CHAPTER 9. HOUSEHOLD AIR POLLUTION

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Household air pollution arising from the use of coal has long been recognized as a cause of lung cancer and possibly of cancers at other sites. Drawing on data from 19 studies in an unpublished review (unpublished review prepared for the Advisory Group to plan a series of IARC Monographs on air pollution and cancer, IARC, 2004), Tian and Smith investigated the risk of lung cancer associated with exclusive coal or mixed coal and biomass use for cooking and/or heating, from which they derived pooled, adjusted odds ratios (ORs) of 1.86 (95% confidence interval [CI], 1.48–2.35) for studies of men and women combined, 1.51 (95% CI, 0.97–2.46) for men only, and 1.94 (95% CI, 1.09–3.47) for women only. Tian and Smith also reviewed the prevalence of coal use, pointing out the extensive use in China and possible increases in rural areas, mechanisms of toxicity, tentative evidence for links with upper aerodigestive tract (UADT) cancers, and the presence of contaminants including arsenic (a known carcinogen for bladder, lung, and skin). The review concluded that tens of thousands of cancer deaths may be attributed to coal use in China, and that similar risks (although involving fewer households) were likely in other countries such as India and South Africa where coal is used in low-quality stoves for cooking and heating.

Since that review was conducted, several new studies and reports have become available that warrant updating this evidence. In 2010, the International Agency for Research on Cancer (IARC) published a Monograph on household use of solid fuels and high-temperature frying (IARC, 2010). Two new systematic reviews on coal and lung cancer have been published (Hosgood *et al.*, 2011; Kurmi *et al.*, 2012), one of which includes biomass and lung cancer (Kurmi *et al.*, 2012), and another review has been initiated by Bruce *et al.* (unpublished work). Reviews carried out for the Global Burden of Disease (GBD) 2010 project's comparative risk assessment (CRA) included updating evidence on cancers of the UADT and uterine cervix, although evidence for these outcomes was not sufficient for inclusion in the GBD estimates. Results from this new CRA, which do include lung cancer from both coal and biomass use, were recently published (Lim *et al.*, 2012). There is also concern about the health implications of kerosene use for cooking and lighting in developing countries, where simple stoves and lamps known to emit high levels of pollutants are often used. Currently, however, relatively few studies of cancer risk are available (Lam *et al.*, 2012). Accordingly, this update reviews the existing evidence on cancer risks associated with household use of both coal and biomass, with brief consideration of kerosene.

Trends in exposure

The World Health Organization (WHO) compiles data on household fuel use for cooking obtained through nationally representative surveys to assess risk from household air pollution exposure and to monitor trends (WHO, 2012a). Data from 586 surveys for 155 countries for 1974–2010 are available. The headline indicator *percentage of homes using solid fuels as their primary cooking fuel* is updated and published by WHO each year (WHO, 2012b), and a report on trends was recently published (Bonjour *et al.*, 2013). Data on specific fuel type are available, and work is in progress to summarize these for cooking, heating, and lighting.

Solid fuel

Although the percentage of homes using solid fuels as the primary cooking fuel has fallen from 62% in 1980 to 41% in 2010, due to population growth the total number of people affected has remained steady at 2.8 billion (Bonjour *et al.*, 2013). Prevalence is highest in Africa (77%) and South-East Asia (61%), but such fuels are still used by almost half (46%) of the population in the western Pacific region (Figure 9.1). The great majority of solid fuel use is biomass (i.e. wood, animal dung, crop waste, and charcoal), which is estimated to be used by approximately 2.4 billion people. Waste materials, including plastics, are also reportedly used as household fuels and may present cancer risks, but we are not aware of any reliable estimates of their use or of studies of health risks they impose.

