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Indoor smoke from solid fuels

Assessing the environmental burden of disease at national and local levels

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A Microsoft Excel spreadsheet for calculating the estimates described in this document can be obtained from WHO/PHE. E-mail contact: EBDassessment@who.int

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Preface

The disease burden of a population, and how that burden is distributed across different subpopulations (e.g. infants, women), are important pieces of information for defining strategies to improve population health. For policy-makers, disease burden estimates provide an indication of the health gains that could be achieved by targeted action against specific risk factors. The measures also allow policy-makers to prioritize actions and direct them to the population groups at highest risk. To help provide a reliable source of information for policy-makers, WHO recently analysed 26 risk factors worldwide, including indoor smoke from solid fuels, in the *World Health Report* (WHO, 2002).

The Environmental Burden of Disease (EBD) series continues this effort to generate reliable information by presenting methods for assessing the environmental burden of disease at national and local levels. The methods in the series use the general framework for global assessments described in the *World Health Report* (WHO, 2002). The introductory volume in the series outlines the general method (Prüss-Üstün et al., 2003), while subsequent volumes address specific environmental risk factors. The guides on specific risk factors are organized similarly, first outlining the evidence linking the risk factor to health, and then describing a method for estimating the health impact of that risk factor on a population. All the guides take a practical, step-by-step approach and use numerical examples. The methods described in the guides can be adapted both to local and national levels, and can be tailored to suit data availability.

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In preparing this document, we drew on the methods developed for estimating the global burden of disease caused by exposure to indoor smoke from solid fuels. We therefore thank the reviewers of that analysis.

We also thank the United States of America (USA) Environmental Protection Agency for having supported the development of the Environmental Burden of Disease (EBD) approaches. This report has not been subjected to agency review and therefore does not necessarily reflect the views of the agency. Finally, we are grateful to Kevin Farrell and Eileen Brown who put this document into its final format.

List of abbreviations

ALRI	acute lower respiratory infection(s)
ARI	acute respiratory infection(s)
COPD	chronic obstructive pulmonary disease
CI	confidence interval
DALY	disability-adjusted life year
EBD	environmental burden of disease
ETS	environmental tobacco smoke
HIV	human immunodeficiency virus
PM	particulate matter
SFU	solid fuel use
USA	United States of America
WHO	World Health Organization

Note: WHO subregion abbreviations (e.g. SEAR D) are also utilized in tables. Please see Annex 5 for a list of countries within the WHO subregions.

Summary

This guide outlines a method for estimating the disease burden at a national or local level caused by household exposures to indoor smoke from solid fuels. Solid fuel use is defined as the household combustion of coal or biomass (such as dung, charcoal, wood, or crop residues). Worldwide, approximately 50% of all households and 90% of rural households utilize solid fuels for cooking or heating. Solid fuels are commonly burned in inefficient simple stoves and in poorly ventilated conditions. In such situations, solid fuel use generates substantial emissions of many health-damaging pollutants, including respirable particulates and carbon monoxide, and results in indoor air pollution exposures often far exceeding national standards and international guidelines.

The disease burden from solid fuel use is most significant in populations with inadequate access to clean fuels, particularly poor households in rural areas of developing countries. Women and their youngest children are most exposed because of their household roles. Solid fuel use is most firmly associated with acute lower respiratory infections (including pneumonia) in young children, and chronic obstructive pulmonary disease and lung cancer in women (and to a lesser degree in men). Each of these three health outcomes is a major disease category in most societies and thus household solid fuel use is likely to be a major cause of disease burden in communities where it is prevalent. Globally, 2.6% of all ill-health is attributable to indoor smoke from solid fuels, nearly all in poor regions.

The approach described in this guide utilizes a binary classification scheme for exposure levels, separating the study population into those exposed to solid fuel use and those not exposed. This strategy enables the application of relative risks derived from a comprehensive review of the current epidemiological literature on solid fuel use. The guide presents ways to assess household fuel use, and discusses the evidence linking solid fuel use with major health outcomes. The combination of exposure levels and relative risks enables the calculation of disease burdens. Uncertainty in final results can be suggested through low-risk and high-risk scenarios. The guide closes with an illustrative case study for India.

The recommended methodology does not include all possible health outcomes suspected to be associated with solid fuel use, but just those for which the evidence is best. Annexes cover other important sources of indoor air pollution; studies linking solid fuel use with various other health outcomes; alternative approaches to determine the disease burden from solid fuel use; and sample fuel use survey questions.

Determining the impact of solid fuel use at national or local levels is important for identifying and prioritizing environmental and public health interventions. The two main intervention options focus on developing the physical and economic infrastructure to either encourage households to switch to cleaner fuels, or to employ improved stoves with chimneys or other means of reliable ventilation. In either case, education plays a vital role.

1 Introduction

1.1 Organization of the guide

On a global basis, most indoor air pollution results from the burning of solid fuels for household cooking and heating. This guide is designed to help public health professionals determine at a national or local level the environmental burden of disease (EBD) from such solid fuel use (SFU). To begin, a definition and description of SFU as a risk factor is given, followed by a summary of the general method for determining the EBD from SFU. The evidence linking SFU with a variety of health outcomes is then presented, and ways to assess SFU exposure are suggested. Sources of uncertainty in the methodology, and approaches for addressing this uncertainty, are also discussed. Finally, the general method is illustrated with a specific case study for India, a country with one of the highest disease burdens from SFU.

1.2 Solid fuel use and indoor air pollution

Air pollution has been consistently linked with ill-health in both developed and developing countries (Hong, 1996; Murray & Lopez, 1996; Cohen et al., 2004; Smith, Mehta & Feuz, 2004). Historically, however, public health attention has focused mainly on the risks from outdoor air pollution. Indeed, the first estimate of the global burden of disease from air pollution only addressed the impact from outdoor sources (Hong, 1996; Murray & Lopez, 1996). Even today, most research continues to emphasize outdoor air pollution, which is not surprising given that vehicular and industrial emissions in urban areas of the developing world are rising at alarming rates, and recent evidence indicates that outdoor air pollutants could have marked effects, even at low ambient levels. Yet despite being somewhat neglected, indoor air pollution may pose a far greater health risk than outdoor air pollution, since people's exposure to many important pollutants from indoor sources exceed their exposure to these pollutants from outdoor sources.

Although outdoor sources often dominate air pollution *emissions*, indoor sources frequently dominate air pollution *exposures.* Exposure is a function of both the pollutant concentration in an environment, and the person-time spent in the environment. Since most people spend the majority of their time in homes, schools and workplaces, human exposure to air pollution is largely a function of pollutant levels in indoor settings (which can arise from outdoor sources, and vice-versa). In many populations, exposures to major pollutants from indoor sources can be higher than exposures to pollutants from outdoor sources (Smith, 1993). Over the past two decades, the hazards of indoor air pollution, particularly those associated with SFU in developing countries, have been documented by a growing body of literature (Bruce, Perez-Padilla & Albalak, 2000).

In this guide SFU is defined as: *the household combustion of biomass (such as dung, charcoal, wood, or crop residues), or coal***.** Worldwide, approximately 50% of all households and 90% of rural households utilize solid fuels for cooking or heating. In simple stoves, biomass fuels emit substantial amounts of health-damaging pollutants, including respirable particulates, carbon monoxide, nitrogen oxides, benzene, formaldehyde, 1,3 butadiene, and polyaromatic compounds such as benzo(α)pyrene (Smith, 1987). Depending on their quality, coal fuels may also emit sulphur oxides and other toxic elements, including arsenic, lead and fluorine. When these fuels are used in poorly ventilated conditions and burned in open fires or inefficient stoves, conditions common in households throughout the developing world, SFU may result in indoor air pollutant levels well above those in even the dirtiest of cities (Smith, 1993).

Although there are relatively few data on the levels of indoor air pollutants from SFU, compared to the data on outdoor air pollutants, what evidence there is illustrates the magnitude of the problem. The United States of America (USA) Environmental Protection Agency annual standard for particulate matter less than 10 μm in diameter (PM_{10}) is 50 $\mu g/m^3$, and for carbon monoxide is 9 ppm over eight hours (USA Environmental Protection Agency, 1997). In households utilizing solid fuels, over a 24-hour period typical mean PM_{10} concentrations can exceed 1000 $\mu g/m^3$, and carbon monoxide concentrations can exceed 20 ppm (Bruce, Perez-Padilla & Albalak, 2000). During actual cooking or heating, the levels of these two pollutants can exceed their 24-hour averages by an additional order of magnitude (Bruce, Perez-Padilla & Albalak, 2000). The profile of many other pollutants from SFU follows a similar pattern, typically far exceeding health-based national standards and World Health Organization (WHO) guidelines.[1]

The full scale of this environmental health problem is clear when the high pollutant concentrations from SFU are combined with the large amount of time people spend indoors. In particular, few activities involve as much person-time as cooking. Women responsible for preparing meals, and the young children they care for, are most heavily exposed to indoor air pollution from SFU. Older children and men may also spend significant time indoors, although their activity patterns are less generalizable. Access to clean fuels is lowest among poor households in rural areas of developing countries, and poor households in urban or periurban areas of developing countries may also have inadequate access to clean fuels. The EBD from SFU is likely to be most significant in these situations.

It has been estimated that indoor exposures to the combustion products of solid fuels are responsible for the majority of non-smoking human exposures to particulates and other major pollutants (Smith, 1987, 1993). As a result, large numbers of people are at increased risk of contracting acute lower respiratory infections (ALRIs), chronic obstructive pulmonary disease (COPD), lung cancer, and other afflictions associated with SFU. The recent global comparative risk assessment organized by WHO calculated that SFU accounted for approximately 2.6% of global ill-health in 2000 (Smith, Mehta & Feuz, 2004). Estimating the nature, size and distribution of this impact at more specific local levels is clearly vital for informing regional and national decision-making on environmental health.

1.3 Other sources of indoor air pollution

This guide stresses the importance of SFU in households, since this is the single most important situation by which people become exposed to air pollution. However, other

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[1] A database of published indoor air pollution studies in developing-country households can be found at http://ehs.sph.berkeley.edu/krsmith/news/database.htm.

sources and settings may be locally important for determining the EBD from indoor air pollution more broadly defined. For example, other key indoor environments include schools, vehicles and workplaces. Yet to date, there is a lack of exposure-response studies for schools and vehicles, and workplace exposures are highly diverse and better dealt with separately. Most exposure to air pollution from outdoor sources actually occurs indoors, because outdoor air pollutants often penetrate indoor environments and people spend most of their time indoors. The impact of outdoor sources of air pollution, which produce considerable ill-health in many parts of the world, is addressed in another guide in this series (Ostro, 2004).

In addition to pollutants from solid fuels, pollutants from indoor sources include radon (from the soil beneath buildings), tobacco smoke, cooking oil smoke, kerosene smoke, incense smoke, mosquito coil smoke, natural gas combustion products, toxic elements (from burning certain forms of coal), pesticides, and volatile organic compounds (from furnishings). Biological pollutants, such as dander, spores and dust, may be organic or inorganic in origin, and can also be generated indoors. Owing to the dearth of widespread exposure and risk information, however, no attempt is made here to quantify their health impacts (see Annex 1 for a short discussion of other indoor air pollutants).

Locally specific information will help to identify priorities for determining the EBD from additional sources of indoor air pollution. For instance, a region may be located on bedrock types associated with radon gas, or a region may document an increase in the prevalence of asthma. In such areas, it may be advisable to gauge the size and distribution of exposure to the corresponding indoor air pollutants (i.e. radon gas or asthma-related biological pollutants). In practice, however, it may be more feasible and cost-effective to measure surrogates of exposure, such as the location or dampness of households, than to measure actual pollutant levels. Potentially, a method similar to the general method described in this guide could then be applied to estimate the disease burden.

2 Summary of the method

The approach outlined in this guide is based on the most scientifically reliable information for SFU exposure-response relationships and exposure levels; a global assessment based on a similar approach is described elsewhere (Smith, Mehta & Feuz, 2004). The method utilizes relative risks[2] for exposure-response relationships, and a binary classification scheme for exposure levels, which separates the study population into those exposed to SFU and those not exposed. The disease burden of the study population can be measured using various metrics, such as disability-adjusted life years (DALYs) lost or deaths (Prüss-Üstün, Woodward & Corvalán, 2003). The general method is summarized in Box 1.

Box 1: Summary of the general method

Step 1. **Obtain key data.** Obtain estimates of the local assessment's key data: exposure levels (percentage of the population exposed to SFU), and disease burdens (DALYs lost or deaths from health outcomes associated with SFU), from either primary research or secondary sources.

Step 2. **Calculate attributable fractions.** Using exposure levels, relative risks, and the appropriate equation, calculate attributable fractions for each disease/age/sex grouping.

Step 3. **Calculate the attributable burdens.** Multiply attributable fractions from Step 2 by corresponding disease burdens, and calculate attributable burdens for each disease/age/sex grouping.

Step 4. **Final results.** Sum attributable disease burdens calculated in Step 3 to obtain the total EBD from SFU. The results can also be presented on a per capita basis, by disease, and by age/sex grouping.

Step 5. **Uncertainty.** Identify and discuss sources of uncertainty in the data. If desired, explore low and high scenarios of the EBD from SFU.

To further illustrate the general method, example calculations for the first three steps are presented below, using data from a case study for India (see Section 6). For brevity, the examples focus on a single health outcome, ALRI in children under five years of age, and a single measure of disease burden, DALYs lost.

The most important and challenging step in the general method is Step 1, obtaining the exposure levels and disease burdens for the local assessment. The sources of information for the example calculations are given in Box 2, as are the exposure levels and disease burdens obtained from these sources.

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[2] Technically, the relative risks are odds ratios, since most exposure-risk relationships are derived from case-control studies. The odds ratio approximates the relative risk (risk ratio) when the condition is "rare" (<10% prevalence).

Box 2: Step 1 – obtain key data

Exposure level

The 1991 national census for India included a question asking households to identify their primary fuel source (Government of India, 1995). The results indicated that 81% of households used solid fuels. For illustration, it can be assumed that this is a reasonable estimate of the percentage of children under five years of age were exposed to SFU in the year 2000.

Disease burden

The World Health Report 2001 provides disease burden data for the WHO subregion SEAR D (WHO, 2001). Since India's population comprises 81.6% of the total population of SEAR D, the disease burden for India can be estimated by multiplying the disease burden for the entire SEAR D subregion by this percentage. There were 21.7 million DALYs lost to ALRI in children under five years of age within SEAR D during 2000, and thus the corresponding disease burden from ALRI for India is 17.7 million DALYs lost (0.816 x 21.7 million).

The recommended relative risks, presented in Section 3 of this guide, are derived from a review of the global literature relating SFU exposure to health impacts (Smith, Mehta & Feuz, 2004). The rationale for using these relative risks in local assessments is that the nature and level of indoor air pollution caused by SFU is similar across settings. Thus, using all the internationally available evidence for relative risks in a local assessment will help to provide the most reliable results.

The relative risk for exposure to SFU and ALRI in children under five years of age is 2.3 (see Table 1). To estimate the attributable fraction, the relative risk and the exposure level are inserted into the equation for the attributable fraction, as shown in Box 3.

Box 3: Step 2 – calculate the attributable fractions

Attributable fraction =

((% population exposed × relative risk + % population unexposed × 1) – 1)
/ (% population exposed × relative risk + % population unexposed × 1)

Attributable fraction =

(81% population exposed × 2.3 + 19% population unexposed × 1) – 1 /
(81% population exposed × 2.3 + 19% population unexposed × 1)

= **0.51**

The attributable fraction is then multiplied by the chosen measure of disease burden to estimate the attributable burden (Box 4).

