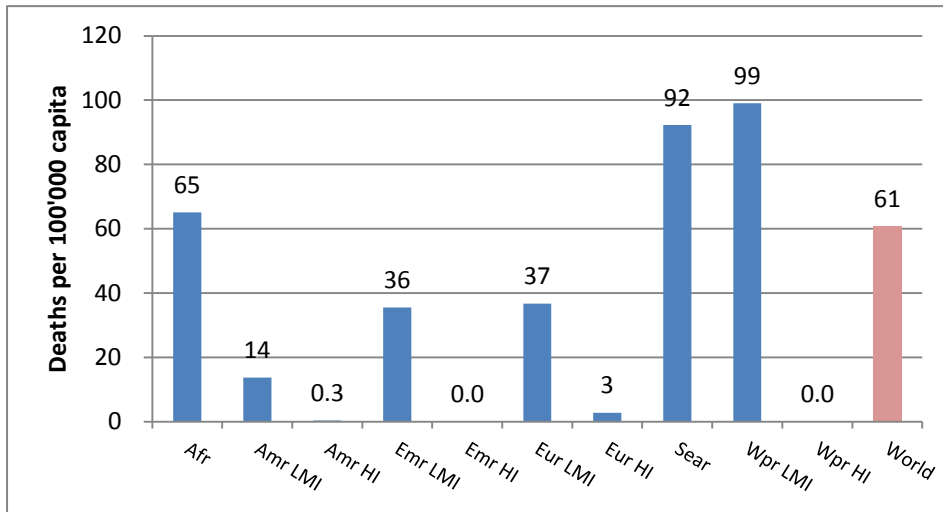
² Smith K, Bruce N et al. (2014). *Annu. Rev. Public Health*, Vol 35.

<http://www.annualreviews.org/doi/abs/10.1146/annurev-publhealth-032013-182356>.

³ Burnett R et al. (2014), *Environmental Health Perspectives*, advanced publication 7 February 2014, <http://dx.doi.org/10.1289/ehp.1307049>.

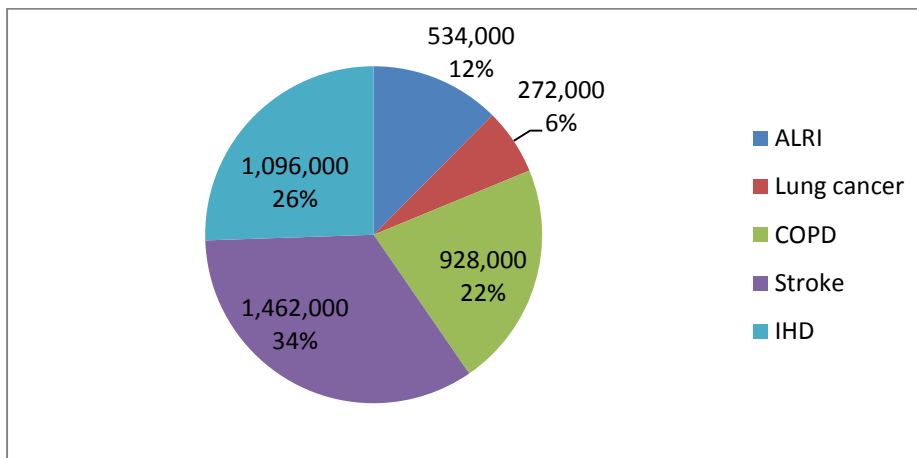
⁴ Balakrishnan K et al. (2013). *Environmental Health*, 12:77 <http://www.ehjournal.net/content/12/1/77>

Figure 2. Deaths per capita attributable to HAP in 2012, by region



HAP: Household air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: High-income.

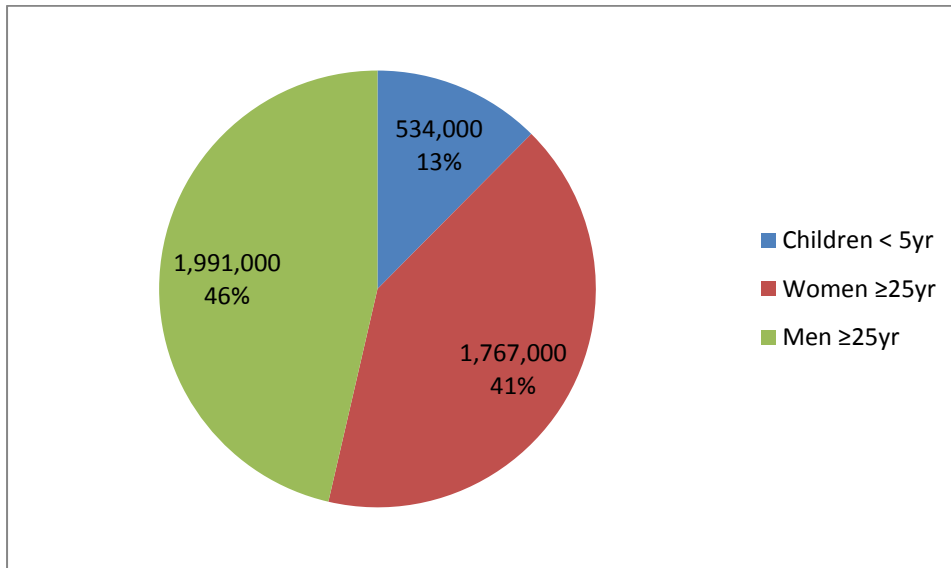
Figure 3. Deaths attributable to HAP in 2012, by disease