Coal

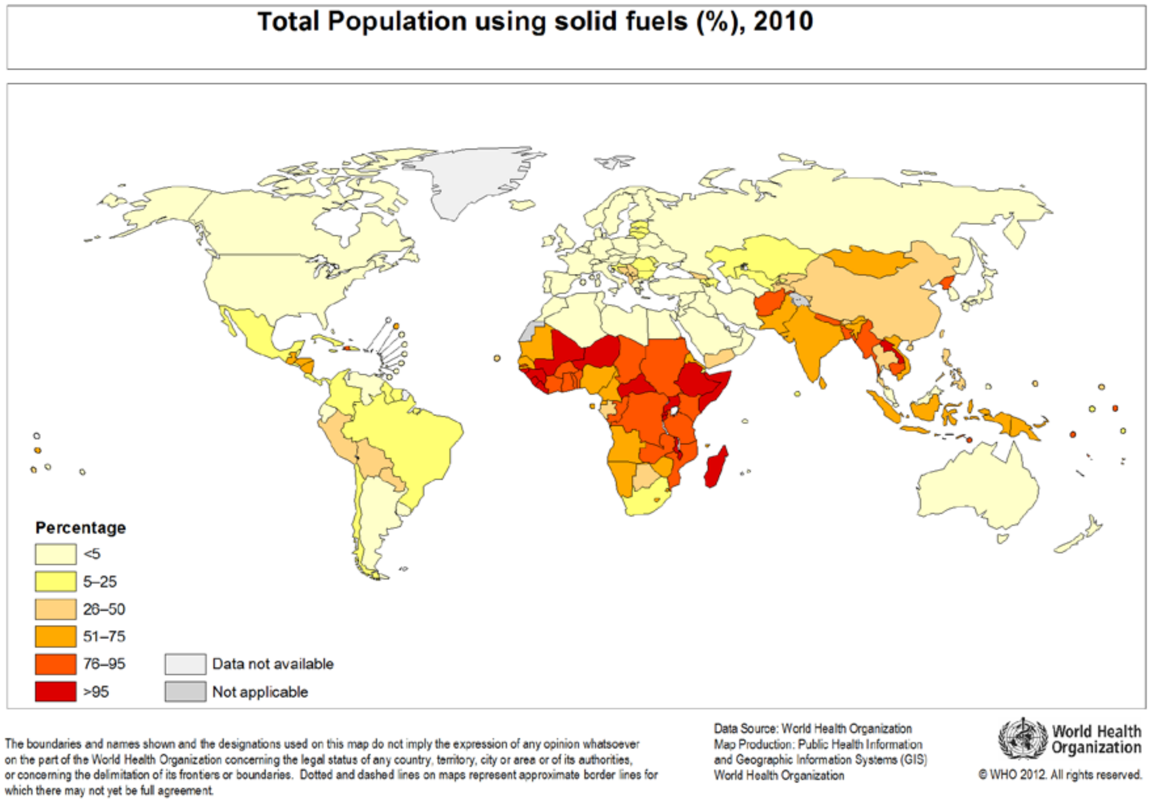
Coal continues to be used by substantial numbers of households for cooking and heating, although data on heating use are sparse. Table 9.1 summarizes estimates for the percentage of homes (and equivalent populations) using coal for cooking in countries for which nationally representative surveys conducted since 2005 are available. China has the largest number of users, with 25% of homes still using coal in 2005, although several other countries have similar proportions of users. Even though only 2% of homes in India are thought to be using coal for cooking, given the population of 1.22 billion (2012) this figure translates into more than 20 million people at risk of exposure in homes that use coal for cooking, in addition to other residents of neighbourhoods where coal is used. While there has been a downward trend in some countries, as noted by Tian and Smith in their unpublished review, coal use may be increasing in rural China as biomass becomes scarcer.

Assuming that the percentage of homes relying on coal has changed minimally, if at all, since the most recent survey, the total number of people using coal for cooking in 2010 is estimated to be about 400 million, with more than 300 million in China alone (assuming that the percentage of households using coal on the most recent national survey [2005 or later] is equivalent to the percentage of the total 2010 national population). Currently, no useful estimates are available of the number of people using coal for heating because many homes using coal for cooking will also use it for heating, while others cooking with cleaner fuels will use coal for heating. Exposure levels resulting from coal heating can be expected to vary markedly between countries and settings, depending on the nature and quality of the stove, the coal, and the presence or absence and condition of the flue or chimney used.

Kerosene

The use of kerosene as the primary cooking fuel varies widely between developing countries, from zero to > 50% in urban areas of some countries, including Indonesia, Kenya, and Nigeria. Generally, use of kerosene for cooking is greater in urban than in rural areas. For most developing

Fig 9.1 Households using solid fuels as the primary cooking fuel, by country, 2010.



Source: WHO (2012b); reproduced with permission from the World Health Organization.

countries, the proportion is < 10% in urban areas and < 5% overall (WHO, 2012a). The situation for lighting, however, is quite different as kerosene is the primary fuel for the great majority of homes where electricity is unavailable or unreliable, especially in sub-Saharan Africa. Use in rural areas is as great as, or greater than, that for urban homes, where electricity is more available. The majority of homes using this fuel for lighting do so with simple wick lamps.