Box 4: Step 3 – calculate the attributable burdens

Attributable burden = attributable fraction × current disease level

Attributable burden = 0.51 × 17.7 million DALYs lost = 9.0 million DALYs lost

This sequence is repeated for each health outcome considered. The final results can be combined into a total EBD from SFU, as well as examined on a per capita basis, or separately by specific health outcomes and age/sex groupings (Step 4).

Addressing the sources and implications of uncertainty is important (Step 5; see Section 5 for further discussion). The quantified uncertainty in relative risks may enable low-risk and high-risk scenarios to be calculated, in addition to the central estimate (e.g. the relative risk estimate for ALRI in children under five years of age, 2.3, has a 95% confidence interval of 1.9-2.7). Finally, publication of a local assessment of the EBD from SFU should include a detailed description of the procedure followed, including assumptions and modifications.

Several important points about the general method should be noted. The counterfactual scenario that represents minimum exposure to this risk factor, and that should be used as a baseline for estimating the attributable burden, is "100% of households not using solid fuels as their primary fuel source." This assumes a balance between households primarily using solid fuels that sometimes use other fuels, and households primarily using other fuels that sometimes use solid fuels. Both conditions are common, but not well tabulated in most data on household fuel use. In reality, there are remaining exposures to indoor air pollution from the combustion of liquid and gaseous fuels. These exposures might be further reduced by switching to electricity, or by using well-ventilated cooking conditions. Thus, the counterfactual exposure is not zero exposure from all cooking fuels, but no exposure from SFU.[3]

Local assessments should tailor their approach to local data that can be reasonably obtained or generated. In particular, exposure levels and disease burdens derived from reliable and representative local data are preferable. If these data cannot be obtained or generated, then a local assessment can utilize studies conducted at larger scales by applying or adjusting the large-scale results to the local region of interest. Nevertheless, local data on exposure levels and disease burdens should be used whenever possible.

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[3] This is different from the "theoretical minimum counterfactual level" (Prüss-Üstün et al., 2003) for household fuel use, which would be 100% of households cooking and heating with electricity or other energy sources with no indoor emissions. Unfortunately, there are not enough exposure or risk data to estimate what the additional health benefit might be for this situation compared to the situation examined here, which is zero households using solid fuels. Even with no emissions from the fuel, there might still be emissions from the cooking itself, for example, fumes from cooking oil.

3 Estimates of relative risk

3.1 Choice of health outcomes

The epidemiological literature on studies linking SFU with a variety of health outcomes has been qualitatively evaluated (Smith, Mehta & Feuz, 2004). Each association between SFU and a health outcome was ranked as strong, moderate, or insufficient, based on the strength of evidence. “Strong” indicates that the results of studies on household pollution in developing countries reveal a consistent, sizeable, plausible and coherent relationship, with supporting evidence from studies of outdoor air pollution, active and passive smoking, and laboratory animals. The health outcomes that have strong associations with SFU include ALRI in young children, and COPD and lung cancer (from exposure to coal smoke) in adult women.[4] Because of the limitations of the available epidemiological studies, only risks in young children and adult women are in the strong category.

“Moderate” indicates a relatively small number of suggestive findings from studies on household pollution in developing countries, and some evidence from studies on outdoor air pollution, smoking, or laboratory animals. This indicates that additional, carefully conducted studies are needed to strengthen the evidence base and pinpoint risks. Moderate can be further subdivided into “moderate-I”, which refers to an association between SFU and a health outcome for which there is strong evidence for specific age and sex groups; and “moderate-II”, for which there is as yet no strong evidence. Health outcomes with moderate-I associations include COPD and lung cancer (from exposure to coal smoke) in men. Health outcomes with moderate-II associations include lung cancer (from exposure to biomass smoke) in women, asthma in school-aged children and adults, cataracts in adults, and tuberculosis in adults.

In addition, a number of health outcomes were classified as insufficient for quantification on the basis of the available evidence (Smith, 2000). These include adverse pregnancy outcomes, ischaemic heart disease, *cor pulmonale*, interstitial lung disease, nasopharyngeal cancer, upper aerodigestive tract cancers, and trachoma. The strong, moderate-I, and moderate-II health outcomes are presented in Table 1.

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[4] Lung cancer in adult women is strongly associated with exposure to coal smoke, but only moderately associated with exposure to biomass smoke.

Table 1 Relative risks for strong and moderate health outcomes

Evidence	Health outcome	Group (sex, age in years)	Relative risk[a]	CI [b]
Strong	ALRI	Children <5	2.3	1.9–2.7
	COPD	Women ≥30	3.2	2.3–4.8
	Lung cancer (from exposure to coal smoke)	Women ≥30	1.9	1.1–3.5
Moderate-I	COPD	Men ≥30	1.8	1.0–3.2
	Lung cancer (from exposure to coal smoke)	Men ≥30	1.5	1.0–2.5
Moderate-II	Lung cancer (from exposure to biomass smoke)	Women ≥30	1.5	1.0–2.1
	Asthma	Children 5-14	1.6	1.0–2.5
	Asthma	All ≥15	1.2	1.0–1.5
	Cataracts	All ≥15	1.3	1.0–1.7
	Tuberculosis	All ≥15	1.5	1.0–2.4

[a] See Section 3.1 for a description of how central estimates and confidence intervals were calculated.

[b] Abbreviations: ALRI = acute lower respiratory infection; CI = confidence interval; COPD = chronic obstructive pulmonary disease.

Based on the strength of evidence, it is recommended that the quantification of health impacts from SFU should only be reported for the three endpoints with strong and moderate-I evidence (i.e. ALRI, COPD and lung cancer (from exposure to coal smoke)). The evidence for the moderate-II category is not sufficiently robust to warrant inclusion of these endpoints in a local assessment, particularly given the need to maintain a conservative approach within the entire EBD exercise (Smith, Mehta & Feuz, 2004). However, as more results become available, it may be feasible to estimate the disease burdens from additional health outcomes.

The relative risks shown in Table 1 are widely applicable, since they are based on the entire evidence base. The relative risks include the results of formal meta-analyses for ALRI, COPD, and lung cancer (from exposure to coal smoke), the strong endpoints. Details of the meta-analyses, including discussions on the identification of studies, aggregation of studies, estimation of risk factor-disease relationships, and sources of bias, are provided in Smith, Mehta & Feuz (2004). For moderate health endpoints, the lower end of the range of relative risks was set at 1.0 (no effect), and the upper end at the geometric mean of the available relative risks from household studies in developing countries. The central estimate was set as the geometric mean between the upper and lower ends of the nominal confidence interval. The literature considered for the strong and moderate endpoints is presented in Sections 3.2–3.8. Section 3.9 covers literature on the health outcomes for which available data were deemed insufficient.

3.2 Acute lower respiratory infections

Indoor air pollution from SFU is a significant risk factor for acute respiratory infections (ARI), which account for a remarkable 7% of the global burden of disease (WHO, 2001). ARI belongs to a class of infections that result from a wide range of viruses and bacteria, but exhibit similar symptoms and risk factors (Smith et al., 2000), and are typically diagnosed on a symptomatic basis, rather than by identification of a specific pathogen. Interventions to reduce susceptibility and transmission commonly work to reduce ARI in general. Although ARI is an important cause of death in the elderly, their largest impact is on young children, with 2 million deaths in children under five years of age attributable to ARI in the year 2000 (WHO, 2001). Given the high background rates of ARI, and its importance in young children, ARI is among the major health outcomes associated with the burden of disease from SFU.

In virtually every country, young children contract ARI at similar rates, but in developing countries cases often proceed to severe stages, including pneumonia and death. In developing countries, ALRI constitutes 98% of all deaths from ARI and poses the greatest risk of mortality, although in developed countries severe childhood ALRI is rare. As a result, few air pollution studies in developed countries have focused on ALRI, either through a lack of interest, or because there were too few cases to be statistically significant. Ironically, therefore, when exposure-response information from developed countries is applied to situations in developing countries, ALRI is often omitted. Recently, however, more attention has been paid to ALRI, including investigations of the mechanisms by which air pollution may increase the risk of pneumonia (Verma & Thakur, 1995; Becker & Soukup, 1999). In addition, a number of studies have now shown an association between outdoor air pollution and childhood ALRI (Romieu et al., 2002). As a result, ALRI was included in the global assessment of the EBD from outdoor air pollution (Cohen et al., 2004).

A larger group of studies show that various respiratory symptoms are associated with SFU, but do not provide sufficient evidence to calculate the relative risks for ALRI itself (Smith et al., 2000). However, the relative risk of severe ALRI for young children living in households with SFU was estimated in several studies in developing countries (Smith et al., 2000). Thirteen such studies were identified for a meta-analysis. The developing countries and studies include: Argentina (Cerqueiro et al., 1990); Brazil (Victora et al., 1994); The Gambia (Campbell, Armstrong & Byass, 1989; Armstrong & Campbell, 1991; de Francisco et al., 1993; O'Dempsey et al., 1996); India (Shah et al., 1994); Kenya (Ezzati & Kammen, 2001); Nepal (Pandey et al., 1989); Nigeria (Johnson & Aderele, 1992); South Africa (Kossove, 1982); Tanzania (Mtango et al., 1992) and Zimbabwe (Collings, Sithole & Martin, 1990). Exposure proxies ranged from “fuel type” to “whether or not children were carried on the mother’s back during cooking”. As is often the case when comparing groups of studies, each of these ALRI studies had problems of one sort or another, for example, weak measures of exposure, health outcome, or confounders. As a group, however, they tend to compensate for each other’s shortcomings. Together, the data indicated that young children in households with SFU had a relative risk of 2-3 for acute ALRI. Two additional studies among the Navaho of North America also showed that the use of woodstoves had a strong and significant effect on ALRI rates at much lower indoor air pollutant levels than found in developing countries (Morris et al., 1990; Robin et al., 1996). These 15 studies are summarized in Table A2.1 of Annex 2.

Seven of the studies were excluded from the meta-analysis, after applying inclusion/exclusion criteria (Kossove, 1982; Cerqueiro et al., 1990; Armstrong &

Campbell, 1991; Mtango et al., 1992; Shah et al., 1994; Victora et al., 1994; Ezzati & Kammen, 2001). Generally, this was because of uncertainty in measures of exposure or health outcomes. The remaining eight studies were included in the meta-analysis (Campbell, Armstrong & Byass, 1989; Pandey et al., 1989; Collings, Sithole & Martin, 1990; Morris et al., 1990; Johnson & Aderele, 1992; de Francisco et al., 1993; O'Dempsey et al., 1996; Robin et al., 1996). The results of the meta-analysis indicated that the relative risk for ALRI in children under five years of age was 2.3 (95% confidence interval (CI): 1.9-2.7).

3.3 Chronic obstructive pulmonary disease

Nearly all COPD in developed countries is thought to be due to smoking. Undoubtedly, its incidence among men in developing countries is also significantly due to tobacco. Women, in contrast, have low prevalences of smoking in many developing countries, yet experience high rates of COPD. To examine this issue, a number of studies looked for symptoms of chronic respiratory ill-health in women cooking with biomass fuels (Bruce, Perez-Padilla & Albalak, 2000). Eleven studies quantified the prevalence of COPD. The studies were conducted in Bolivia (Albalak, Frisancho & Keeler, 1999); Brazil (Menezes, Victora & Rigatto, 1994); Columbia (Dennis et al., 1996); India (Malik, 1985; Behera, Dash & Yadav, 1991; Dutt et al., 1996; Gupta & Mathur, 1997); Kashmir (Qureshi, 1994); Mexico (Perez-Padilla et al., 1996); Nepal (Pandey, 1984); and Saudi Arabia (Døssing, Khan & al-Rabiah, 1994). The studies are summarized in Table A2.2 of Annex 2. After applying inclusion/exclusion criteria, the results of three studies (Pandey, 1984; Behera, Dash & Yadav, 1991; Qureshi, 1994) were excluded owing to the lack of adjustment for smoking and/or age, which are important covariates for COPD.

The results of the meta-analysis suggest that a sizeable proportion of COPD among men in developing countries can be attributed to SFU, and that, in general, COPD associated with SFU is likely to be an important contributor to the EBD. The relative risk for COPD in women over 30 years of age, a strong health outcome (see Table 1), is 3.2 (95% CI: 2.3-4.8). The relative risk for COPD in men over 30 years, a moderate-I health outcome, was set according to the procedure described at the conclusion of Section 3.1. The central estimate is 1.8 (95% CI: 1.0-3.2).

Although there were no comparable studies reporting relative risks in China, the high rates of COPD in Chinese non-smoking women argue that the above relative risks should be extended to include coal smoke (National Heart Lung Blood Institute & World Health Organization, 2001).

3.4 Lung cancer (from exposure to coal smoke)

In China, lung cancer in women is an outcome of cooking with open coal stoves, based on the evidence of at least two dozen studies (Smith & Liu, 1994). Seventeen of these studies (Gao et al., 1987; Du et al., 1988; Yang, Jiang & Wang, 1988; Sobue, 1990; Wu-Williams et al., 1990; Liu, He & Chapman, 1991; Liu et al., 1993; Dai et al., 1996; Du et al., 1996; Lei et al., 1996; Luo et al., 1996; Shen et al., 1996; Wang, Zhou & Shi, 1996; Xu et al., 1996; Huang, 1999; Wu et al., 1999; J. Liu & H. Hu, *unpublished* *observations*), along with one Taiwanese (Ko et al., 1997) and one USA study (Wu et al., 1985), were eligible for consideration in the meta-analysis (Smith, Mehta & Feuz, 2004). These studies are summarized in Table A2.3 of Annex 2. After applying inclusion/exclusion criteria, three studies were excluded owing to improper controls (Yang, Jiang & Wang, 1988) or to overlapping study populations (Du et al., 1988; Xu et al., 1996).

In adult women, lung cancer from exposure to coal smoke falls into the strong evidence category. Although the two studies that assessed the impact of exposure to coal smoke on lung cancer in men found that there was no statistically significant effect, five other studies that assessed the risk for men and women combined suggested there was a real effect on men. Coal smoke exposure to men is classified as moderate-I, owing to the paucity of studies that address men's exposures. In regions where coal use is common, lung cancer (from exposure to coal smoke) is likely to be an important component of the EBD from SFU.

The results of the meta-analysis indicate that the relative risk for lung cancer (from exposure to coal smoke) in women over 30 years of age, a strong health outcome, is 1.94 (95% CI: 1.09-3.47). The relative risks for lung cancer (from exposure to coal smoke) in men over 30 years of age, a moderate-I health outcome, were set according to the procedure described at the conclusion of Section 3.1. The central estimate is 1.5 (95% CI: 1.0-2.5).

3.5 Lung cancer (from exposure to biomass smoke)

Biomass smoke contains a range of chemicals that are known, or suspected, human carcinogens, and contains particulates in the small sizes known to penetrate deep into the lungs (Smith, 1987; Purvis, McCrillis & Kariher, 2000). Despite this, only four studies, one in Japan (Sobue, 1990), and three in China (Gao et al., 1987; Liu et al., 1993; Ko et al., 1997), have identified an association between biomass fuel use and lung cancer in women. These studies are summarized in Table A2.3 of Annex 2. No evidence was found for an association between biomass fuel use and lung cancer in men. More careful studies of the relationship between biomass fuel use and lung cancer are warranted (Boffetta, Jourenkova & Gustavsson, 1997).

The relative risks for lung cancer (from exposure to biomass smoke) in women over 30 years of age, a moderate-II health outcome, were set according to the procedure described at the conclusion of Section 3.1. The central estimate is 1.5 (95% CI: 1.0-2.1).