Percentage represents percent of total HAP burden (add up to 100%).

HAP: Household air pollution; ALRI: Acute lower respiratory disease; COPD: Chronic obstructive pulmonary disease; IHD: Ischaemic heart disease.

Figure 4. Deaths attributable to HAP in 2012, by age and sex



Percentage represents percent of total HAP burden (add up to 100%).

HAP: Household air pollution; yr: year.

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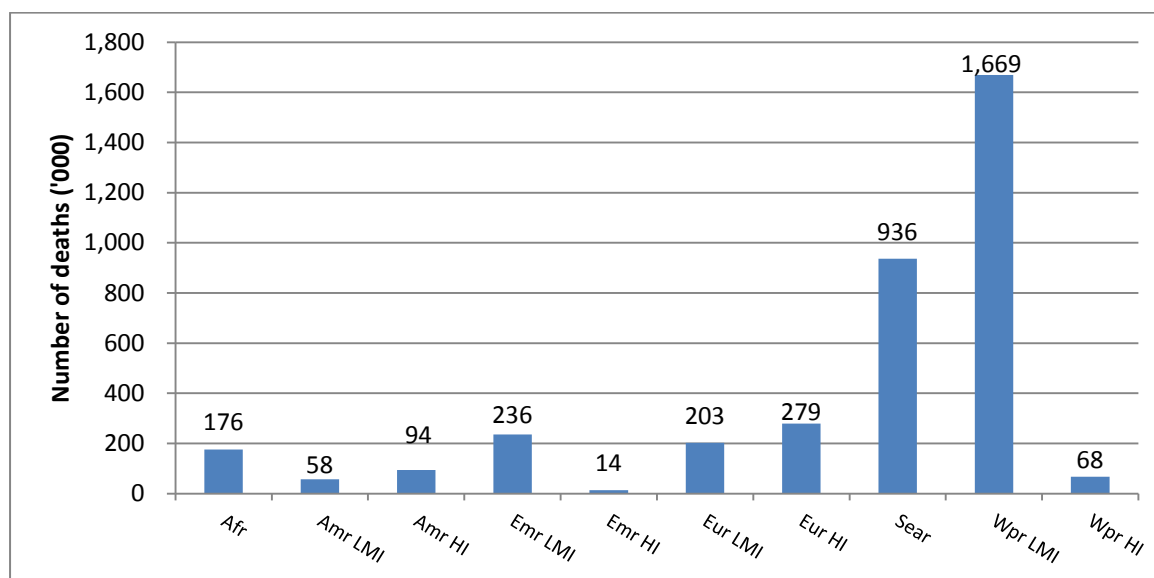
Burden of disease from Ambient Air Pollution for 2012

Summary of results

Globally, 3.7 million deaths were attributable to ambient air pollution (AAP) in 2012. About 88% of these deaths occur in low- and middle-income (LMI) countries, which represent 82% of the world population. The Western Pacific and South East Asian regions bear most of the burden with 1.67 million and 936'000 deaths, respectively. About 236'000 deaths occur in the Eastern Mediterranean region, 200'000 in Europe, 176'000 in Africa, and 58'000 in the Americas. The remaining deaths occur in high-income countries of Europe (280'000), Americas (94'000), Western Pacific (67'000), and Eastern Mediterranean (14'000).

The large increase in burden compared with the previous estimate of 1.3 million deaths from AAP from 2008¹ is due to 1) additional evidence that has become available on the relationship between exposure and health outcomes and the use of integrated exposure-response functions²; 2) an increase in non-communicable diseases; 3) the inclusion of the rural population, whereas the previous estimate only covered the urban population; and 4) the use of a lower counterfactual, i.e. the baseline exposure against which the effect of air pollution is measured³.