IARC Monograph on household use of solid fuels and high-temperature frying

The IARC Monograph on household solid-fuel use, based on an expert group meeting held in 2006, reviewed the evidence from human epidemiological studies, animal studies, and mechanistic work and classified household coal use as carcinogenic (Group 1) and biomass use and high-temperature frying as probably carcinogenic (Group 2A) (IARC, 2010).

For coal, more than 20 case–control studies and one cohort study of lung cancer were reviewed, and those deemed to be most informative showed significant exposure–response relationships. Pooled estimates were not obtained as the purpose was to establish carcinogenicity, not

Table 9.1 Recent estimates from national surveys of the proportion of households primarily using coal for cooking

Country	Year	Survey[a]	Proportion of households (%)	Population using coal[b]
Afghanistan	2010	MICS	< 1	–
Antigua and Barbuda	2007	National Survey	1	887
Bhutan	2010	MICS	< 1	–
Bosnia and Herzegovina	2005	MICS	1	37 601
Burkina Faso	2006	National Survey	1	164 687
China	2005	Census	25	335 333 800
Congo	2009	DHS	3	121 287
Democratic People's Republic of Korea	2008	Census	46	11 199 270
Dominican Republic	2007	DHS	4	397 093
Guinea	2005	DHS	19	1 896 502
India	2006	National Survey	2	24 492 290
Kazakhstan	2005	MICS	15	2 403 955
Kenya	2008	DHS	1	405 127
Kyrgyzstan	2005	MICS	14	746 791
Lao People's Democratic Republic	2006	MICS	21	1 302 188
Mongolia	2005	MICS	19	523 640
Montenegro	2005	MICS	4	25 260
Peru	2010	National Survey	3	872 295
Serbia	2010	MICS	< 1	–
Solomon Islands	2007	National Survey	2	10 763
South Africa	2010	National Survey	1	501 328
Sudan	2006	National Survey	14	6 097 272
Swaziland	2006	National Survey	< 1	–
Tajikistan	2005	MICS	1	68 786
Ukraine	2007	DHS	2	908 967
Viet Nam	2011	MICS	2	2 020 514

[a] DHS, Demographic Health Survey, USAID; MICS, Multi-Cluster Indicator Survey, UNICEF.
[b] Values are estimated by multiplying the percentage of households primarily using coal for cooking by the 2010 population figures.
Compiled from WHO (2012a).

effect size. For biomass, 13 case–control studies of lung cancer were reviewed. While many showed significantly increased risk with exposure, those deemed to be most informative did not provide data on duration of use or other measures from which exposure–response relationships could be assessed. Several other epidemiological studies of lung cancer that combined biomass and coal in the exposed groups or used proxies (such as years of cooking, perceived smokiness, reported fumes from cooking, and kitchen location) were also reviewed. Studies of other cancer sites including UADT and uterine cervix were reviewed, but no firm conclusions about causality could be reached (further details below).

In the overall evaluation of household coal use, the human epidemiological research was assessed as providing sufficient evidence of carcinogenicity, as was the animal evidence on carcinogenicity of emissions and of extracts from coal-derived soot. For biomass, the human epidemiological evidence was assessed as limited, as was the animal evidence on carcinogenicity of emissions, although the evidence for carcinogenicity of woodsmoke extracts was judged to be sufficient.

Reviews of household fuels and lung cancer since 2006

Coal use

Sixteen English-language and nine Chinese-language case–control studies published through 2009 were reviewed using criteria that included specifying coal use distinct from biomass use (Hosgood *et al.*, 2011). The intervention-based study that reported ORs of 0.59 (95% CI, 0.49–0.71) for men and 0.54 (95% CI, 0.4–0.65) for women (Lan *et al.*, 2002) was not included in the meta-analysis by Hosgood *et al.* (2011), as this was restricted to case–control studies. The overall pooled OR for all studies was 2.15 (95% CI, 1.61–2.89), but this was associated with very substantial statistical heterogeneity (I^2 = 90.4%).