3.6 Asthma

Asthma attacks have been associated with urban outdoor pollution (Lipsett, Hurley & Ostro, 1996; García Marcos et al., 1999; Norris et al., 1999). The extent to which air pollution leads healthy people to become asthmatic is still not clear, although there is some evidence to support this idea, both epidemiological (Melsom et al., 2001) and toxicological (Pandya et al., 2002). The effects of environmental tobacco smoke (ETS) on asthma is still controversial, but a number of studies have shown that exposure to ETS during childhood is an important risk factor for the later development of asthma and allergic disease (Bjorksten, 1999) and for asthma attacks (Strachan & Cook, 1998). Based on the usual measures (e.g. PM), however, typical smoke exposures from SFU are much higher than either those from outdoor air pollution or from ETS. One of the challenges of studying asthma is the difficulty in discriminating between the type and size of risk factors for becoming asthmatic from those for developing asthma attacks, a task not accomplished in many studies. Studies in Kenya and China have quantitatively linked childhood asthma with various measures of indoor air pollution from SFU (Mohamed et al., 1995; Xu, Niu & Christian, 1996). In addition, a study of children under five years of age in Malaysia found an association between mosquito coil burning and an increased risk of asthma (Azizi, Zulkifli & Kasim, 1995). These three studies are summarized in Table A2.4 of Annex 2. As the reported background burden is so small in most of the developing world (about 10% of ALRI in the poorest countries, for example), including asthma would contribute relatively little to the EBD from SFU. There is concern, however, that the real rates of asthma may be higher and increasing (Stewart et al., 2001).

The relative risks for asthma in children between 5-14 years of age, a moderate-II health outcome, were set according to the procedure described at the conclusion of Section 3.1. The central estimate is 1.6 (95% CI: 1.0-2.5). The relative risks for asthma in adults over 15 years of age, also a moderate-II health outcome, were similarly set, and the central estimate is 1.2 (95% CI: 1.0-1.5).

3.7 Cataracts

Cataracts are the leading cause of blindness worldwide. Two studies in North India found an excess cataract risk among people using biomass fuel (Mohan et al., 1989; Zodpey & Ughade, 1999). In a third study, an evaluation of the 1992-1993 National Family Health Survey for India (National Family Health Survey, 1995) found a somewhat lower excess risk for partial blindness, but no significant difference for total blindness (Mishra, Retherford & Smith, 1999). These three studies are summarized in Table A2.5 of Annex 2. There is also evidence that ETS exposure is associated with cataracts (West, 1992), and animal studies show that cataracts can be caused by wood smoke (Shalini, Lothra & Srinivas, 1994; Rao et al., 1995). Clearly, more work is needed in this area.

The disease burden from blindness is nearly all due to disability rather than death. Worldwide, there are only approximately 6000 deaths from the direct consequences of blindness each year (WHO, 2001), and few deaths from blindness can be directly attributable to SFU. Studies suggest, however, that the risk of death from all causes is 2-3 times higher in individuals who are blind. Blindness from cataracts could thus be a proximal cause of a much larger burden of death and disability than is usually recognized.

In addition to cataracts, SFU may also be linked to blindness through trachoma (Prüss & Mariotti, 2000). Two separate studies in Tanzania identified a possible link (Taylor & West, 1989; West & Lynch, 1989), although another study in Ethiopia found cooking in a central room to be protective, perhaps because there were fewer flies in such a setting

(Sahlu & Larson, 1992). The total global burden of trachoma, however, is only about 15% of that from cataracts (WHO, 2001).

The relative risks for cataracts in adults over 15 years of age, a moderate-II health outcome, were set according to the procedure described at the conclusion of Section 3.1. The central estimate is 1.3 (95% CI: 1.0-1.7).

3.8 Tuberculosis

Tuberculosis is responsible for almost 2 million deaths worldwide each year (WHO, 2001). Although much remains unknown about the disease transmission and activation, an estimated 2 billion (Tufariello et al., 2003) people have latent infections. The problem is compounded by the rapidly increasing number of drug-resistant strains of bacteria that cause tuberculosis, and by the fact that tuberculosis bacteria are common co-infections with human immunodeficiency virus (HIV). Clearly, tuberculosis is both a long-standing and increasing, public health concern (Dye et al., 1999).

A link between tuberculosis and SFU is suggested both by animal studies and by surveys of human populations. The animal studies have shown that the respiratory immune system is suppressed by wood smoke (Zelikoff, 1994; Thomas & Zelikoff, 1999), and recent studies in India have indicated that indoor air pollution from SFU could be an important risk factor for active tuberculosis in people. An analysis of data from the National Family Health Survey (National Family Health Survey, 1995) found a statistically significant relationship between reported use of biomass fuel and tuberculosis in 260 000 adults over 20 years of age (Mishra, Retherford & Smith, 1999). The same analysis also found that women residing in households using biomass fuels were significantly more likely to have tuberculosis than women residing in households using cleaner fuels, even after correcting for socioeconomic factors. A second study in India found that both adult men and women who were exposed to smoke from dung or wood had a significant relative risk for clinically confirmed tuberculosis (Gupta & Mathur, 1997). Although the two studies in India did not address smoking as a possible confounder, two studies in Mexico City did take smoking into account and still found an association between exposure to wood smoke and tuberculosis (Perez-Padilla et al., 1996, 2001). These four studies are summarized in Table A2.6 of Annex 2. Given the disease burden from tuberculosis, more detailed studies should follow. In such studies, it will be important to determine whether the main effect from SFU is owing to an increased risk of infection with tuberculosis, or to an increased risk of conversion from latent infection to active disease, a distinction not addressed directly by existing studies.

Estimates of the disease burden from tuberculosis often do not include tuberculosis in individuals who are HIV seropositive. This is because the original Global Burden of Disease study categorized opportunistic infections among HIV-seropositive individuals as part of the HIV disease burden (Murray & Lopez, 1996). Many subsequent burden of disease assessments made similar decisions to emphasize the importance of HIV. But since there is little reason to think that SFU will not be a risk factor for tuberculosis among HIV-seropositive individuals, it may be advisable to include HIV-seropositive individuals with tuberculosis in the background rates for tuberculosis when calculating the EBD from SFU.

The relative risks for tuberculosis in adults over 15 years of age, a moderate-II health outcome, were set according to the procedure described at the conclusion of Section 3.1. The central estimate is 1.5 (95% CI: 1.0-2.4).

3.9 Other health outcomes

A number of important disease conditions have been linked to indoor air pollution from SFU but, as with the moderate-II health outcomes, there is currently insufficient evidence to recommend quantifying the disease burdens attributable to SFU (Smith, Mehta & Feuz, 2004).

Of these other disease conditions, the most important are probably adverse pregnancy outcomes, such as stillbirth, low birth weight and perinatal death. Unfortunately, only a few epidemiological studies have examined these issues.

A study conducted in India, examined the relationship between biomass fuel use and stillbirth, and found an excess risk of 50% among women using biomass fuels during pregnancy (Mavalankar, Trivedi & Grah, 1991). A study in Guatemala found that low birth weight was associated with exposure to biomass smoke (Boy, Bruce & Delgado, 2002). A proportion of perinatal deaths (deaths within the first two weeks of life) are due to ALRI, which is linked to SFU, but since specific diagnosis or autopsy is difficult with young infants, no studies have been conducted.

Intrauterine mortality, prematurity, low birth weight, and perinatal death have all been strongly associated with urban outdoor pollution at much lower concentrations than typically found in households using biomass fuels (Xu, Ding & Wang, 1995; Woodruff, Grillo & Schoendorf, 1997; Wang et al., 1997; Pereira et al., 1998; Loomis et al., 1999; Ritz & Yu, 1999; Bobak, 2000). Additionally, in a meta-analysis of 17 studies, exposure to ETS in nonsmoking pregnant women was found to be associated with low birth weight (Windham, Eaton & Hopkins, 1999), and low cognitive development (Johnson et al., 1999), but not with spontaneous abortion (Windham et al., 1999).

Low birth weight, in particular, is an important risk factor for infant and child morbidity and mortality from several diseases (Walsh, 1993), and it has also been linked to ill-health later in life (Barker, 1997). Although it is likely that there is a substantial health impact from adverse pregnancy outcomes resulting from SFU, at present it is difficult to quantify the potential burden.

Ischaemic heart disease is a major component of the burden of disease in virtually all settings. In developed countries, ischaemic heart disease has been linked to outdoor air pollution (Dockery et al., 1993; Borja-Aburto et al., 1998; Seaton et al., 1999), smoking (US Department of Health, 1979) and ETS (Glantz & Parmley 1995; Steenland et al., 1998). However, there is a lack of evidence for developing countries in general, and for SFU in particular. Hence, the only means of analysing the risk of ischaemic heart disease from indoor SFU is to apply risks determined from outdoor urban air pollution studies in developed countries to situations in developing countries (Ostro, 1996; WHO, 1999), not a particularly satisfying approach (see Annex 3). To give an idea of the potential impact, however, the relative risks for adult women range from 1.1 to 1.4, assuming a PM_{10} concentration of about 160 $\mu g/m^3$, a level less than that found in nearly all indoor studies of SFU.

Cor pulmonale is a serious heart condition secondary to COPD. In spite of low smoking rates, it occurs among rural women in South Asia (Smith, 1987; Pandey, Basnayat & Neupane, 1988), and has long been attributed to chronic exposure to biomass smoke (Padmavati & Pathak 1959). There is also good evidence that chronic exposure to biomass smoke causes interstitial lung disease (Ramage et al., 1988; Dhar & Pathania, 1991). Silicosis has also been attributed to SFU exposures, usually in association with soil dust (Norboo et al., 1991; Saiyed et al., 1991). At this time, there is insufficient quantitative evidence to develop relative risks for these conditions.

Two studies in Brazil have shown a strong relationship between exposure to wood smoke and upper aero-digestive tract cancers, with adjusted relative risks of 2.5 (Franco et al., 1989) and 2.7 (Pintos et al., 1998). The latter study also found an association between exposure to wood smoke and nasopharyngeal cancer, but this result contrasted with detailed studies in Asia that found no evidence for such a link (Smith, 1987; Smith & Liu, 1994). It is difficult to draw conclusions from this limited evidence.

4 Estimates of exposure levels

4.1 Choice of exposure variables

An exposure variable for SFU must capture the air pollutant concentrations in various environments, the person-time spent in the environments, and the number of people exposed. Ideally, the indoor air pollutant levels would be measured when people are present, using a probability sample that is representative of the entire at-risk population. Prior studies have shown that indoor levels of air pollutants can be quite high from SFU in developing country households, much higher than health-based standards and guidelines (Bruce, Perez-Padilla & Albalak, 2000). However, the sample sizes in the studies were small and not statistically representative of larger populations, and therefore the data do not allow exposure distributions to be estimated for wide areas. In any case, it will be prohibitively expensive and time-consuming for most local assessments to conduct sufficient indoor air pollution measurements to obtain reliable exposure distributions.

There are, however, less precise, but substantially cheaper, indicators of exposure that can be used instead. In general, as the geographical scale of an exposure variable for SFU decreases, its specificity increases, the availability of pre-existing data decreases, and the cost of collecting new data increases. Even secondary sources, such as national fuel use data, may provide some measure of potential exposure. More accurate, but more expensive, are actual household surveys of fuel use that use a probability sample. Such surveys can generate a binary measure of exposure, categorizing households into those with SFU and those without, to determine the population exposed to SFU. It is recommended that this exposure variable be used in local assessments.

Nearly all of the epidemiological research on SFU has utilized some form of binary exposure classification to test and measure associations. Hence, it is sensible to develop a local assessment based on the same exposure characterization. Moreover, estimates of the prevalence of household SFU can be made with more confidence than estimates of actual pollutant exposures, and such a fuel-based approach avoids many of the pitfalls inherent in a pollutant-based approach (see Annex 3). In most countries where large proportions of the population use solid fuels, data on household fuel use may be available through censuses and other sources, or can be generated through surveys of household fuel use in the population of interest.[5]

It is also valuable to know the age and sex distributions that correspond to the health outcomes of interest for the study population exposed to SFU. The most simple and efficient approach is to assume that the age and sex distributions within the overall population of a country are no different from those in the SFU-exposed population. In other words, if 50% of households in a country were determined to be exposed to SFU, then 50% of all age and sex categories in that country would also be considered exposed. This is a conservative assumption, since typically households that use solid fuels are larger than typical households that do not. If local information is available about actual

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[5] If the prevalence of SFU is relatively high in a country, then environmental health specialists should lobby for the inclusion of household fuel-related questions in national censuses or household surveys.

household sizes then it should be used, of course. In general, demographic statistics from national or local censuses should provide information on the age and sex distributions of the population being examined. Alternatively, statistical tables of demographic and socioeconomic data for most countries of the world can be found at the web sites of the USA Bureau of the Census (http://www.census.gov/ipc/www/idbsprd.html) and the United Nations Statistics Division (http://unstats.un.org/unsd/cdb).

4.2 Ventilation coefficients

SFU does not always correlate with a specific level of exposure, since a number of social, cultural and technological factors, such as stove features, housing layouts, or cooking/heating patterns, may modulate exposure to indoor air pollution from SFU. Certain cuisines or foods may necessitate more or less time spent preparing food. During colder seasons or in cooler climates, households may burn fuel for heat for long periods while shutting windows and making other changes to reduce drafts. Improved stoves, outdoor cooking, or well-ventilated homes may markedly mitigate exposures.

These factors prompted the use of a "ventilation coefficient", set to between 0.00 and 1.00, to account for the attenuation of exposure to SFU by ventilation-related variables. Zero indicates no exposure to pollutants from SFU and 1.00 indicates full exposure.Unfortunately, in most locales, few systematic surveys of ventilation-related factors, such as the presence and size of windows and eaves spaces, have been carried out. In addition, it has not been possible to develop a reliable general method for quantifying the extent to which ventilation mitigates exposure. Thus, an explicit quantitative consideration of all ventilation factors is not yet possible for local assessments of the EBD from SFU. However, the fact that existing epidemiological studies have achieved reasonably consistent results without consideration of these factors (see Section 3), indicates that the current lack of a means to incorporate them into a local assessment is not a serious constraint.

Given these limitations, local assessments should focus on two ventilation-related factors: (i) improved stoves; and (ii) outdoor cooking. Improved stoves, characterized by the presence of a flue, chimney, or hood, can markedly reduce exposures. A ventilation coefficient of 0.00 for these appliances is unwarranted, however, since even well-operating improved stoves still result in some exposure. A more realistic ventilation coefficient for improved stoves is 0.25. The same ventilation coefficient can be applied to outdoor cooking, which also does not eliminate exposure entirely (Balakrishnan et al., 2003). Thus, provided that data on the prevalence of improved stoves and/or outdoor cooking can be obtained or generated, the recommended approach is:

- apply a ventilation coefficient of 1.00 to the population that uses traditional stoves;
- apply a ventilation coefficient of 0.25 to the population that uses improved stoves, or cooks outdoors.

Incorporating a ventilation coefficient, the equation for calculating the population exposed to SFU is given in Box 5.

Box 5: Equation for determining the population exposed to SFU

Population exposed to SFU =

(population size) x (% of households using solid fuels with traditional stoves) x (ventilation coefficient of 1.00)

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(population size) x (% of households using solid fuels and either improved stoves or cooking outdoors) x (ventilation coefficient of 0.25).

If there is uncertainty about the types of stoves used, the percentage of the population covered by improved stoves, or the percentage of the population cooking outdoors, then it is recommended that a survey of household fuel use be undertaken that includes an examination of these factors (see Section 4.3). It is important not to rely on statistics reporting an accumulation of past production, sales, or dissemination of improved stoves, since such stoves sometimes have short lifetimes in the field. If information on the prevalence of improved stoves and/or outdoor cooking is not available or cannot be generated, then a ventilation coefficient of 1.00 should be used for all households using solid fuels.