Figure 1. Total deaths ('000) attributable to AAP in 2012, by region



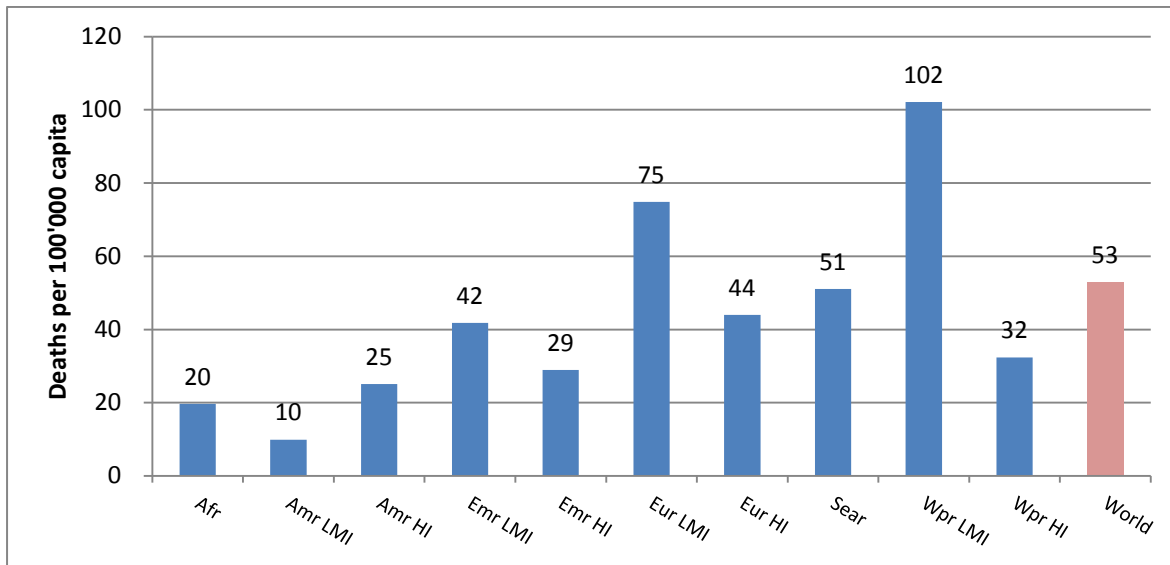
AAP: Ambient air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: High-income.

¹ *Burden of disease attributable to outdoor air pollution*, World Health Organization, Geneva 2011, www.who.int/phe/health_topics/outdoorair/databases/burden_disease/en/.

² Burnett R et al. (2014), EHP, <http://dx.doi.org/10.1289/ehp.1307049>.

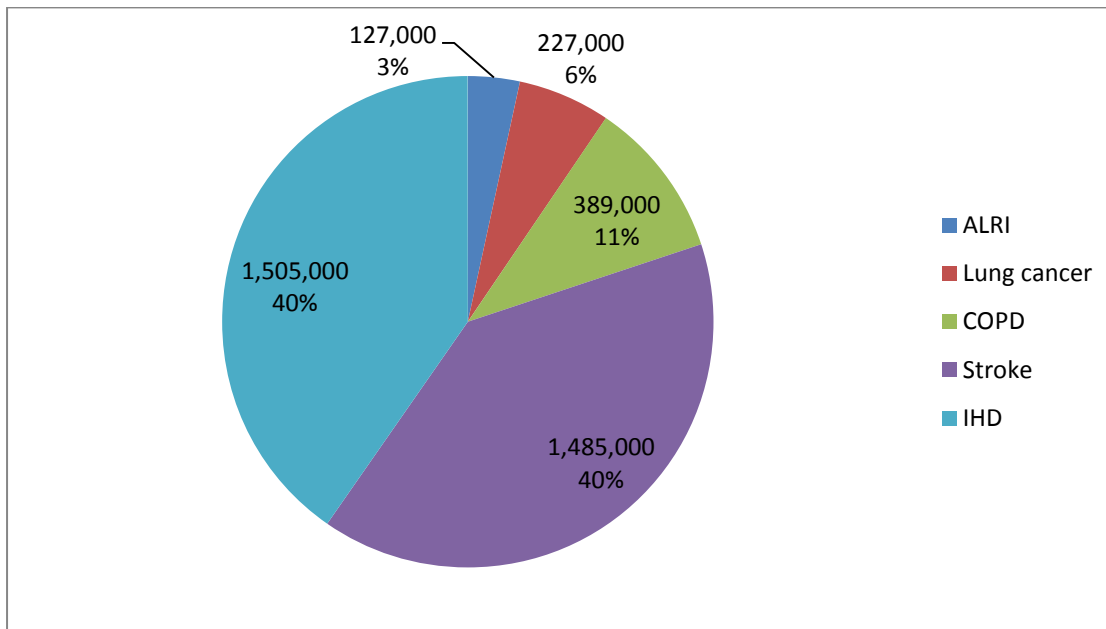
³ Previously, the 1.3 million deaths represented the health gains if the WHO Air Quality Guideline levels were reached.