The majority of studies were from mainland China and Taiwan, China, and were used for more detailed sensitivity analysis focused on identifying estimates by sex and determining whether design issues affected the risk estimates in any substantive way. Pooled ORs were 2.50 (95% CI, 1.56–4.00) for women (eight studies) and 2.76 (95% CI, 1.44–5.27) for men (three studies). For nonsmoking women (three studies) the OR was 2.93 (95% CI, 1.40–6.12), but no studies were available for nonsmoking men. Various study design features did not produce very different effect estimates, other than for three rural studies with an OR of 3.28 (95% CI, 1.46–7.39). This finding may, however, have been confounded by geographical variations across China, analysis of which found the highest risk (OR > 2.5) among six studies in the south, south-eastern, and south-western parts of the country, including Xuan Wei. A key conclusion of the review was that while risks of lung cancer with household coal use may vary by location and type, elevated risks are seen with coal use across a wide range of settings.

The second systematic review, published by Kurmi *et al.* (2012), examined cancer risk with exposure to both coal and biomass (see below). For coal, 22 studies including Chinese-language studies were included. While all study designs were eligible, most were case–control in design and inclusion criteria required that effect estimates were adjusted. The overall pooled OR was 1.82 (95% CI, 1.60–2.06), with evidence of statistical heterogeneity (I^2 = 43.4%). Sensitivity analysis reported pooled ORs of 1.54 (95% CI, 1.25–1.88) for men (three studies) and 1.70 (95% CI, 1.40–2.06) for women (10 studies), and a larger effect in the studies combining men and women. Analysis by histological type found the largest risk for squamous cell carcinoma (five studies) (OR, 3.81; 95% CI, 1.37–10.58) compared with adenocarcinoma (four studies) (OR, 2.22; 95% CI, 1.60–3.08), but histology was not available for the majority (16 studies). Effect estimates for smoking-adjusted studies and nonsmokers were very similar. Notable among other methodological subgroup analyses was a larger effect for Chinese-language studies (which may relate to higher exposures in that country, or parts of it as identified by Hosgood *et al.*, 2011) and a trend of increasing effect estimates with lower quality exposure assessment (based on the Newcastle-Ottawa scale).

Conclusion: coal and lung cancer

Coal continues to be widely used as a cooking fuel by approximately 400 million people, with an additional unknown number using coal for heating. The 2010 IARC Monograph on household use of solid fuel and high-temperature frying found household use of coal to be a Group 1 carcinogen. Recent systematic reviews provide estimates of the increased risk of lung cancer associated with exposure to be about 2.0, with higher risk in women (> 2) reflecting their higher levels of exposure. The geographical variation in reported risk estimates, which are highest in southern China (> 2.5), may well reflect higher exposures as well as use of coal with greater carcinogenic potential. However, nearly all of the available studies lacked measurements of particulate matter (PM) or other indicators. Consequently, the exposure gradients within the studies cannot be quantified and also cannot be compared across studies; however, considerable variation in levels and exposure gradients across the studies is likely. Contaminants in coal, including arsenic, present additional risk. WHO estimated that coal used for cooking was responsible for 36 000 lung cancer deaths in 2004. Given the technological challenges in burning coal cleanly in homes (including removal of toxins such as arsenic), policy on household fuel use should aim for the complete substitution of coal with cleaner fuels and should closely monitor levels and trends in the household use of coal.

Biomass

Given that biomass is used by some 2.4 billion people for cooking, even a small elevated cancer risk would, if confirmed, have very important public health implications. As noted above, the human epidemiological evidence on biomass and cancer was assessed by IARC as limited, although some support for carcinogenicity was available from animal (limited) and mechanistic (sufficient) studies. The reviews published and in preparation since the 2006 IARC workshop provide some new and updated perspectives on the evidence.

The published review, part of the same paper that reported on coal and lung cancer risk, found seven studies, including one with separate estimates for males and females and one with estimates for squamous cell carcinoma and adenocarcinoma, but none in the Chinese language (Kurmi *et al.*, 2012). Two other studies included mixed coal and biomass use in the exposed group. In a pooled analysis, there was marginally significant statistical heterogeneity (I^2 = 41.2%, *P* = 0.092) and an OR of 1.50 (95% CI, 1.17–1.94). A set of sensitivity analyses similar to those for coal were carried out, although the relatively small number of studies limited the conclusions. The OR for females (five studies) was 1.98 (95% CI, 1.44–2.73), but there was only one estimate for males. Only two of the studies provided data by histological type. There was no assessment of exposure–response data.