4.3 Surveys of household fuel use

Local assessments can generate the most reliable estimates of household fuel use by conducting well-designed surveys of household fuel use that are statistically representative of the larger population of interest. Since exposure-response information for SFU relies primarily on a binary classification of SFU, a local assessment should at least tally the dominant fuel types used within surveyed households and gauge the prevalence of improved stoves and outdoor cooking. The essential questions for a survey of household fuel use are given in Box 6.

Box 6: Essential questions in a survey of household fuel use

- what is the dominant fuel used for cooking? [a]
- what is the dominant fuel used for heating? [a]
- which stove type is used (improved or traditional)?
- where is the kitchen located (indoor or outdoor)?

[a] Possible fuel types should include biomass fuels (e.g. dung, charcoal, wood, or crop residues), coal, and low-emission or no-emission fuels (e.g. kerosene, biogas, natural gas, liquefied petroleum gas, or electricity).

If the means exist for conducting a survey of household fuel use, the survey can be extended by gathering data on additional variables central to the estimation of ventilation coefficients and to the characterization of exposed populations. Such variables include stove types, household characteristics, cooking/heating practices, demographics, and time-activity patterns (see Annex 4). This information can facilitate interventions by generating locally relevant statistics on the most important variables related to exposure. The additional information may also be used to apply more refined exposure-response relationships, as these become available.

To conduct a survey of household fuel use, a questionnaire and sampling scheme needs to be devised. Local circumstances should guide the development of a site-specific questionnaire, tailored to the social, cultural, and economic situation of the study region. In general, categorical response choices specific to the region streamline data collection and facilitate data analysis. In addition to the items listed in Box 6 and Annex 4, a local assessment may also survey for potentially confounding, or effect-modifying, sources of indoor air pollution (e.g. ETS).

The practical constraints of the survey will determine the optimal sampling scheme for obtaining statistically representative estimates. As a rule, random population-based sampling is preferable to convenience sampling. It may be important to strategically cluster sampling in certain areas, using a stratified random sampling scheme. The biases inherent in convenience sampling are unpredictable and potentially seriously distorting. For assistance on developing a sound sampling strategy, refer to resources such as the World Health Survey (http://www3.who.int/whs/P/sampling.html).

4.4 Examples of exposure levels

In some cases, due to funding or time constraints, surveys of household fuel use will have to rely on secondary sources of data. One such secondary source is the global assessment (Smith, Mehta & Feuz, 2004), which estimated household fuel use in 156 countries (see Annex 5). These results can be adjusted to a region of interest and provide preliminary estimates of the SFU exposure for local assessments, if local-level data are not available.

The approach used in the global assessment (Smith, Mehta & Feuz, 2004) was based on an extensive literature search that resulted in a household fuel use database, as well as a linear regression model (Mehta, 2002). Although the original studies included in the database were conducted over the past decade, it is unlikely that patterns of fuel use have changed dramatically in any given country or region over this time. In the original studies, the data were also presented in numerous forms. As a result, many assumptions were made to facilitate data manipulation and allow comparisons. Every effort was made to clearly explain the assumptions and manipulations, and to leave room for future corrections should more sophisticated approaches or more accurate data emerge. In the database, all the available estimates of household SFU were compiled, and expressed as the percentage of households (i.e. population) using each fuel type. These SFU estimates, based on actual data, were arbitrarily assigned a ±5% uncertainty range.

As data on SFU were available for only 52 of the 156 countries in the global assessment, a statistical model was developed to predict household SFU in the remaining countries (Mehta, 2002). The model used SFU values from the household fuel use database, and assumed that as countries develop economically, people gradually shift up an energy ladder from solid fuels to cleaner fuels. Although the picture may be more complex at local and household levels, it was assumed that this generally holds true over the long-term on a national scale. To be conservative, all countries with a per capita gross national product greater than US$ 5000 in 1999 were assumed to have made a complete transition either to “clean” household cooking systems (electricity or cleaner liquid or gaseous fuels), or to fully ventilated appliances (if solid fuels were still used for cooking or heating). Confidence intervals (95%) were calculated for the predicted SFU estimates generated by the linear regression model.

Although the global assessment applied a ventilation coefficient to actual and predicted SFU estimates, a value of less than 1.00 was used in only two cases because of the paucity of systematic data on ventilation conditions by country or by region (Smith, Mehta & Feuz, 2004). The two instances were for the countries of Eastern Europe and the former Soviet Union, and for China. These cases are described below to inform local assessments in these countries that use exposure estimates from the global assessment (Smith, Mehta & Feuz, 2004). Note, however, that this type of expert judgement approach to assigning ventilation coefficients is not suggested for local assessments (see Section 4.2 for the recommended approach).

Before the recent economic declines in the countries of Eastern Europe and the former Soviet Union, a long history of household SFU under cold climatic conditions and relatively high standards of living led to the development of energy technologies with low levels of indoor emissions. In light of this, the ventilation coefficient was set to 0.20 for countries that were classified as Formerly Socialist Economies of Europe[6] in the first edition of the Global Burden of Disease Study (Murray & Lopez, 1996). In China, a national programme has disseminated improved stoves with chimneys to some three-quarters of rural, solid-fuel using households since 1981 (United Nations Development Programme et al., 2000). This has decreased the effective exposures in Chinese households, and the ventilation coefficient for China was set to 0.25 for child health outcomes. It was not set lower, because even well-operating improved stoves in China still produce some indoor exposure (Sinton et al., 1995). For adult health outcomes the ventilation coefficient was set to 0.50, as current disease patterns for adults partly reflect exposures that pre-date improved stoves.

Household SFU estimates from the global assessment are presented by subregion in Table 2, and the regions of greatest concern are readily apparent (Smith, Mehta & Feuz, 2004). The actual and predicted estimates of household SFU at the country level, as well as ventilation coefficients, are aggregated into population-weighted regional estimates. Country level results are presented in Annex 5.[7]

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[6] Albania, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Slovakia, Slovenia, Ukraine and Yugoslavia.

[7] The model for global household fuel use will be updated twice a year, according to new survey results. The most current version can be found at web site: http://ehs.sph.berkeley.edu/krsmith/fuel_database/default.htm.. If readers of this guide conduct any large-scale surveys of household fuel use, or find any studies that have not yet been incorporated into the model, the authors would be grateful if you could notify them. Please contact Kirk R. Smith at e-mail address: krksmith@berkeley.edu

Table 2 Household SFU[a] by WHO subregion

			Taking ventilation into account		
WHO Subregion[b]	**Household SFU (%)**	**Ventilation Coefficient**	**Central estimate (%)**	**Low estimate (%)**	**High estimate (%)**
AFR D	73	1.00	73	68	78
AFR E	86	1.00	86	80	89
AMR A	1	1.00	1	1	2
AMR B	25	1.00	25	19	31
AMR D	53	1.00	53	43	63
EMR B	6	1.00	6	2	12
EMR D	55	1.00	55	50	60
EUR A	0	0.97	0	0	1
EUR B	41	0.65	26	21	31
EUR C	23	0.25	7	5	11
SEAR B	66	1.00	66	61	72
SEAR D	83	1.00	83	78	88
WPR A	0	1.00	0	0	0
WPR B[c]	78	0.26/0.58	28/45	26/42	30/47

[a] SFU = solid fuel use, WHO = World Health Organization.

[b] See Annex 5 for a list of countries in WHO subregions.

[c] The WPR B WHO subregion includes China, for which the ventilation coefficient is 0.25 for children and 0.50 for adults. Thus, the smaller estimates are for children and the larger estimates are for adults.

5 Uncertainty

5.1 Relative risks

Ninety-five percent confidence intervals exist for all relative risks associated with health outcomes in the strong evidence category (Table 1). For health outcomes in the moderate-I category, the use of a lower estimate of 1.0 (no risk) is quite conservative (i.e. likely biased toward understating risks), and the central and upper estimates are also conservative. As mentioned previously, the evidence for moderate-II outcomes is too limited to recommend any quantitative estimate of disease burden.

Since the method addresses only certain health outcomes in certain populations, owing to a lack of available epidemiological studies, it tends to underestimate the total burden. Perhaps the most important source of this error stems from the fact that the method does not address the effects of *in utero* exposures on pregnancy outcomes. The two population groups primarily assessed, young children and adult women, experience the greatest exposures, so the method does not seem to greatly underestimate the total burden. However, the impact of this underestimation for other groups, particularly young women aged 5–15 years, may still be significant.

Although attempts have been made to correct for confounders such as poverty in most epidemiological studies, residual confounding may remain that could bias relative risks. That the studies derive fairly consistent results is evidence, but not proof, of an association between SFU and a health outcome. Nonetheless, the epidemiological studies at best derive risk estimates related to the exposure measure utilized.

5.2 Exposure levels

In reality, exposures to indoor air pollution from SFU result in a wide range of exposures. Since the distribution of exposures is continuous, exposures would best be categorized into multiple exposure categories. A range of variables affecting the degree of exposure have already been discussed in previous sections. Examples include differences in fuel types, stove types, cooking/heating practices, demographics, and climate or season. In addition, indoor air pollutant levels will be heavily influenced by differences in household characteristics, as well as by household location with regard to other sources of air pollution, including other households with solid fuels. Actual human exposures will be further influenced by differences in time-activity patterns, particularly the time spent within the household and in close proximity to the pollution source.

Unfortunately, given the currently available information on indoor air pollution exposures associated with SFU, as well as on related relative risks, the influence of variation in the variables above on uncertainties in final results cannot be reliably quantified. As a start, however, assessments can begin to address the variability in indoor air pollutant levels from SFU by using a ventilation coefficient of 0.25 for households that use improved stoves or cook outdoors. Establishing defensible lower and upper exposure estimates, as would be achieved through a random population-based sample in a survey of household fuel use, can also help capture variability in exposure.

5.3 Addressing uncertainty

Although the approach described in this guide is commensurate with much of the available data, it does have important limitations with respect to chosen measures of relative risk and exposure level. There is uncertainty inherent in both the methodology and data sources, including often-neglected uncertainty in estimates of the disease burden. At present, however, there is no straightforward mechanism for capturing various sources of uncertainty and for calculating lower and upper bounds for estimates generated by local assessments. In the global assessment, a Monte Carlo analysis was used to obtain lower and upper estimates of the EBD from SFU (Smith, Mehta & Feuz, 2004). This technique utilized quantified uncertainty in both relative risk and exposure level estimates. However, the effort required to execute such an approach seems unsuitable for most local assessments, particularly as the additional information gained may not be substantial.

Given these limitations, we recommend that final results derived from the central relative risk and exposure level estimates be presented without accompanying ranges. Admittedly, this is a less-than-satisfactory approach. We do suggest that sources of uncertainty and their possible influence on final results be described and discussed in local assessments. Of course, it remains important to quantify uncertainty in relative risks and exposure levels. The confidence intervals for relative risks are presented in Tables 1 & 3 of this guide. A survey of household fuel use, based on a random population-based sample, will enable a confidence interval for exposure level to be calculated as well. A series of scenarios can help explore the impact of uncertainties on final results.

If some presentation of uncertainty is required in the final results, then calculations for attributable fractions can be repeated with the lower and upper relative risk confidence intervals, along with the central exposure level. The ranges that result for attributable fractions and burdens cannot be interpreted in a statistical fashion. They serve simply as "low" and "high" scenarios, not lower and upper bounds around a central estimate, and only point to other possibilities for the actual impact.

6 Case study

6.1 Overview

To illustrate the approach described in this guide, we present a case study for India. Smith (2000) conducted a preliminary assessment of the national burden of disease from indoor air pollution in India using household fuel use data from the 1991 national census (Government of India, 1995), relative risks from the epidemiological literature, and disease burden data from the original Global Burden of Disease study (Murray & Lopez, 1996). It was found that approximately 4.2–6.1% of the total burden of disease in India was attributable to SFU (Smith, 2000). The present case study updates this approach by utilizing the methodology presented in this guide, a rigorous and explicit approach that is widely applicable and allows for comparisons with other studies. The present case study also uses the most recent disease burden and population estimates.

The case study follows the steps outlined in Box 1. With respect to health outcomes, the case study:

- focuses on strong and moderate-I health outcomes;
- utilizes the relative risks presented in Tables 1 & 3.

Table 3 Relative risks for health outcomes in a case study for India

Health outcomes	**Strength of evidence**	**Sex, age group**	**Relative risk**[a]	**CI**[b]
Acute lower respiratory infections	Strong	Children <5 yrs	2.30	1.90–2.70
Chronic obstructive pulmonary disease		Women ≥30 yrs	3.20	2.30–4.80
	Moderate-I	Men ≥30 yrs	1.80	1.00–3.20
Lung cancer (from exposure to coal smoke)	Strong	Women ≥30 yrs	1.94	1.09–3.47
	Moderate-I	Men ≥30 yrs	1.50	1.00–2.50

[a] See Section 3.1 for a description of how central estimates and confidence intervals (CI) were calculated.

[b] CI = confidence interval.

6.2 Step 1 – obtain key data

The 1991 Indian national census (Government of India, 1995) provided data both on SFU and demographics for the case study. The national census included for the first time a question asking households to identify their primary fuel. Of 152 million households nationwide, 81% reported using solid fuels as their main fuel source (78% used biomass and 3% used coal; Table 4). A striking 95% of rural households relied on biomass fuels. An independent, probability-weighted national survey of 89 000 households in 1992 obtained similar results (National Family Health Survey, 1995).

In India, as elsewhere, exposure to SFU is modified by ventilation-related factors. Some households cook outdoors at least part of the year, which decreases exposures. During cold and rainy reasons, especially in the highlands or in Northern India, solid fuels are used for space heating, which increases exposures. India has experienced numerous programmes to promote the use of improved stoves (Ramakrishna, 1991). The principal objective of most such programmes has been to improve fuel efficiency; lowering smoke exposures has often been a secondary goal. Although some progress has been made, it has been surprisingly difficult to widely disseminate improved stoves. Unfortunately, few of the distributed improved stoves last more than two years. Thus, only a small fraction of the improved stoves that were introduced are still likely to be in use (Natarajan, 1999). Since there are no estimates of ventilation-related factors over such a diverse subcontinent, the case study uses a ventilation coefficient of 1.00. The SFU estimates from the national census are shown in Table 4.

Table 4 Household SFU in India[a]

Fuel type	Estimate of household use (%)
SFU[b]	81
Biomass	78
Coal	3

[a] Sources: Government of India (1995); Smith, Mehta & Feuz (2003).

[b] SFU = solid fuel use

Complete data from the 2001 Indian census were unavailable at the time this case study was carried out. Hence, year 2000 population data were obtained from the USA Bureau of the Census (USA Bureau of the Census, 2002). The average population distribution within any given household was assumed to be the same as the population distribution at the national level. No adjustments were made for rural households versus urban households, nor for households using solid fuels versus other fuels. Thus, for the purposes of the case study, the percentage of any age/sex group exposed to SFU was the same as the percentage of households exposed to SFU. The relevant age/sex distribution for India is given in Table 5.

Table 5 Population distribution by age and sex for India[a]

Age (years)	Male (millions)	Female (millions)	All (millions)
0–4	59.0	56.0	115.2
5–14	114.6	107.5	222.1
>15	352.6	328.6	681.2
>30	203.8	194.6	398.4
Totals	526.3	492.2	1018.5

[a] Source: USA Bureau of the Census (2002).

Burden of disease estimates for WHO subregion SEAR D for year 2000 were adjusted by population weight for the case study (WHO, 2001). India comprised 81.6% of the total population of SEAR D, so the pattern of its national disease burden is not likely to be dramatically different from the pattern of the region as a whole (Table 6).