Figure 2. Deaths per capita attributable to AAP in 2012, by region



AAP: Ambient air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: High-income.

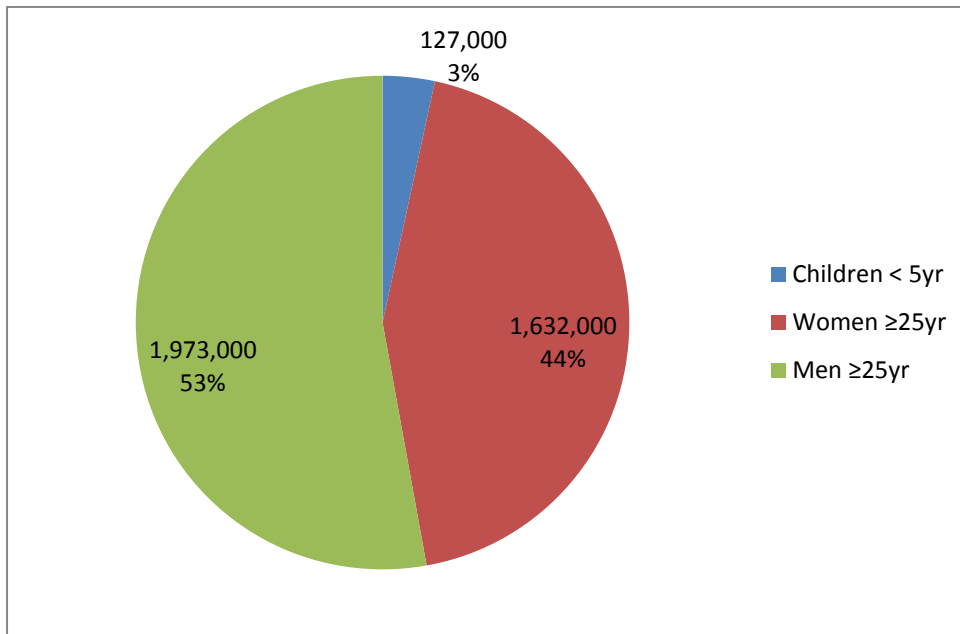
Figure 3. Deaths attributable to AAP in 2012, by disease



Percentage represents percent of total AAP burden (add up to 100%).

AAP: Ambient air pollution; ALRI: Acute lower respiratory disease; COPD: Chronic obstructive pulmonary disease; IHD: Ischaemic heart disease.

Figure 4. Deaths attributable to AAP in 2012, by age and sex



Percentage represents percent of total AAP burden (add up to 100%).

AAP: Ambient air pollution; yr: year.

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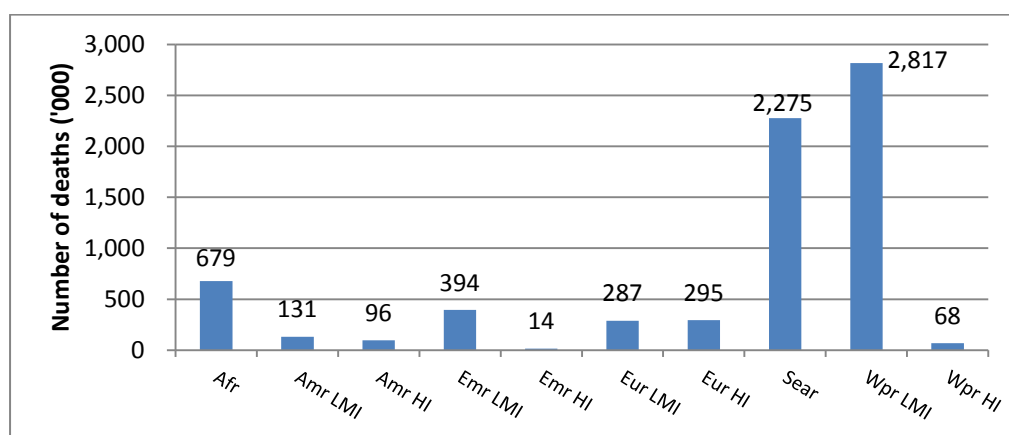
Burden of disease from the joint effects of Household and Ambient Air Pollution for 2012

Summary of results

Globally, 7 million deaths were attributable to the joint effects of household (HAP) and ambient air pollution (AAP) in 2012. The Western Pacific and South East Asian regions bear most of the burden with 2.8 and 2.3 million deaths, respectively. Almost 680'000 deaths occur in Africa, about 400'000 in the Eastern Mediterranean region, 287'000 in Europe and 131'000 in the Americas. The remaining deaths occur in high-income countries of Europe (295'000), Americas (96'000), Western Pacific (68'000), and Eastern Mediterranean (14'000).