The review by Bruce *et al.* (unpublished work) searched for studies on household use of biomass, but required estimates for cooking (separate from other uses such as heating) for the GBD 2010 analysis, and found 11 case–control studies eligible for meta-analysis. These included a re-analysis of data from the European study by Lissowska *et al.* (2005) carried out by IARC for this review in order to obtain sex-stratified estimates for cooking and to examine exposure–response relationships. There was no evidence of publication bias, moderate heterogeneity (I^2 = 41%), and a pooled OR of 1.23 (95% CI, 1.03–1.48), but with evidence of a larger but marginally nonsignificant effect for women of 1.31 (95% CI, 0.99–1.74), *P* = 0.06 when stratified by sex.

As noted previously, all of the studies used proxy descriptions for exposure measurements. Of crucial importance was the finding that seven (of the 11) studies did not specify the type of cooking fuel used in the *unexposed* group and, in at least one study, wood may have been compared with some solid fuel use including coal (Gupta *et al.*, 2001). Sensitivity analysis of the studies for which the comparison group used cleaner fuel found stronger and significant ORs of 1.26 (95% CI, 1.04–1.52) for men (two studies) and 1.81 (95% CI, 1.07–3.06) for women (five studies). A recent report of a pooled analysis of previously unpublished data from four European and North American studies found a significant risk for wood use for cooking or heating of 1.21 (95% CI, 1.06–1.38) (Hosgood *et al.*, 2010), but this report was excluded from the meta-analysis because wood use for heating and cooking were combined. Assessment of exposure–response data found no good evidence of such a relationship except in the re-analysis of Lissowska *et al.*

(2005), which was based on duration of wood use for heating or cooking as a percentage of lifetime use. There was a significant ($P < 0.01$) adjusted trend for men but not for women; similar findings for use of coal for heating or cooking were reported.

Summary: biomass and lung cancer

Biomass is still used as the primary cooking fuel by approximately 2.4 billion people, while many more use wood for heating, including in rural areas of developed countries. Although the trend is generally downward for biomass as a cooking fuel, levels remain high in some countries, with little change in the past 10 years, notably in sub-Saharan Africa. Household use of biomass fuel was assessed as probably carcinogenic (Group 2A) by IARC. Since the 2006 IARC review, a few new studies of lung cancer and a re-analysis of one have strengthened the epidemiological evidence somewhat, but it is still hampered by poor definition of exposure comparisons and limited exposure–response data. However, with pooled ORs only slightly less than those for coal, the presence of known carcinogens in wood smoke, and IARC's assessment of animal and mechanistic evidence, it seems highly probable that biomass smoke at the levels common across developing countries increases the risk of lung cancer. Further evidence comes from a recent analysis of the exposure–response relationship for combustion-derived fine PM ($PM_{2.5}$) and lung cancer, which includes estimates from both second-hand and active smoking, a form of exposure to pollutants from biomass combustion. This is consistent with the association of exposure to household-derived biomass smoke at the average levels typically recorded (several hundred g/m^3) being associated with an elevated lung cancer risk (Pope *et al.*, 2011). Confirmation and further quantification of the risk of lung cancer from household biomass use with research designs that address current methodological limitations, including exposure assessment, should be a research priority.

Cancer of the upper aerodigestive tract

A systematic review carried out for the GBD 2010 project found 13 case–control studies of solid fuel use and cooking. Studies of nasopharyngeal cancer (nine studies) were analysed separately for those reporting on cancer of the larynx, oropharynx, and hypopharynx (four studies) as these have distinct risk factor profiles. Exposure was assessed as solid fuel since there was insufficient information to separate coal and wood.

Nasopharyngeal cancer

Five studies were considered for meta-analysis, although there was very substantial and significant statistical heterogeneity ($I^2 = 89\%$) as well as wide variation in the methods of exposure assessment and generally weak designs. The pooled OR was 1.10 (95% CI, 0.98–1.24), but overall the evidence was determined to be inadequate to support a causal association.

Cancer of the larynx, oropharynx, and hypopharynx

The four studies included showed significant statistical heterogeneity ($I^2 = 78\%$, $P = 0.008$) and a significant pooled OR of 1.90 (95% CI, 1.39–2.59). Again, exposure assessment was variable and unclear, and only one study compared solid fuel use against cleaner fuel. While these investigations suggest that there may well be increased risk of cancers of the larynx, oropharynx, and hypopharynx with solid fuel use in the home, further studies are required.