Table 6 Indian burden of disease from selected diseases in 2000[a]

Disease, sex, age group	DALYs [b] lost (thousands)	Deaths (thousands)
ALRI, children <5 years	17 674	499
COPD, women ≥30 years	1 856	104
COPD, men ≥30 years	1 890	101
Lung cancer[c], women ≥30 years	209	18
Lung cancer[c], men ≥30 years	763	77
All causes	22 392	799

[a] Source: WHO (2001). Values here are 81.7% of the total for SEAR D

[b] Abbreviations: ALRI = acute lower respiratory infection; COPD = chronic obstructive pulmonary disease; DALYs = disability-adjusted life years.

[c] From exposure to coal smoke.

6.3 Step 2 – calculate attributable fractions

A sample calculation of the central estimate for the attributable fraction from SFU for ALRI in children under five years of age is given in Box 3. The results of this procedure for all health outcomes are given in Table 7. Low and high estimates, based on relative risk confidence intervals, are discussed in Section 6.6.

Table 7 Attributable fractions from SFU [a] for India

Disease, sex, age group	Attributable fractions		
	Low	Central	High
ALRI, children, <5 years	0.42	0.51	0.58
COPD, women ≥30 years	0.51	0.64	0.75
COPD, men ≥30 years	0.00	0.39	0.64
Lung cancer[b], women ≥30 years	0.00	0.02	0.05
Lung cancer[b], men ≥30 years	0.00	0.01	0.03

[a] Abbreviations: ALRI = acute lower respiratory infection; COPD = chronic obstructive pulmonary disease; SFU = solid fuel use.

[b] From exposure to coal smoke.

6.4 Step 3 – calculate attributable burdens

A sample calculation of the central estimate for the attributable burden (in DALYs lost) from SFU for ALRI in children under five years of age is given in Box 4. The results of this procedure for all health outcomes are given in Table 8. Lower and upper estimates, based on relative risk confidence intervals, are discussed in Section 6.6.

Table 8 Attributable burdens from SFU[a] for India

Disease, sex, age group	Attributable burden					
	DALYs lost (thousands)			Deaths (thousands)		
	low	central	high	low	central	high
ALRI, children <5 years	7 452	9 065	10 238	210	256	289
COPD, women ≥30 years	952	1 189	1 401	53	66	78
COPD, men ≥30 years	0	743	1 211	0	40	65
Lung cancer[b], women ≥30 years	0	6	14	0	0	1
Lung cancer[b], men ≥30 years	0	11	33	0	1	2

[a] Abbreviations: ALRI = acute lower respiratory infection; COPD = chronic obstructive pulmonary disease; SFU = solid fuel use.

[b] From exposure to coal smoke.

6.5 Step 4 – final results

The burden of disease from SFU in India is 11 million DALYs lost and 360 000 deaths. Either figure represents 3.7% of the national total in 2000, and thus by any standard SFU classifies as a major cause of ill-health in India. The disease burdens associated with each health outcome and age/sex grouping are shown in Table 9.

Table 9 Burden of disease from SFU[a] for India

Measure	ALRI (thousands)	COPD (thousands)	Lung cancer (thousands)	Children <5 years (per 1000 people)	Women ≥30 years (per 1000 people)	Men ≥30 years (per 1000 people)
DALYs lost	9 065	1 932	17	78.72	6.14	3.70
Deaths	256	106	2	2.22	0.34	0.20

[a] Abbreviations: ALRI = acute lower respiratory infection; COPD = chronic obstructive pulmonary disease; SFU = solid fuel use.

ALRI accounts for the bulk of both DALYs lost and deaths from SFU. COPD accounts for an intermediate fraction of the burden of disease from SFU, whereas lung cancer accounts for only a small fraction. It follows that per capita health impacts are greatest for young children, followed by adult women and then adult men.

To place the final results in Table 9 in context, the disease burden from SFU is compared with the disease burden for certain diseases and for age/sex categories in India (Table 10). The three disease categories selected (diarrhoeal diseases, ischaemic heart disease, and road traffic accidents) are among the largest categories of infectious disease, chronic disease, and injuries, respectively, for India. As can be seen, the burden of disease from SFU is 40-50% smaller than that from diarrhoeal diseases and 30–40% larger than that from road traffic accidents. SFU also accounts for roughly one-seventh to one-sixth of the total burden of disease for children under five years of age, and 1–2% of the total disease burden for adults over 30 years of age.

Table 10 Comparison of burden of disease data and SFU[a] results for India[b]

	Diarrhoeal diseases	**Ischaemic heart disease**	**Road traffic accidents**	**Children <5 years**	**Women ≥30 years**	**Men ≥30 years**
	(thousands)	**(thousands)**	**(thousands)**	**(per 1000 population)**	**(per 1000 population)**	**(per 1000 population)**
DALYs lost	18 268	13 411	8 258	529.4	326.2	367.6
SFU as % of above[c]	60%	82%	133%	15%	2%	1%
Deaths	752	1 392	261	12.9	16.9	21.5
SFU as % of above[c]	48%	26%	139%	17%	2%	1%

[a] Abbreviations: DALYs = disability-adjusted life years; SFU = solid fuel use.

[b] Source: WHO (2001).

[c] EBD from SFU as a percentage of the row above.

Although the disease burdens associated with moderate-II outcomes should not be included in the total burden reported for SFU because of insufficient evidence at present, a preliminary estimate of the additional impact they may represent was made. It was found that moderate-II health outcomes could add an additional 3.7 million DALYs lost and 126 000 deaths to the burden of disease from SFU. Tuberculosis, which primarily afflicts adults over 15 years of age, dominates this additional impact.

6.6 Step 5 – uncertainty

Uncertainty in exposure, particularly the variations in conditions and practices that affect ventilation, cannot be easily quantified. In an effort to provide some presentation of uncertainty, calculations for attributable fractions were repeated with the upper and lower relative risk confidence intervals, along with the exposure level. The resulting attributable fractions and burdens are presented in Tables 7 and 8, respectively. Corresponding scenarios for the final results are presented in Table 11.

Table 11 Low and high scenarios for the burden of disease from SFU[a] for India

Measure	**Scenario**	**ALRI** (thousands)	**COPD** (thousands)	**Lung cancer** (thousands)	**Children <5 years** (per 1000 population)	**Women ≥30 years** (per 1000 population)	**Men ≥30 years** (per 1000 population)
DALYs lost	Low	7 452	952	1	64.71	4.89	0.00
	Central	9 065	1 932	17	78.72	6.14	3.70
	High	10 238	2 611	47	88.91	7.27	6.10
Deaths	Low	210	53	0	1.83	0.27	0.00
	Central	256	106	2	2.22	0.34	0.20
	High	289	143	5	2.51	0.41	0.33

[a] Abbreviations: ALRI = acute lower respiratory infections; COPD = chronic obstructive pulmonary disease; DALYs = disability-adjusted life years; SFU = solid fuel use.

As explained in section 5.3, these low and high scenarios cannot be interpreted as the lower and upper statistical bounds around the central estimates. They serve simply to illustrate what other results are possible. The low scenario suggests that SFU may account for 2.8% of the total DALYs lost in India in 2000 and 2.7% of the total deaths. The high scenario suggests that, for the year 2000, SFU may account for as much as 4.3% of the total DALYs lost in 2000 and 4.5% of total deaths.

7 Interventions to reduce the burden of disease from SFU

As the previous case study demonstrates, SFU can be a major cause of ill-health. In such settings, efforts should be made to reduce the burden of disease from SFU through public health and primary care programmes. There is, however, no magic solution for reducing SFU exposures. Efforts to reduce indoor air pollution from SFU centre on the four general categories of interventions listed below (Smith, 1987, 1989; Barnes et al., 1993; Ezzati & Kammen, 2001; WHO, 2002).

- behavioural modifications to reduce exposure (e.g. encouraging mothers to keep their young babies away from the fire);
- household changes to improve ventilation (e.g. increasing the number of window openings in the kitchen, providing gaps between the roof and walls, or moving the stove out of the living area);
- improvements to cooking stoves (e.g. ventilation by flues, hoods or chimneys, or increases in combustion efficiency - nearly all pollutants damaging to health are products of incomplete combustion);
- interventions to enable people to use higher-quality, lower-emission liquid or gaseous fuels (e.g. petroleum-based kerosene and liquid petroleum gas, or biomass-based alcohol and bio-gas).

The cost, effectiveness and efficacy of these interventions generally increase as one moves down the above list. Clearly, the extent to which an intervention can be applied successfully varies across different populations, depending on local circumstances of income, housing, biomass availability, clean fuel access, cultural factors, and climate. These issues can be characterized through surveys of household fuel use, thus helping to inform and tailor interventions. Although much research is needed on all four categories of interventions (e.g. Smith, 2002), most assessments have focused on the last two approaches.

Programmes can be designed to encourage urban and periurban households that use solid fuels to move up the “energy ladder” to cleaner fuels (such as kerosene or liquid petroleum gas), and do so at lower income levels (i.e. sooner) than would occur without intervention. This approach requires that the availability and affordability of cleaner fuels be enhanced. On the other hand, the poorest rural populations with nearly no cash income, but access to wood and/or agricultural wastes, are unlikely to acquire improved cooking stoves – let alone cleaner fuels – without large subsidies, which are often unsustainable in the long term. There do seem to be large populations between these extremes, however, that can be effectively targeted by efforts to disseminate improved stoves.

Most improved stove programmes have utilized systems that remove combustion smoke from the household environment through venting devices such as flues, hoods or chimneys. Improved stoves are deceptively simple in concept, yet designing dependable and acceptable low-cost systems has proved to be a challenge, and the success rate of programmes to introduce improved stoves is low. Many programmes designed to introduce improved cooking stoves have relied entirely on local materials, such as mud and sand, which limits the durability and performance – and thus the long-term acceptability – of the improved stoves. Inexpensive and simple venting devices have also reduced the fuel efficiency of some improved stoves, owing to the added airflow from natural drafts induced by the vent, again hampering the acceptability of the improved stoves. Improved stove programmes should therefore consider using stoves made with more long-lasting materials, such as ceramics and metals, and encourage the local development of skills necessary to work with the materials. Additionally, programmes should pay careful attention to fuel efficiency, since this is a decisive criterion for most stove users. Many of the more successful programmes have taken this approach, notably the Chinese effort which has introduced nearly 200 million improved cooking stoves since the early 1980s (Smith, 1993; Goldemberg et al., 2000). Substantially more research and development work is needed, however, to learn how to apply the lessons learned in China and elsewhere to other parts of the world.

The factors leading to the adoption of a new household appliance, or to the modified use of existing household appliances, extend well beyond technical and economic issues, to include social, cultural and perceptual factors. Marketing, advertising, education and other avenues directed at assessing and influencing behaviour need to play important roles in efforts to mitigate SFU exposures. In particular, education can play an important role by conveying the value of cleaner kitchens and air to households. In this, hygiene education may be as important in reducing the impact of dirty combustion and lack of ventilation as it is in reducing the impact of dirty water and lack of sanitation.

Finally, the reader should be reminded that the purpose of this exercise is to make the best estimate possible of the health impacts from SFU. If this is to be used for comparison across risk factors, it is necessary to apply as uniform a set of guidelines as possible for accepting risk evidence and determining exposure. The results do not necessarily fully reflect the priority ranking of potential exposure-reduction interventions within each risk factor, however, although there is some relationship.

In part, this is a function of the time delays involved. For example, although COPD in older women is among the largest impacts, it does not necessarily follow that smoke exposures in older women ought to be addressed first by interventions, because this COPD is the result of long exposures starting in early years. Similarly, although ALRI affects infants most heavily, we are not yet able to tell what proportion of that impact is due to causes operating through exposures to the mother during or after pregnancy.

As there are large sets of laboratory, physiological, and epidemiological studies that show the fetus to be highly susceptible to the mother's pollution exposures of various kinds, and that the resulting impact can extend through and beyond infancy, there is good reason to believe that pregnant women represent the single most important group to protect (see Section 3.9). This is so even though we do not yet have sufficient epidemiological evidence to directly quantify the impact under a burden of disease framework. As progenitors of the child and the old woman to be, therefore, the groups that probably should be the first target of interventions are young women and their progeny, just born and to be born.

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Annex 1: Other indoor air pollutants

Other sources of indoor air pollution include radon (from the soil beneath buildings), tobacco smoke, cooking oil smoke, kerosene smoke, incense smoke, mosquito coil smoke, natural gas combustion products, toxic metals (from burning certain forms of coal), pesticides, and volatile organic compounds (from furnishings). Biological pollutants, such as dander or spores, and dust, which may be organic or inorganic in origin, can also be generated indoors. For most of these sources of pollution, not enough is known about exposure levels and health outcomes to include them in local assessments of the environmental burden of disease (EBD).

Three possible exceptions include environmental tobacco smoke (ETS), radon gas, and asthma-related biological pollutants. Much is known about the health risks of ETS (California Environmental Protection Agency, 1997; Cook & Strachan, 1999), although it is still difficult to determine exposure levels in many countries. Exposure to radon gas poses a significant risk of lung cancer, according to data for developed countries (USA National Research Council, 1999). This strong association indicates that attention should be paid to radon gas in regions where exposure data exist. Given an apparent increase in the prevalence of asthma worldwide (Stewart et al., 2001), efforts should also be made to gauge the impact of asthma-related biological pollutants in regions where the disease is already significant or is growing. Dander, spores and dust from biological sources are known to aggravate allergies and induce asthmatic episodes (Jones, 1998; Nelson, 1998), and indoor moisture (dampness), presumably an indicator of such biological sources, is also a risk factor for asthma according to some studies (Bornehag et al., 2001).

Limited information about exposures and health outcomes can be generated for other sources of indoor air pollution. Most of the following studies, for example, classify exposures categorically and provide some quantitative information about the relationships between exposure and associated health outcomes:

- Studies in East Asia indicate relative risks for lung cancer of 3–5 from certain cooking oils, especially when used in woks (Zhong et al., 1999; Ko et al., 2000).
- Unfortunately, few studies have examined the health impact of burning kerosene, which is a common fuel in many parts of the world with emissions and exposures intermediate between solid and gaseous fuels (Smith, 1987).
- A handful of studies have suggested a link between respiratory effects and burning incense (Yang et al., 1997) or mosquito coils (Azizi, Zulkifli & Kasim, 1995).
- Meta-analyses have associated natural gas use with childhood respiratory diseases and other effects. The relative risks were small but statistically significant (Basu & Samet, 1999).
- In China, the use of contaminated coal caused significant and widespread health impacts from fluorine and arsenic (Finkelman, Belkin & Zheng, 1999).
- Pesticides can infiltrate the indoor environment through a variety of routes, including directly from using vector control chemicals indoors, and indirectly from pesticide residue brought indoors from the outside on clothing and footwear (Eskenazi, Bradman & Castorina, 1999).

- For some volatile organic compounds, there are published risk factors for cancer and other health endpoints, but these are usually extrapolated from animal and other models, and are not based on epidemiological studies.