Note of caution: An approximation of the combined effects of risk factors is possible if independence and little correlation between risk factors with impacts on the same diseases can be assumed¹. In the case of air pollution, however, there are some limitations to estimate the joint effects: limited knowledge on the distribution of the population exposed to both household and ambient air pollution, correlation of exposures at individual level as household air pollution is a contributor to ambient air pollution, and non-linear interactions^{2,3}. In several regions, however, household air pollution remains mainly a rural issue, while ambient air pollution is predominantly an urban problem. Also, in some continents, many countries are relatively unaffected by household air pollution, while ambient air pollution is a major concern. If assuming independence and little correlation, a rough estimate of the total impact can be calculated, which is less than the sum of the impact of the two risk factors. The joint effects of both ambient and household air pollution would result in the impacts shown in Figure 1-4. Given the limitations, however, the estimates presented below should be interpreted with caution, and provide indicative values only.

Figure 1. Total deaths attributable to the joint effects of HAP and AAP in 2012, by region



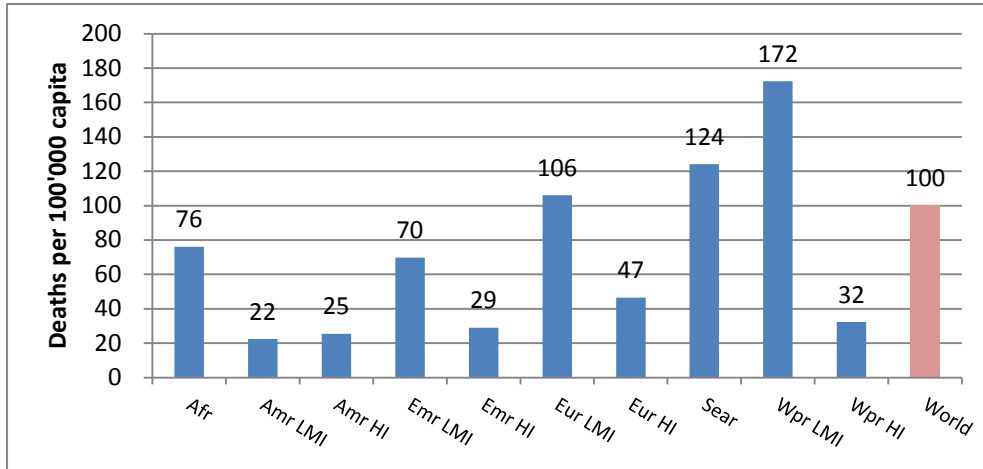
HAP: Household air pollution; AAP: Ambient air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: High-income.

¹ Ezzati et al (2003), *The Lancet*, 362:271-80.

² Lim et al (2012), *The Lancet*, 380:2224-2260.

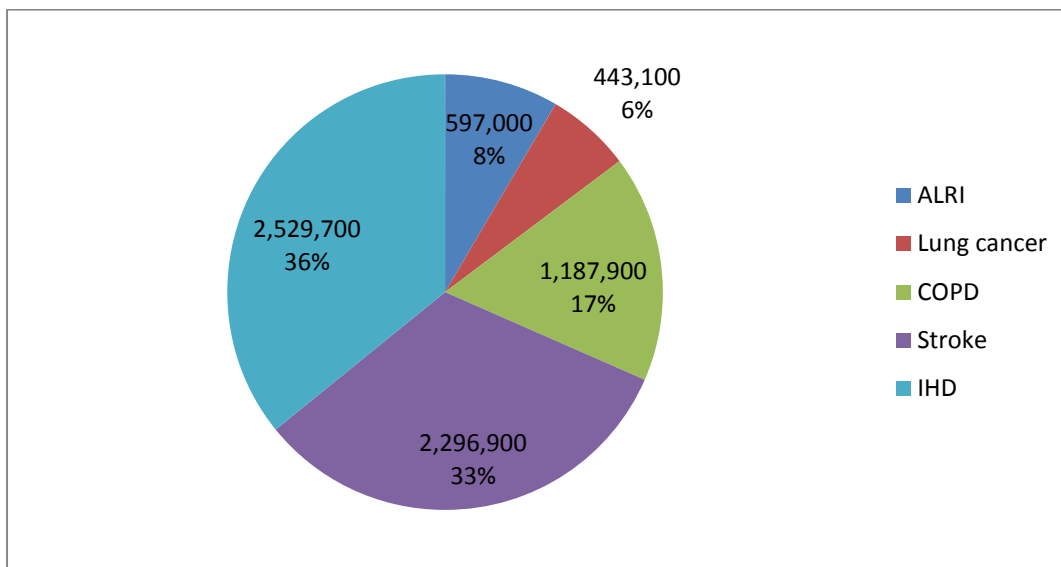
³ Smith, Bruce, Balakrishnan et al (2014), *Annual Review of Public Health*, in press.