Cancer of the uterine cervix

A further systematic review conducted for the GBD 2010 project found three case–control studies of cancer of the uterine cervix for exposure to wood (Ferrera *et al.*, 2000; Velema *et al.*, 2002; Sierra Torres *et al.*, 2006) and one for coal (Wu *et al.*, 2004). For wood use, one study was of cervical dysplasia and carcinoma *in situ*, but all three found significantly elevated risks among human papillomavirus (HPV)-positive women, with ORs in the range of 3–7, but much smaller effects (not statistically significant) in HPV-negative women. Although neither of the two Honduran studies was adjusted for smoking, few women smoked; significant exposure–response relationships were reported based on duration of exposure (Ferrera *et al.*, 2000; Velema *et al.*, 2002). In the one study on coal exposure from Taiwan, China, a nonsignificant OR of 2.09 (95% CI, 0.86–5.10) comparing coal with gas was reported.

This limited set of studies does suggest that there may be an increased risk of cancer of the uterine cervix with household use of solid fuel, and this would be consistent with the well-established evidence from smoking, which is another form of exposure to pollutants from biomass combustion. Given the high incidence and mortality of cervical cancer, particularly in rural areas of developing countries where exposure to solid fuels in the homes is highest, further research on this risk should be a research priority.

Kerosene

A recently published systematic review on kerosene reported levels of pollutants and exposure and covered evidence on health implications (Lam *et al.*, 2012). IARC has previously found inadequate evidence that kerosene is a human carcinogen; limited evidence is available for animals as well (IARC, 1989). Kerosene emissions include both formaldehyde and polycyclic aromatic hydrocarbons, both classified by IARC as Group 1 carcinogens. Levels of particulate pollution from widely used kerosene lamps were found to be high during use, reaching more than 6000 μg/m^3 for total suspended particulate with simple wick lamps, somewhat lower for hurricane lamps, and 40 μg/m^3 in one study of pressurized lamps. Studies of cooking with kerosene (stove type not stated in all studies) found indoor 24–48 hour average concentrations of PM_5 in the range of 590–1280 μg/m^3, while 24 hour personal PM_5 exposures were similar (450–1650 μg/m^3). Even allowing for the short averaging times (1–2 hours) and particle size fractions in the lighting studies, these levels far exceed WHO air quality guideline levels for particulate matter (WHO, 2005).

Few studies on the risk of cancer from kerosene use are available. In their review, Lam *et al.* (2012) reported three case–control studies from the Hong Kong Special Administrative Region for which unadjusted ORs range between 0.75 (95% CI, 0.32–1.70) and 17.8 (95% CI, 6.2–7.0), but exposure comparisons are either not specified or include solid fuels. One other case–control study of lung cancer, from urban Cuba, found nonsignificant adjusted ORs for lung cancer among individuals using kerosene versus those using gas of 1.26 for women (95% CI, 0.81–0.95) and 1.14 for men (95% CI, 0.87–1.47) (Esquivel *et al.*, 1996). A study of salivary gland cancer reported an OR of 3.0 (95% CI, 1.4–6.8) but was judged as hard to interpret because of few cases and many exposures (Lam *et al.*, 2012).

Conclusions

The household use of solid fuels for cooking and heating remains prevalent across developing countries, and solid fuel is also widely used for heating in mainly rural areas of developed countries (usually in higher quality, vented stoves). While the majority of solid fuel use is biomass, coal remains important and its use may be increasing in some settings.

IARC has classified coal use as Group 1 (carcinogenic) and biomass as Group 2A (probably carcinogenic). Recent reviews find ORs for lung cancer with household coal use of about 2, higher for women and in southern China, while ORs for household biomass use are somewhat lower.

Household use of coal and biomass may also increase the risk of other cancers, including those of the UADT and uterine cervix (the latter is among the most common female cancers in developing countries where solid fuel use is greatest), but further research is needed to confirm these relationships.

When last estimated, the burden of cancer from solid fuel use was restricted to exposures and outcomes for which evidence was best established, namely coal use and lung cancer. About 36 000 deaths and 338 000 disability-adjusted life years were attributed to this exposure, the great majority in China (WHO, 2009).

Kerosene is widely used in developing countries, especially for lighting, and the simple wick stoves and lamps used by most households emit high levels of pollutants, including carcinogens. The few studies on cancer risk are limited by exposure assessment and adjustment for confounding, but do suggest that there may be an increased risk that warrants further investigation.

Air pollution from household coal use already results in a substantial cancer risk, and if the estimates reported here for biomass exposure and links with kerosene use and other common cancers such as that of the uterine cervix are confirmed, this will further increase the cancer burden. These cancer risks add weight to the urgency of ensuring a rapid transition by all households to technologies and fuels that deliver clean household air, and the need to focus attention on the importance of substituting coal.

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