Annex 2: Summary of studies linking SFU with health outcomes

Table A2.1 Studies linking SFU with ALRI[a]

Study	Location	Design, *N,* age	Exposure assessment	Outcome assessment	Adjusted covariates	Odds ratio	95% CI [c]
Armstrong & Campbell, 1991[b]	The Gambia	cohort 500 0–59 months	questionnaire: mother carries child on her back while cooking	ALRI, by weekly home visits	birth interval, ETS, crowding, SES, nutrition, vaccination, education	F: 1.9 M: 0.5	1.0–3.9 0.2–1.2
Campbell, Armstrong & Bypass, 1989	The Gambia	cohort 271 0–11 months	questionnaire: mother carries child on her back while cooking	ALRI, by weekly home visits	birth interval, ETS, crowding, SES, nutrition, vaccination, education	2.8	1.3–6.1
Cerquiero et al., 1990[b]	Argentina	case–control 616, 669 0–59 months	questionnaire: type of cooking fuel used (wood, kerosene, gas)	ALRI within the last 12 days (well-baby clinic)	none	9.9	1.8–31.4
Collings, Sithole & Martin, 1990	Zimbabwe	case–control 244, 500 0–35 months	questionnaire: household uses open wood-fire for cooking	ALRI hospital cases, clinical signs and X-ray	ETS, crowding, housing, No. of siblings	2.2	1.4–3.3
de Francisco et al., 1993	The Gambia	case–control 129, 270 0–23 months	questionnaire: mother carries child on her back while cooking	death from ALRI by verbal autopsy confirmed by three independent physicians	SES, ETS, maternal education, crowding	5.2	1.7–15.9
Ezzati & Kammen, 2001[b]	Kenya	cohort 93 0–47 months	mean daily household PM_{10} concentrations	rate of ALRI during study period by interview	age, sex, crowding, smoking, village type	2.9	1.34–6.39
Johnson & Aderele, 1992	Nigeria	case–control 103, 103 0–59 months	questionnaire: type of cooking fuel used (wood, kerosene, gas)	ALRI hospital cases, clinical signs, X-ray and laboratory tests	none	0.8	0.4–1.7
Kossove, 1982[b]	South Africa	case–control 132, 18 0–12 months	questionnaire: does the child stay in the smoke	ALRI hospital cases, clinical signs and X-ray	none	4.8	1.7–13.6

Study	Location	Design, *N*, age	Exposure assessment	Outcome assessment	Adjusted covariates	Odds ratio	95% CI [c]
Armstrong & Campbell, 1991[b]	The Gambia	cohort 500 0–59 months	questionnaire: mother carries child on her back while cooking	ALRI, by weekly home visits	birth interval, ETS, crowding, SES, nutrition, vaccination, education	F: 1.9 M: 0.5	1.0–3.9 0.2–1.2
Morris et al., 1990	Arizona, USA	case–control 58, 58 0–23 months	questionnaire: primary source for heating and cooking	ALRI hospital cases, clinical signs and X-ray	family history of asthma, recent respiratory illness, dirt floor, running water	4.9	1.7–12.9
Mtango et al., 1992[b]	Tanzania	case–control 456, 1160 0–59 months	questionnaire: child sleeps in room where cooking is done	death, by verbal autopsy and physician	village, age, questionnaire respondent, maternal education, parity, water source, child's eating habits	2.8	1.8–4.3
O'Dempsey et al., 1996	The Gambia	case–control 80, 159 0–59 months	questionnaire: mother carries child on her back while cooking	ALRI hospital cases, clinical signs, X-ray and laboratory tests	ETS, mother's income, weight slope, recent illness	2.5	1.0–6.6
Pandey et al., 1989	Nepal	cohort 280 0–23 months	questionnaire: average time spent near the fireplace	ARI, by bi-weekly home visits	none	2.3	1.8–2.9
Robin et al., 1996	Arizona, USA	case–control 45, 45 0–23 months	questionnaire: household uses wood for cooking	ALRI hospital cases	No. of siblings, electricity, running water, difficulty in obtaining transportation to clinic, ETS, housing	5.0	0.6–42.8
Shah et al., 1994[b]	India	case–control 400, 400 0–60 months	questionnaire: household has a smoke-producing stove	severe ARI hospital cases, clinical symptoms	smoking, housing, No. of siblings, income, education, birth weight	1.2	0.7–2.3
Victora et al., 1994[b]	Brazil (urban)	case–control 510, 510 0–23 months	questionnaire: presence of indoor smoke	ALRI hospital cases, clinical signs and X-ray	smoking, housing, No. of siblings, income, education, history of respiratory illness	1.1	0.6–2.0

[a] All studies examined both sexes. [b] Excluded from the meta-analysis.

[c] Abbreviations: ALRI = acute lower respiratory infections; CI = confidence interval; ETS = environmental tobacco smoke; F = female; M = male; SES = socioeconomic status; SFU = solid fuel use.

Table A2.2 Studies linking SFU with COPD[a]

Study	Location	Design, *N*, population	Exposure Assessment	Outcome assessment	Adjusted covariates	Odds ratio	95% CI
Albalak, Frisancho & Keeler, 1999	Bolivia	cross-sectional 241 F + M >20 yrs	cooking inside or outside	chronic bronchitis[b]	age, sex	2.5	1.3-5.0
Behera, Dash & Yadav, 1991[c]	Northern India	cross-sectional 3718 F involved in cooking	use of solid biofuel for cooking (wood + dung)	chronic bronchitis	none	1.97	1.16-3.22
Dennis et al., 1996	Colombia (urban)	case-control 104, 104 F >35 yrs	use of solid biofuel for cooking (wood)	COPD[d], COPD + chronic bronchitis	age, smoking, hospital	3.9	1.7-9.1
Døssing, Khan & al-Rabaiah, 1994	Saudi Arabia	case-control 50, 71 F + M hospital admissions	ever exposed to open cooking fire	COPD[e]	none, matched for age and sex	14.4	5.5-37.5
Dutt et al., 1996	Southern India (urban)	cohort 315 F 15-60 yrs	use of solid biofuel for cooking (wood)	chronic bronchitis	none, age stratified sampling	2.8	0.7-11.4
Gupta & Mathur, 1997	India (rural)	cross-sectional 707 F + M >15 yrs	use of solid biofuel for cooking (wood+dung)	chronic bronchitis + bronchial asthma	age	7.9	2.8-21.8
Malik, 1985	Northern India	cross-sectional 2180 F >20 yrs	use of solid biofuel for cooking (wood)	COPD + chronic bronchitis, chronic bronchitis,	none	3.0	1.8-4.9
Menezes, Victora & Rigatto, 1994	Brazil (urban)	cross-sectional 1053 F + M >40 yrs	presence of at least two of the following: open fire, charcoal stove, paraffin lamp or coal heater	chronic bronchitis	age, sex, race, income, schooling, smoking, childhood respiratory illnesses, occupational exposures	1.3	0.8-2.3

Study	Location	Design, *N,* population	Exposure Assessment	Outcome assessment	Adjusted covariates	Odds ratio	95% CI
Albalak, Frisancho & Keeler, 1999	Bolivia	cross-sectional 241 F + M >20 yrs	cooking inside or outside	chronic bronchitis[b]	age, sex	2.5	1.3-5.0
Pandey, 1984[c]	Nepal	cross-sectional 748 F + M >20 yrs	use of solid biofuel for cooking (wood + straw)	chronic bronchitis	none	5.4	3.0-9.8
Perez-Padilla et al., 1996	Mexico (urban)	case-control 126, 375 F >40 yrs	use of solid biofuel for cooking and heating (wood)	chronic bronchitis	age, place of residence, education, income, smoking	4.1	2.3-9.4
Qureshi, 1994[c]	Kashmir	cross-sectional 560 F + M >15 yrs	average time spent near the fireplace (>4 hours vs. <4 hours)	chronic bronchitis	none	3.5	1.4-8.8

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[a] Abbreviations: CI = confidence interval; COOPD = chronic obstructive pulmonary disease; F = female; FEV1 = forced expiratory volume; FVC = forced vital capacity; M = male; SES = socioeconomic status; SFU = solid fuel use; yrs = years.

[b] Chronic bronchitis was defined as a cough and sputum on most days for at least three consecutive months of two successive years.

[c] Excluded from the meta-analysis.

[d] COPD = FEV1/FVC <70% without asthma, or FEV1 <70% of predicted value.

[e] COPD = FEV1/FVC <70%, FEV1 <70% of predicted value and <15% or <250 cc absolute increase after administration of 200 µg of aerosolized salbutamol.

Table A2.3 Studies linking SFU[a] with lung cancer

Study	Location	Design, *N*, population	Exposure assessment	Outcome assessment	Adjusted covariates	Odds ratio	95% CI
Dai et al., 1996	China, Liaoning Province, Harbin City	case–control 120, 120 F, non-smoking	use of coal heater for 25–34 years	Newly diagnosed lung cancer	history of family cancer, income, carrot consumption, deep fried cooking	4.7	1.28–17.18
Du et al., 1988[b]	China, Guangzhou Province	case–control 662, 662 F + M	exposed to coal fumes yes/no	Death from lung cancer	matched for age, sex, residence	14.52	missing
Du et al., 1996	China, Guangzhou Province	case–control 120, 240 F + M, non-smoking	exposed to coal fumes yes/no	Death from lung cancer	smoking, chronic respiratory disease	F: 1.56 M: 1.50	0.57–4.25 0.69–3.27
Gao et al., 1987[c]	China, Shanghai	case–control 672, 735 F	cooking with coal or biofuel	Newly diagnosed lung cancer	smoking, education, age	coal: 0.9 biomass: 1.0	0.7–1.3 0.6–1.8
Huang, 1999	China, Nanning City	case–control 122, 244 F + M	use of coal	Newly diagnosed lung cancer	smoking, chronic lung disease, meat consumption, depression, SES, BMI, exercise	1.76	1.30–2.38
Ko et al., 1997[c]	Taiwan	case–control 117, 117 F	started cooking with either coal or biofuel between 20–40 years of age	Newly diagnosed lung cancer	education, place of residence, SES	coal: 1.3 biomass: 2.7	0.3–5.8 0.9–8.9
Lei et al., 1996	China, Guangzhou Province	case–control 792, 792 F + M	cooking for more than 40 years	Death from lung cancer	matched for age, sex	0.93	0.67–1.21
Liu, He & Chapman, 1991	China, Yunnan Province	case–control 110, 426 F + M farmers	started to cook before 10 years of age	Newly diagnosed lung cancer	smoking; matched for age, sex, village	F: 1.25 M: 3.36	0.45–3.49 1.27-8.88
Liu et al., 1993[c]	China, Guangzhou Province	case–control 316, 316 F + M	use of coal and wood for cooking	Newly diagnosed lung cancer	smoking, passive smoking, education, SES, history of cancer	coal: 1.46 biomass: 1.19	0.83–2.56 0.46–3.11

Study	Location	Design, *N*, population	Exposure assessment	Outcome assessment	Adjusted covariates	Odds ratio	95% CI
Dai et al., 1996	China, Liaoning Province, Harbin City	case–control 120, 120 F, non-smoking	use of coal heater for 25–34 years	Newly diagnosed lung cancer	history of family cancer, income, carrot consumption, deep fried cooking	4.7	1.28–17.18
J. Liu & H. Hu, unpublished data	China, Beijing	case–control 220, 440 F + M farmers	combustion of coal cakes	Death from lung cancer	smoking, chronic respiratory disease; matched for age	1.9	1.16–3.43
Luo et al., 1996	China, Fujan Province, Fuzhou City	case–control 102, 306 F + M	indoor combustion of coal	newly diagnosed lung cancer	smoking, ETS, chronic bronchitis; matched for age, sex	ADC: 6.0 SCC: 14.1	1.36–23.49 1.67–119.4
Shen et al., 1996	China, Nanjing City	case–control 263, 263 F + M	use of solid fuels	newly diagnosed lung cancer	matched for age, sex, multivariates (final model not shown)	4.97	0.80–30.88
Sobue, 1990[b,c]	Japan, Osaka	case–control 144, 731 F, non-smoking	use of biofuel for cooking at 15 or 30 years of age	newly diagnosed lung cancer	age, education	1.77	1.08–2.91
Wang, Zhou & Shi, 1996	China, Liaoning Province, Shenyang City	case–control 135, 135 F	use of coal for cooking	newly diagnosed lung cancer	family history of cancer, ETS	0.75	0.43–1.31
Wu et al. 1985	USA, Los Angeles	case–control 220, 220 F + M	use of coal for cooking and heating during childhood	newly diagnosed lung cancer	smoking; matched for age, place of residence	ADC: 2.3 SCC: 1.9	1.0–5.5 0.56–6.5
Wu-Williams et al., 1990	China, Liaoning Province, Shenyang and Harbin Cities	case–control 956, 952 F	use of coal stove for more than 40 years	newly diagnosed lung cancer	age, education, smoking	1.3	1.0–1.7
Wu et al., 1999	China, Guanzhou City	case–control 258, 258 F	use of coal as residential fuel	newly diagnosed lung cancer	smoking, history of tuberculosis, fruit consumption, ventilation of kitchen	1.57	0.89–2.82
Xu et al., 1996[b]	China, Shenyang City	case–control 1249, 1345 F + M	use of coal stove for cooking	newly diagnosed lung cancer from cancer registry	none	F: 1.5 M: 2.3	NA

Study	Location	Design, *N*, population	Exposure assessment	Outcome assessment	Adjusted covariates	Odds ratio	95% CI
Dai et al., 1996	China, Liaoning Province, Harbin City	case–control 120, 120 F, non-smoking	use of coal heater for 25–34 years	Newly diagnosed lung cancer	history of family cancer, income, carrot consumption, deep fried cooking	4.7	1.28–17.18
Yang, Jiang & Wang, 1988[b]	China, Hubei Province, Wuhan City	case–control unknown *N* F + M	use of coal for cooking	death from lung cancer	none	NA	NA

[a] Abbreviations: ADC = adenocarcinoma; BMI = body mass index; CI = confidence interval; F = female; M = male; NA = not applicable; SCC = squamous cell carcinoma; SES = socioeconomic status; SFU = solid fuel use.

[b] Excluded from meta-analysis on lung cancer (from exposure to coal smoke).

[c] Also addresses lung cancer (from exposure to biomass smoke).

Table A2.4 Studies linking SFU[a] with asthma

Study[b]	Location	Design, *N,* population	Exposure assessment	Outcome assessment	Adjusted covariates	Odds ratio	95% CI
Azizi, Zulkifli & Kasim, 1995	Malaysia, Kuala Lumpur	case–control 158, 201 1 month to 5 years	questionnaire: sharing bedroom with adult smoker (ETS), mosquito coil used more than three nights in the past week	first time hospitalization for asthma	history of allergy, asthma in first-degree relatives, low birth weight, coughing sibling	ETS: 1.91 coil: 1.73	1.13–3.21 1.02–2.93
Mohamed et al., 1995	Kenya, Nairobi	case–control 77, 77 9–11 years	visible air pollution in the home	history of asthma symptoms of persistent or frequent wheeze; or 10% or more decline in FEV1 at 5 or 10 minutes after exercise	damp damage in child's bedroom; furniture, rugs and carpets in child's bedroom; extra salt intake of the child; matched age, sex controls	2.5	2.00–6.40
Xu, Niu & Christian, 1996	China (rural)	cross-sectional 28 946 ≥15 years	questionnaire: coal used for cooking	reported physician diagnosis of asthma	age, education, occupation, marital status	F: 1.15 M: 1.86 both: 1.51	0.66–2.02 1.15–3.01 1.05–2.17

[a] Abbreviations: CI = confidence interval; ETS = environmental tobacco smoke; F = female; FEV1 = forced expiratory volume; M = male; SFU = solid fuel use.

[b] All studies examined both sexes.