Figure 2. Deaths per capita attributable to the joint effects of HAP and AAP in 2012, by region



HAP: Household air pollution; AAP: Ambient air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: High-income.

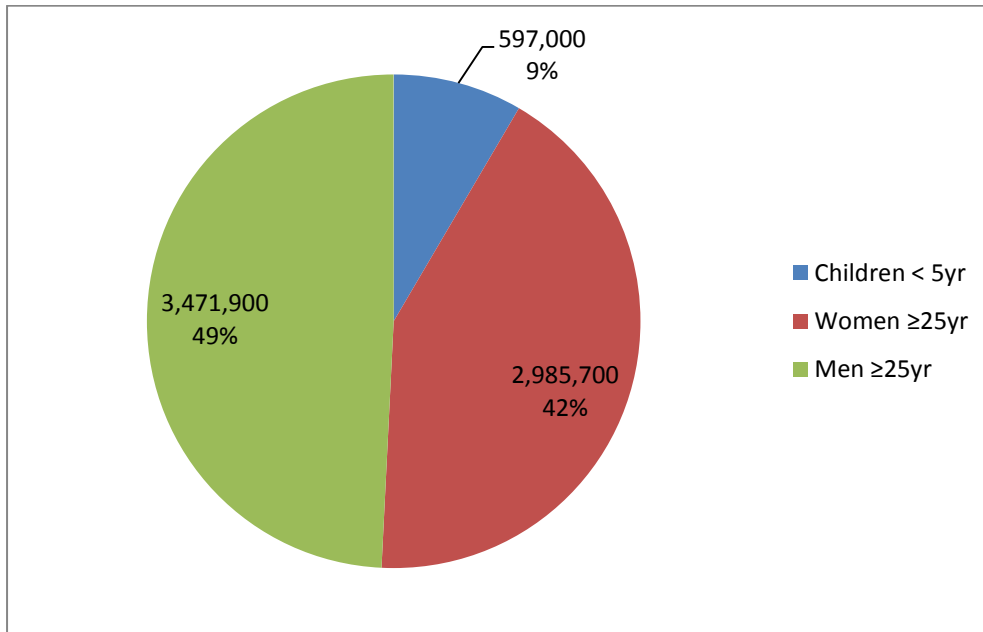
Figure 3. Deaths attributable to the joint effects of HAP and AAP in 2012, by disease



Percentage represents percent of total HAP burden (add up to 100%).

HAP: Household air pollution; AAP: Ambient air pollution; ALRI: Acute lower respiratory disease; COPD: Chronic obstructive pulmonary disease; IHD: Ischaemic heart disease.

Figure 4. Deaths attributable to the joint effects of HAP and AAP in 2012, by age and sex



Percentage represents percent of total burden (add up to 100%).

HAP: Household air pollution; AAP: Ambient air pollution; yr: year.

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Burden of disease from Household Air Pollution for 2012

Description of method

Version 1.2

The burden of disease attributable to household air pollution was estimated for the year 2012 based on Comparable Risk Assessment methods (1) and methods developed by IHME (Institute for Health Metrics and Evaluation) and expert groups for the Global Burden of Disease (GBD) 2010 study (2-3).

Source of the data

Health data

The total number of deaths and DALYs (disability-adjusted life years) by disease, country, sex and age group have been developed by the World Health Organization (4).

Exposure data

Modelled estimates for 2012 of the percentage of the population using solid fuels for cooking have been developed by the World Health Organization (5) according to methods described in Bonjour et al. (6) and were used as basis for disease burden calculation.

Exposure-risk relationships

The integrated exposure-response functions (IER) developed for the GBD 2010 study were used for ALRI (acute lower respiratory infections), lung cancer, stroke and IHD (ischaemic heart disease) (7) (Table 1). Personal exposure values for women, men and children were derived by Balakrishnan et al. (8) for the GBD 2010 (Table 2).

For COPD (chronic obstructive pulmonary disease), the relative risks from the systematic review / meta-analysis conducted for the GBD 2010 study were used (3).

Table 1. Relative risks

Disease	RR (95% CI) women	RR (95% CI) men	Reference
ALRI	2.9 (2.0-3.8) for children		(3, 7)
COPD	2.3 (1.7- 3.1)	1.9 (1.2- 3.1)	(3)
Lung cancer	2.3 (1.5-2.8)	1.9 (1.4-2.3)	(3, 7)
IHD	(1.4-2.2)	(1.4-2.2)	(3, 7)
Stroke	(1.4-2.4)	(1.3-2.4)	(3, 7)

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. Children refer to children under 5 years.

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 over all ages.

Table 2. Personal exposure values

Group	Mean PM _{2.5} (95% CI)	Reference
Children	285 $\mu\text{g}/\text{m}^3$ (201,405)	(3, 8)
Women	337 $\mu\text{g}/\text{m}^3$ (238,479)	(3, 8)
Men	204 $\mu\text{g}/\text{m}^3$ (144,290)	(3, 8)

PM_{2.5}: particulate matter with a diameter of 2.5 micrometre or less; CI: confidence interval. . Women, resp. men, refer to adult women, resp. men aged ≥ 25 years. Children refer to children under 5 years.

Demographic data

Population data used were from the United Nations Population Division, Revision 2012 (9).

Methods

Estimation of disease burden

The percentage of the population exposed to household air pollution was provided by country; relative risks were calculated separately for men, women and children, based on the integrated exposure-response functions (IER) for all diseases but COPD. The counterfactual concentration was selected to be between 5.8 and 8.8 $\mu\text{g}/\text{m}^3$, as described in (2) and (6). The country population attributable fractions for ALRI, COPD, LC, stroke and IHD were calculated using the following formula:

$$(1) PAF = \frac{P_e(RR-1)}{P_e(RR-1)+1}$$

where P_e is the percentage of the population exposed to that level of air pollution, i.e. the percentage of the population using solid fuels for cooking.

Uncertainty analysis

The uncertainty intervals are based on the 2.5th and 97th percentiles of 1000 draws for the relative risks of the integrated exposure-response functions, the personal exposure values and the modelled solid fuel use estimates. Uncertainty is however still underestimated given that uncertainty for baseline mortality is not taken into account.

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Burden of disease from Ambient Air Pollution for 2012

Description of method

Version 1.3

The burden of disease attributable to ambient air pollution was estimated for the year 2012 based on Comparable Risk Assessment methods (1) and methods developed by IHME (Institute for Health Metrics and Evaluation) and expert groups for the Global Burden of Disease (GBD) 2010 study (2).

Source of the data

Health data

The total number of deaths and DALYs (disability-adjusted life years) by disease, country, sex and age group have been developed by the World Health Organization (3).

Exposure data

Annual mean estimates of particulate matter of a diameter of less than 2.5 $\mu\text{g}/\text{m}^3$ ($\text{PM}_{2.5}$) were modelled using a combination of estimates from data provided by satellites, outputs from the global chemical transport model TM5, and ground measurements (4). The output of the model was based on a grid of $0.1^\circ \times 0.1^\circ$. Values were developed for 1990 and 2005, and extrapolated estimates for 2010 were used as basis for disease burden estimation (2).

Exposure-risk relationships

The integrated exposure-response functions (IER) developed for the GBD 2010 study were used for ALRI (acute lower respiratory infections), lung cancer, COPD (chronic obstructive pulmonary disease), stroke and IHD (ischaemic heart disease) (5).

Demographic data

Population data used were from the United Nations Population Division, Revision 2012 (6).

Methods

Estimation of disease burden

The percentage of the population exposed to $\text{PM}_{2.5}$ was provided by country and by increment of $1 \mu\text{g}/\text{m}^3$; relative risks were calculated for each $\text{PM}_{2.5}$ increment, based on the integrated exposure-response functions (IER). The counterfactual concentration was selected to be between 5.8 and $8.8 \mu\text{g}/\text{m}^3$, as described in (2) and (5). The country population attributable fractions for ALRI, COPD, LC, stroke and IHD were calculated using the following formula:

$$(1) \quad PAF = \frac{\sum_{i=1}^n P_i (RR-1)}{\sum_{i=1}^n P_i (RR-1) + 1}$$

where i is the level of $\text{PM}_{2.5}$ in $\mu\text{g}/\text{m}^3$, and P_i is the percentage of the population exposed to that level of air pollution.