Table A2.5 Studies linking SFU[a] with cataracts

Study	Location	Design, *N*, population	Exposure assessment	Outcome assessment	Adjusted covariates	Odds ratio	95% CI
Mishra, Retherford & Smith, 1999	India	cross-sectional 173, 520 F + M, >30 years of age	questionnaire: wood or dung used for cooking	householder reported partial or complete blindness	separate kitchen, housing type, crowding, age, urban/rural residence, education, religion, caste/tribe, geographic region	F: 1.30 M: 1.31	1.12–1.50 1.12–1.52
Mohan et al., 1989	Delhi, India	Case–control 1441, 549 F + M, 37–62 years of age	questionnaire: dung or wood used for cooking	ophthalmologist diagnosed posterior subcapsular, cortical, nuclear, or mixed cataract	aspirin use, education, dietary protein, systolic blood pressure, body mass index, cloud cover, time spent near work, year of examination, sex; age matched controls	1.61[b]	1.02-2.50
Zodpey & Ughade, 1999	Nagpur, India	Case–control 223, 223 F, 35–75 years of age	questionnaire: smoky fuels (coal, dung, wood, kerosene) used for cooking	hospital diagnosed age-related cataract (corrected visual acuity 6/60 or worse)	socioeconomic status, age and sex matched controls	2.37	1.44-4.13

[a] Abbreviations: CI = confidence interval; F = female; M = male; SFU = solid fuel use.

[b] Cortical, nuclear, and mixed cataract; no risk observed for posterior subcapsular cataracts.

Table A2.6 Studies linking SFU[a] with tuberculosis

Study	Location	Design, *N*, population	Exposure assessment	Outcome assessment	Adjusted covariates	Odds ratio	95% CI
Gupta & Mathur, 1997	India, Lucknow	cross-sectional 707, 707 F + M >16 years of age	questionnaire: wood or dung used for cooking	physician diagnosed active pulmonary tuberculosis	age	2.54	1.07–6.04
Mishra, Retherford & Smith, 1999	India	cross-sectional 260, 162 F + M >20 years of age	questionnaire: wood or dung used for cooking	householder reported prescence of active tuberculosis	age, separate kitchen, housing type, crowding, sex, residence, education, religion, caste/tribe, geographic region	F: 2.74 M: 2.46 both: 2.58	1.86–4.05 1.79–3.39 1.98–3.37
Perez-Padilla et al., 1996	Mexico, Mexico City	case–control 83, 292 F: >40 years of age	questionnaire: >200 hour-years of woodsmoke exposure	physician diagnosed pulmonary tuberculosis	age, income, smoking, education, place of residence, place of birth	4.0	1.03–15.00
Perez-Padilla et al., 2001	Mexico, Mexico City	case–control 288, 545 F + M	questionnaire: past and current use of wood burning stove at home	physician diagnosed pulmonary tuberculosis	age, sex, urban/rural residence, crowding, education, smoking, income	past: 1.1 current: 2.2 both: 1.5	0.6–2.0 1.1–4.2 1.0–2.4

[a] Abbreviations: CI = confidence interval; F = female; M = male; SFU = solid fuel use.

Annex 3: Alternative approaches

Four different methods have been used to estimate the burden of disease from SFU in developing countries, each with advantages and disadvantages (Smith & Mehta, 2003). The pollution-based approach has been widely used, but appears to be more suitable for studies on urban air pollution in developed countries. The fuel-based approach, advocated here, appears to be the most reliable method for assessing the EBD from SFU in developing countries. These two methods are compared below. Two other methods have been applied in limited situations and rely on large data sets: the child survival approach in India and the cross-national approach in a single global study. These approaches are unlikely to be reproduced in other settings, and are only briefly discussed below. Table A3.1 summarizes these assessment methods.

Table A3.1 Assessment methods for determining the EBD[a] from SFU

Approach	Methodology	Data used
pollutant-based	exposure–response extrapolation	– estimated exposure concentrations for indicator pollutants, usually PM. – exposure–response relationships from urban outdoor studies, usually based in developed countries. – current rates of morbidity and mortality.
fuel-based	disease-by-disease summation	– estimated distribution of exposure surrogates, usually fuel type. – relative risks from studies of specific diseases in specific populations experiencing exposure surrogates, usually based in developing countries. – current rates of morbidity and mortality.
child survival	Survival analysis	– survival curves for different risk factors based on household surveys.
cross-national	Regression analysis	– cross-country comparisons of national-level data on health and energy conditions.

[a] Abbreviations: EBD = environmental burden of disease; PM = particulate matter; SFU = solid fuel use.

Pollutant-based approach

The pollutant-based approach has been commonly applied in developed countries, and it has been suggested that the approach could be used as a standard for broad application (Ostro, 1996). The pollutant-based approach involves several steps that parallel the fuel-based approach. First, the population exposures to an indicator pollutant, generally PM, are estimated in terms of some measure of concentration-time. Then, the best available exposure-response relationships for the indicator pollutant are applied to determine excess morbidity and mortality. Last, these figures are compared to current rates to estimate attributable fraction.

It is questionable, however, whether exposure–response relationships derived from pollutant-based investigations are applicable to populations exposed to indoor air pollution in rural areas of developing countries, since most pollutant-based epidemiological studies were conducted outdoors in urban areas of developed countries. Potential problems include differences in pollutant mix and composition, exposure patterns and levels, and population characteristics.

The chemical pollutants produced by burning solid fuels, for example, are different from those produced by burning fossil fuels. Moreover, indoor air pollutant concentrations can attain levels 10–50 times greater than pollutant concentrations outdoors, and indoor air pollutant levels vary more than counterpart outdoor levels (Smith, 1993). In addition, quantitative studies of indoor exposures from SFU that were carried out in developing countries have had small sample sizes and were not done with sampling frames oriented toward developing statistically valid population-wide estimates. Lastly, the age distributions, current disease rates, and competing risk factors differ dramatically between urban developed country populations, the world's oldest, healthiest and richest, and rural developing country populations, among the youngest, most stressed and poorest in the world. Nevertheless, in the absence of alternatives, efforts have been made to derive regional and global average exposures to PM, the best indicator pollutant (Sarnat et al., 2001), so that pollutant-based calculations can be done (Smith, 1993).

Besides requiring rather heroic extrapolations of available exposure measurements, pollutant-based assessments have frequently been forced to assume an arbitrary shallowing of the exposure-response curves at the high pollutant levels found in households (Smith & Liu, 1994). Indeed, without such a shallowing, estimates of the health burdens from SFU are so large as to stretch credibility. Although there is qualitative evidence for such shallowing, there are insufficient data to derive quantitative expressions. Finally, use of exposure-response curves requires an arbitrary counterfactual level to calculate burdens, since zero exposure is not feasible. Because of the assumptions and extrapolations required in the pollutant-based approach, this approach is perhaps most useful for generating initial estimates.

Fuel-based approach

By contrast, the fuel-based approach described in this guide takes advantage of the large number of epidemiological investigations conducted primarily in rural areas of developed countries that treat exposure to indoor air pollution from SFU as a single category of exposure. In doing so, the fuel-based approach addresses many of the concerns described above for the pollutant-based approach, substantially reducing discrepancies in pollutant mix and composition, exposure patterns and levels, and population characteristics. Because the epidemiological studies employed use binary exposure variables, it is unnecessary to extrapolate pollutant exposures from incomplete data. Since the fuel-based approach compares exposed versus less-exposed populations, there is no need to define an arbitrary counterfactual level.

The fuel-based approach is not without weaknesses, however. Section 5 describes sources of uncertainty in the approach. In addition, three issues inherent to the fuel-based approach constrain its accuracy and utility. First, although the epidemiological studies are in many ways more appropriate, they are far fewer in number, have smaller sample sizes and lack the sophistication of the outdoor, urban studies that measure particulate concentrations. Second, the use of a binary category of exposure hinders the creation of a exposure-response curve. Ideally, it would be useful to have an exposure-response curve for different combinations of fuel use patterns and housing conditions. Last, there is a need to estimate ventilation factors to determine SFU household equivalents. Unlike the situation with SFU, there does not appear to be a model for estimating ventilation factors for the fuel-based approach.

The child survival approach

The child survival approach (Hughes & Dunleavy, 2000) analysed the rich data set generated by India's National Family Health Survey (NFHS, 1995), which focused on fertility, family planning, mortality and child health. The National Family Health Survey is part of a series of demographic and health surveys funded primarily by the USA Agency for International Development in about three dozen countries. Survival curves were determined for children under five years of age living in different household conditions, and controlled for potential confounders, such as house type, mother's education, parity, household size, caste, etc. The results indicate the impact that differences in household conditions can have on childhood mortality. Of course, this approach does not address the burden experienced by other population groups, particularly women. Countries with national family health survey data may also be able to pursue the child survival approach.

The cross-national approach

The cross-national approach relies on a regression model of demographic and health statistics, cross-nationally corrected for confounders, as has been done for 122 nations in a recent publication (Bloom & Rosenfield, 2000). Input data included basic demographic indicators, such as life expectancy, mortality, fertility, birth rate and death rate. The exposure measure, "percent of traditional fuel use," is difficult to interpret, since it refers to the percentage of total fuel use in the economy, not in households. This approach suffers from a lack of specificity, common to all ecological studies, in which relationships are examined on a population basis without linking exposure and effect at the household or individual level. In addition, such a broad-scale analysis relies inevitably on parameters that are commonly available and thus have a significant chance for residual confounding. Until the full details of the method are published, it is difficult to further assess this approach, but it could potentially be employed within large countries with diverse regions.

Annex 4: Additional questions for surveys of household fuel use

To both assist local assessments and suggest local interventions, the following boxes provide a nearly comprehensive list of additional questions which, tailored to local circumstances, may be included in surveys of household fuel use. Additional questions on fuel use (Box A4.1) can further specify the types of fuels used and their respective purposes. Additional questions on stove types (Box A4.2), housing characteristics (Box A4.3), and cooking/heating practices (Box A4.4) can inform ventilation coefficients. Questions on time-activity patterns (Box A4.5) and demographics (Box A4.6) can help to describe relevant features of the exposed and nonexposed populations.

Box A4.1: Fuel use

- distinguish between low-emission and high-emission coal
- dominant fuel used for boiling water
- energy source for lighting and/or appliances
- primary fuel used for cooking and heating in each season.

Box A4.2: Stove types

Traditional biomass stove:
- type
- material
- number of pot holes
- height
- hood (Y/N)
- used for space heating (Y/N).

Improved biomass stove (characterized by the presence of a chimney or flue):
- type
- material
- number of pot holes
- height
- hood (Y/N)
- used for space heating (Y/N)
- chimney height
- chimney condition
- controllable damper (Y/N).

Kerosene or biogas stove:
- type
- use purposes/patterns.

Liquid petroleum gas (propane/butane) stove:
- number of burners
- cylinder volume
- frequency of cylinder refilling
- mode of acquisition
- use purposes/patterns.

Box A4.3: Housing characteristics

With respect to the kitchen:
- type (with or without partition separating it from main living area)
- location within household
- dimensions
- number and size of doorways
- number and size of windows or major openings.

For households with kitchen partition:
- partition extends to ceiling (Y/N); if no, size of gap.

For households with open air kitchens:
- roof or canopy present (Y/N); if yes, describe.

Overall household:
- rooms in household
- roof and wall heights
- gap between roof and wall (Y/N)
- roof material
- wall material
- floor material
- number and size of doorways
- number and size of windows or major openings.

Box A4.4: Cooking/heating practices

The cook is asked to describe, with respect to each fuel type used:
- amount used per day (in kilograms or litres)
- how the fuel was acquired (collected or purchased)
- amount of time/money spent acquiring the fuel
- used for what/where/when/why
- recent changes in any of the above.

The cook is also asked to describe:
- amount of time spent cooking in morning/afternoon/evening
- seasonal patterns of fuel use
- seasonal patterns of cooking
- seasonal patterns of heating.

Box A4.5: Time–activity patterns

For each household member, a typical day's activities are described:

- activity
- duration
- location (in kitchen close to stove, in kitchen far from stove, indoors at home but not in kitchen, indoors not at home, outdoors).

Box A4.6: Demographics

The interviewee is asked to provide the following information for all household members:

- name
- relationship to head of household
- sex
- age
- education level
- involved in cooking (Y/N)
- present in kitchen during cooking (Y/N)
- smoker (Y/N).

With respect to the household:

- socioeconomic status
- household assets.

Annex 5: Estimates of SFU by country

Known and predicted values of SFU are shown in Table A5.1. Countries for which estimates are based on predictions from the global assessment's statistical model are listed in **bold**, and the low and high estimates are 95% confidence intervals generated by the model. For all other countries, estimates are based on known values extrapolated from surveys of household fuel use. For this set of countries, low and high estimates are based on an arbitrary ±5% uncertainty range. See Section 4.4 for more information. In the global assessment, it was possible to distinguish between biomass and coal fuel types only for China and India, the countries with the most prevalent coal use. These results are presented in Table A5.2.

Table A5.1 Household SFU by country[a]

				Taking ventilation into account		
Sub-region	**Country**	**Household SFU (%)**	**Ventilation coefficient**	**Central estimate (%)**	**Low estimate (%)**	**High estimate (%)**
AFR D	Algeria	4	1.00	4	0	9
AFR D	Angola	100	1.00	100	95	100
AFR D	**Benin**	88	1.00	88	79	98
AFR D	Burkina Faso	97	1.00	97	92	100
AFR D	**Cameroon**	77	1.00	77	69	86
AFR D	Chad	100	1.00	100	95	100
AFR D	**Equatorial Guinea**	83	1.00	83	74	92
AFR D	**Gabon**	34	1.00	34	16	52
AFR D	Gambia	98	1.00	98	93	100
AFR D	Ghana	95	1.00	95	90	100
AFR D	Guinea	99	1.00	99	94	100
AFR D	Guinea-Bissau	95	1.00	95	90	100
AFR D	**Liberia**	83	1.00	83	74	92
AFR D	Madagascar	99	1.00	99	94	100
AFR D	Mali	100	1.00	100	95	100
AFR D	Mauritania	69	1.00	69	64	74
AFR D	**Mauritius**	75	1.00	75	69	81
AFR D	Niger	98	1.00	98	93	100
AFR D	Nigeria	67	1.00	67	62	72
AFR D	Senegal	79	1.00	79	74	84
AFR D	Sierra Leone	92	1.00	92	87	97
AFR D	**Togo**	96	1.00	96	88	100
AFR E	Botswana	65	1.00	65	60	70
AFR E	**Burundi**	100	1.00	100	100	100
AFR E	Central African Republic	99	1.00	99	94	100
AFR E	Congo	100	1.00	100	95	100
AFR E	Cote d'Ivoire	93	1.00	93	88	98
AFR E	Dem Rep of Congo	100	1.00	100	95	100
AFR E	Ethiopia (including Eritrea)	97	1.00	97	92	100