Uncertainty analysis

The uncertainty intervals are based on the following sources of uncertainty: (a) uncertainty around relative risks of the integrated exposure-response function, and (b) a semi-quantitative estimation of uncertainty in exposure to $\text{PM}_{2.5}$ based on the difference between modelled exposures and ground level measurements. For the integrated exposure-response function, 1,000 draws of each parameter of the function were obtained from Burnett and co-workers (5) and population attributable fractions were calculated for each draw. To account for

uncertainty in exposure, alternative burden of disease estimates were developed based on ground level measurements available for urban areas, combined with modelled PM data for rural areas. These were used as upper or lower ends of triangular uncertainty distribution by region. The other end of the triangular distribution was calculated as by halving the difference in burden. The final uncertainty intervals were obtained as the 2.5 and 97.5 percentiles of the draws from the combined uncertainties. Uncertainty for baseline mortality was not taken into account.

Further rationale and information on exposure data used

Previous burden of disease estimates have mainly been based on urban ground measurements (7). While reliable ground measurements, when performed in locations representative for human exposure such as in residential or commercial areas, are best representing exposure in those specific locations, they are unfortunately only available in a limited number of locations and cities worldwide. Furthermore, in many developing countries measurements are often limited to PM₁₀, and a conversion factor needs to be applied to estimate PM_{2.5} levels which are needed to estimate health risks. Finally, exposure in rural areas have been poorly documented in many areas. Particularly where urban emissions travel outside urban agglomerations, and where solid fuels are burned in households for cooking or heating, rural exposures to particulate matter can be substantial. For these reasons, a more comprehensive set of modelled exposure has been used as a basis for burden of disease estimation (4).

Apart from the strengths, the modelled dataset also has a number of weaknesses, and further improvement is required in order to improve accuracy. The main weaknesses include the following: (a) Time of estimation. The currently available modelled data are based on satellite data, emission inventories and ground measurements some of which date back several years. Collecting and processing all the required data represents a heavy process and a full cycle can take several years. A new cycle is currently under way, and data will be updated as soon as they become available. (b) Divergence of modelled data from measured data. Modelled data do not always match measured data. This can be due for example to measurement error or non-representative locations in ground measurements, inadequate calibration of the model to ground measurements, insufficient information in the emission inventory or time lag between the modelling cycle and the availability of new ground measurement data. (c) Limited information on rural exposure. Limited information is currently available on rural exposures, and the validity of the model therefore needs to be further evaluated for these areas. The use of combined data from remote sensing and emission models which have been verified in urban areas nevertheless represents an advancement over assuming no exposure in rural areas as done previously.

The combined remote sensing/chemical transport/ground measurement model should, for the reasons enumerated above, be seen as work in progress, but they nevertheless present an advantage over the use of ground measurement alone as a basis for burden of disease estimation. It is anticipated that future rounds will gradually improve accuracy. Countries are further encouraged to improve ground measurements in order to improved calibration of the model and thereby produce more comprehensive and coherent exposure estimates for the entire population within a country. A number of sensitivity analyses have been performed in order to estimate the variation on results according to various exposure assumptions and datasets, in view of further characterizing uncertainty. Given those uncertainties, results are currently provided only for the regional and global level. Further improvements in the methods used for modelling exposure should lead to improved country estimates. These are currently being refined in particular for certain low- and middle-income countries.

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Burden of disease from joint Household and Ambient Air Pollution for 2012

Description of method

The burden of disease attributable to the joint effects of household and ambient air pollution for the year 2012 was estimated based on the calculation of the joint population attributable fractions assuming independently distributed exposures and independent hazards as described in (1). The joint population attributable fractions (PAF) were calculated using the following formula:

$$PAF = 1 - \prod_{i=1}^n (1 - PAF_i)$$

where PAF_i is PAF of individual risk factors.

Detailed method descriptions of the separate burden of disease attributable to household and ambient air pollution are described elsewhere (2).

Note of caution

An approximation of the combined effects of risk factors is possible if independence and little correlation between risk factors with impacts on the same diseases can be assumed (1). In the case of air pollution, however, there are some limitations to estimate the joint effects: limited knowledge on the distribution of the population exposed to both household and ambient air pollution, correlation of exposures at individual level as household air pollution is a contributor to ambient air pollution, and non-linear interactions (3, 4). In several regions, however, household air pollution remains mainly a rural issue, while ambient air pollution is predominantly an urban problem. Also, in some continents, many countries are relatively unaffected by household air pollution, while ambient air pollution is a major concern. If assuming independence and little correlation, a rough estimate of the total impact can be calculated, which is less than the sum of the impact of the two risk factors. The joint effects of both ambient and household air pollution would result in the impacts shown the document “Burden of disease from the joint effects of Household and Ambient Air Pollution for 2012”. Given the limitations, however, the estimates presented should be interpreted with caution, and provide indicative values only.

References

1. Ezzati M, Vander Hoorn S, Rodgers A, Lopez AD, Mathers CD et al. Estimates of global and regional potential health gains from reducing multiple major risk factors. *Lancet*. 2003;362:271-80.
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