Sub-region	Country	Household SFU (%)	Ventilation coefficient	Taking ventilation into account		
				Central estimate (%)	Low estimate (%)	High estimate (%)
AFR D	Algeria	4	1.00	4	0	9
AFR E	Kenya	85	1.00	85	80	90
AFR E	**Lesotho**	85	1.00	85	77	92
AFR E	**Malawi**	99	1.00	99	89	100
AFR E	**Mozambique**	87	1.00	87	78	96
AFR E	**Namibia**	83	1.00	83	75	90
AFR E	**Rwanda**	100	1.00	100	95	100
AFR E	South Africa	28	1.00	28	23	33
AFR E	Swaziland	88	1.00	88	83	93
AFR E	Tanzania	96	1.00	96	91	100
AFR E	Uganda	97	1.00	97	92	100
AFR E	Zambia	87	1.00	87	82	92
AFR E	Zimbabwe	67	1.00	67	62	72
AMR A	**Cuba**	42	1.00	42	26	57
AMR A	Canada	0	1.00	0	0	0
AMR A	United States	0	1.00	0	0	0
AMR B	**Barbados**	57	1.00	57	43	72
AMR B	Brazil	27	1.00	27	22	32
AMR B	**Chile**	15	1.00	15	0	31
AMR B	**Columbia**	36	1.00	36	24	48
AMR B	**Costa Rica**	58	1.00	58	45	71
AMR B	**Dominican Republic**	48	1.00	48	37	59
AMR B	**El Salvador**	65	1.00	65	54	77
AMR B	**Honduras**	66	1.00	66	58	73
AMR B	**Jamaica**	47	1.00	47	36	57
AMR B	Mexico	22	1.00	22	17	27
AMR B	**Panama**	37	1.00	37	24	50
AMR B	**Paraguay**	64	1.00	64	52	77
AMR B	**Suriname**	69	1.00	69	61	76
AMR B	**Trinidad and Tobago**	0	1.00	0	0	20
AMR B	**Venezuela**	0	1.00	0	0	5
AMR B	Argentina	0	1.00	0	0	0
AMR B	Uruguay	0	1.00	0	0	0
AMR D	**Bolivia**	61	1.00	61	49	72
AMR D	Ecuador	28	1.00	28	23	33
AMR D	**Guatemala**	73	1.00	73	61	85
AMR D	**Haiti**	82	1.00	82	76	88
AMR D	**Nicaragua**	73	1.00	73	62	85
AMR D	**Peru**	40	1.00	40	27	53
EMR B	**Bahrain**	0	1.00	0	0	0
EMR B	**Cyprus**	24	1.00	24	0	47
EMR B	Iran	2	1.00	2	0	7
EMR B	**Jordan**	10	1.00	10	0	22
EMR B	**Kuwait**	0	1.00	0	0	0
EMR B	Lebanon	9	1.00	9	4	14
EMR B	Libya	3	1.00	3	0	8

Sub-region	**Country**	**Household SFU (%)**	**Ventilation coefficient**	**Taking ventilation into account**		
				Central estimate (%)	**Low estimate (%)**	**High estimate (%)**
AFR D	Algeria	4	1.00	4	0	9
EMR B	**Oman**	0	1.00	0	0	13
EMR B	**Qatar**	0	1.00	0	0	13
EMR B	**Saudi Arabia**	0	1.00	0	0	0
EMR B	**Syria**	19	1.00	19	2	36
EMR B	Tunisia	29	1.00	29	24	34
EMR B	**United Arab Emirates**	0	1.00	0	0	0
EMR D	Afghanistan	98	1.00	98	93	100
EMR D	Djibouti	6	1.00	6	1	11
EMR D	Egypt	8	1.00	8	3	13
EMR D	Iraq	2	1.00	2	0	7
EMR D	Morocco	11	1.00	11	6	16
EMR D	Pakistan	76	1.00	76	71	81
EMR D	Sudan	100	1.00	100	95	100
EMR D	**Yemen**	66	1.00	66	50	81
EUR A	**Croatia**	15	0.20	3	0	8
EUR A	**Israel**	0	1.00	0	0	30
EUR A	Austria	0	1.00	0	0	0
EUR A	Belgium	0	1.00	0	0	0
EUR A	Czech Republic	0	0.20	0	0	0
EUR A	Denmark	0	1.00	0	0	0
EUR A	Finland	0	1.00	0	0	0
EUR A	France (including Monaco)	0	1.00	0	0	0
EUR A	Germany	0	1.00	0	0	0
EUR A	Greece	0	1.00	0	0	0
EUR A	Ireland	0	1.00	0	0	0
EUR A	Italy (including San Marino)	0	1.00	0	0	0
EUR A	Netherlands	0	1.00	0	0	0
EUR A	Norway	0	1.00	0	0	0
EUR A	Portugal	0	1.00	0	0	0
EUR A	Slovenia	0	0.20	0	0	0
EUR A	Spain	0	1.00	0	0	0
EUR A	Sweden	0	1.00	0	0	0
EUR A	Switzerland (including Liechtenstein)	0	1.00	0	0	0
EUR A	United Kingdom	0	1.00	0	0	0
EUR B	**Albania**	76	0.20	15	14	17
EUR B	**Bosnia and Herzegovina**	74	0.20	15	14	16
EUR B	**Bulgaria**	31	0.20	6	3	9
EUR B	**Armenia**	66	1.00	66	49	83
EUR B	**Azerbaijan**	37	1.00	37	15	59
EUR B	**Georgia**	71	1.00	71	58	84
EUR B	**Kyrgyzstan**	96	1.00	96	87	100
EUR B	**Macedonia**	58	0.20	12	9	14
EUR B	**Poland**	37	0.20	7	5	10
EUR B	**Romania**	45	0.20	9	7	11

				Taking ventilation into account		
Sub-region	**Country**	**Household SFU (%)**	**Ventilation coefficient**	**Central estimate (%)**	**Low estimate (%)**	**High estimate (%)**
AFR D	Algeria	4	1.00	4	0	9
EUR B	**Slovakia**	24	0.20	5	1	8
EUR B	**Tajikistan**	100	1.00	100	93	100
EUR B	Turkey	11	1.00	11	6	16
EUR B	**Turkmenistan**	50	1.00	50	33	68
EUR B	**Uzbekistan**	79	1.00	79	72	85
EUR B	**Yugoslavia**	69	0.20	14	12	15
EUR C	**Belarus**	10	0.20	2	0	6
EUR C	**Estonia**	39	0.20	8	5	11
EUR C	**Hungary**	26	0.20	5	2	8
EUR C	**Kazakhstan**	51	1.00	51	42	59
EUR C	**Latvia**	19	0.20	4	0	7
EUR C	**Lithuania**	42	0.20	8	6	11
EUR C	**Moldova**	72	0.20	14	13	16
EUR C	**Russian Federation**	7	0.20	1	0	6
EUR C	**Ukraine**	56	0.20	11	9	14
SEAR B	Indonesia	63	1.00	63	58	68
SEAR B	**Sri Lanka**	89	1.00	89	79	100
SEAR B	Thailand	72	1.00	72	67	77
SEAR D	Bangladesh	96	1.00	96	91	100
SEAR D	India	81	1.00	81	76	86
SEAR D	**Korea, DPR**	68	1.00	68	56	80
SEAR D	Myanmar	100	1.00	100	95	100
SEAR D	Nepal	97	1.00	97	92	100
WPR A	**Brunei Darussalam**	70	1.00	70	63	77
WPR A	Australia	0	1.00	0	0	0
WPR A	Japan	0	1.00	0	0	0
WPR A	New Zealand	0	1.00	0	0	0
WPR A	Singapore	0	1.00	0	0	0
WPR B	China[b]	80	0.25/0.50	20/40	19/37	21/42
WPR B	**Cambodia**	100	1.00	100	100	100
WPR B	**Laos**	95	1.00	95	87	100
WPR B	**Malaysia**	29	1.00	29	13	45
WPR B	**Mongolia**	67	1.00	67	53	81
WPR B	**Papua New Guinea**	97	1.00	97	84	100
WPR B	Philippines	85	1.00	85	80	90
WPR B	Vietnam	98	1.00	98	93	100
WPR B	**Hong Kong SAR, China**	0	1.00	0	0	0
WPR B	**Korea, Republic of**	0	1.00	0	0	0

[a] Source: Smith, Mehta & Feuz (2004).

[b] For China, the ventilation coefficient for children is 0.25 and for adults is 0.50. Thus, the smaller estimates are for children and the larger estimates are for adults.

Table A5.2 Percentage of households using coal[a]

Country	Households using coal (%)	Ventilation coefficient	Taking ventilation into account Central estimate (%)	Low estimate (%)	High estimate (%)
India	3	1.00	3	0	8
China	31	0.50[b]	16	13	18

[a] For India and China, the difference between the percentage of households using coal and households using solid fuels yields the percentage of households using biomass fuels.

[b] Lung cancer, the only distinct health outcome associated with coal use, occurs almost exclusively in adults. Hence, the ventilation coefficient used for China is 0.50.

Annex 6: Summary results of the global assessment of disease burden from SFU

A global analysis of the disease burden caused by exposure to SFU for cooking in the home was performed on the basis of the same approach as described in this guide. The analysis was performed for 14 regions of the world, grouped as shown in Figure A6.1 and Table A6.1, and by age and sex groups.

Figure A6.1 Regional country groupings for the global disease burden

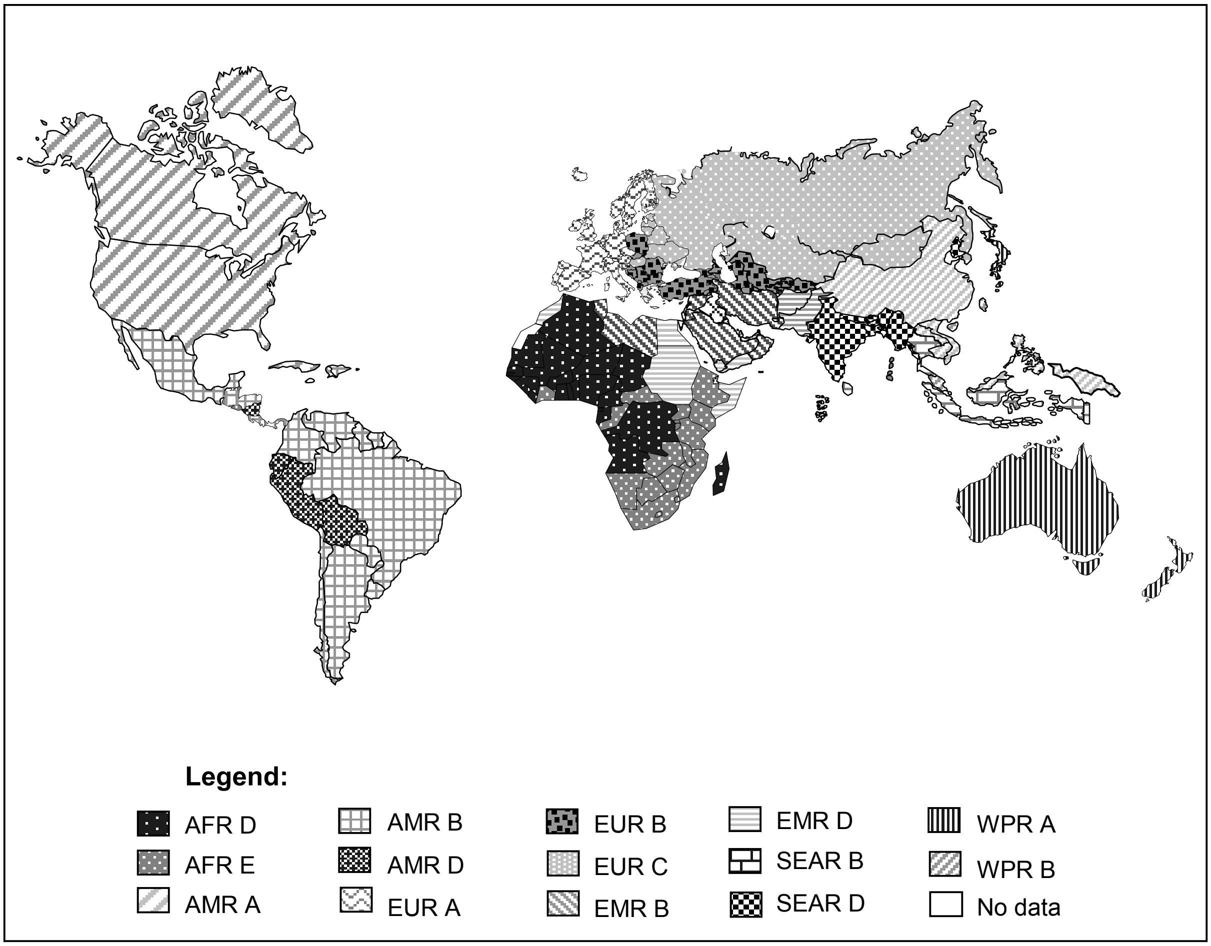

Table A6.1 Regional country groupings for global assessment (according to WHO subregion and mortality strata)[a]

Sub-region[b]		WHO Member States
AFR	D	Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Togo.
AFR	E	Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe.
AMR	A	Canada, Cuba, United States of America.
AMR	B	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela.
AMR	D	Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru.
EMR	B	Bahrain, Cyprus, Iran (Islamic Republic of), Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates.
EMR	D	Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen.
EUR	A	Andorra, Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom.
EUR	B	Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Slovakia, Tajikistan, The Former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Uzbekistan, Yugoslavia.
EUR	C	Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine.
SEAR	B	Indonesia, Sri Lanka, Thailand.
SEAR	D	Bangladesh, Bhutan, Democratic People's Republic of Korea, India, Maldives, Myanmar, Nepal, Timor Leste.
WPR	A	Australia, Brunei Darussalam, Japan, New Zealand, Singapore.
WPR	B	Cambodia, China, Cook Islands, Fiji, Kiribati, Lao People's Democratic Republic, Malaysia, Marshall Islands, Micronesia (Federated States of), Mongolia, Nauru, Niue, Palau, Papua New Guinea, Philippines, Republic of Korea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Viet Nam

[a] Source: WHO (2001).

[b] Regions: AFR = Africa; AMR = Americas; EMR = Eastern Mediterranean; EUR = Europe; SEAR = South-East Asia; WPR = Western Pacific; A: Very low child, very low adult mortality; B: Low child, low adult mortality; C: Low child, high adult mortality; D: High child, high adult mortality; E: High child, very high adult mortality.

Exposure was based on a combination of assessed and modelled data on the percentage of households using solid fuel as the main fuel for cooking. Country data (Annex 5) were pooled by population weighting to provide regional data (Table 2). The results indicated that globally approximately 50% of all households and 90% of rural households in the world utilize solid fuels. While very little exposure occurs in developed regions, this is not the case in developing regions, where more than 50% of the population relies on solid fuels. The exposure data were then combined with relative risks (Table 1) to determine attributable fractions and burdens. The resulting disease burdens from SFU for the 14 WHO regions is summarized in Table A6.2. A breakdown by disease, age group and sex is further detailed in Tables A6.3 and A6.4.

Table A6.2 Mortality and DALYs [a] attributable to SFU for 14 regions of the world [b]

Sub-region	Attributable mortality (thousands)	Percentage of total mortality in the region	Attributable DALYs (thousands)	Percentage of total DALYs in the region
AFR D	173	4.0	5 394	3.6
AFR E	219	3.5	6 924	3.3
AMR A	0	0.0	6	0.0
AMR B	16	0.6	444	0.5
AMR D	10	1.8	329	1.9
EMR B	2	0.3	64	0.3
EMR D	116	3.4	3 508	3.1
EUR A	0	0.0	0	0.0
EUR B	17	0.9	477	1.2
EUR C	4	0.1	67	0.1
SEAR B	37	1.7	990	1.6
SEAR D	522	4.3	14 237	4.0
WPR A	0	0.0	0	0.0
WPR B	503	4.8	6 097	2.5
World	1 619	2.9	38 539	2.6

[a] Abbreviations: DALYs = disability-adjusted life years; SFU = solid fuel use.

[b] Source: WHO (2002).

Table A6.3 Selected population attributable fractions from SFU[a,b]

Disease	Male (%)	Female (%)	Both sexes (%)
Chronic obstructive pulmonary disease	13	34	22
Acute lower respiratory infections	36	36	36
Trachea/bronchus/lung cancers	1	3	1

[a] Abbreviation: SFU = solid fuel use.

[b] Source: WHO (2002).

Table A6.4 Attributable mortality and DALYs[a] from SFU, by age group and sex[b]

	Age group (years)				Sex	
	0-4	**5-14**	**15-59**	**60+**	**Male**	**Female**
Distribution of attributable deaths (% of attributable events)	56	0	5	38	41	59
Distribution of attributable DALYs (% of attributable events)	83	0	8	9	49	51

[a] Abbreviations: DALYs = disability-adjusted life years; SFU = solid fuel use.

[b] Source: WHO (2002).

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