White Paper

The Health Consequences of Indoor Air Pollution: A Review of the Solutions and Challenges

Daniel Polsky

Caroline Ly

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Abstract: Indoor Air Pollution from solid fuel usage kills 2 million people annually. These deaths are primarily concentrated in low and lower-middle income countries. While many countries have reduced their population's reliance on solid fuels, low income countries with limited economic growth and/or Sub-Saharan African countries have seen large increases between 2000 and 2010 of 45% and 31% in their populations' exposures, respectively. Targeted policies to transition populations to cleaner, modern fuels that take into account specific country contexts are needed to avoid leaving behind these populations. Liquefied Petroleum Gas provides one clean alternative, though the higher initial costs may be a barrier in some markets. More research is needed to understand the appropriateness of policies given the health, economic and environmental tradeoffs among the fuel alternatives.

Daniel Polsky, Ph.D., Professor of Medicine, Perelman School of Medicine; Professor of Health Care Management, the Wharton School, University of Pennsylvania. Director of Research, Leonard Davis Institute of Health Economics. Polsky@upenn.edu

Caroline Ly, M.A. Doctoral candidate in Health Care Management in the Wharton School at the University of Pennsylvania.

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Key Points

- 2.0 million deaths annually can be attributed to the health risks of Indoor Air Pollution.
- The risk is entirely within low income and lower-middle income countries where solid fuels are used for cooking.
- The number of people exposed to harmful pollution from solid fuels continues to rise with rapid population growth in low income countries.
- An emerging consensus agrees that the health effects from indoor air pollution may extend beyond COPD and pneumonia to other diseases as well. Accounting for this will raise the number of deaths attributable to indoor air pollution. It may double it.
- These health risks could be reduced substantially if solid fuel users switched to cleaner fuels for cooking. LPG is one of the cleanest alternatives. LPG can be an attractive option over solid fuels and kerosene and natural gas. Country specific contexts need to be taken into consideration to understand tradeoffs between cleaner fuel options.
- Recent evidence demonstrates cookstoves have limited effectiveness in the field. This strengthens the argument for advocating for clean fuels, but many lessons from the cookstove evidence will apply to implementing clean fuels.

Recommendations:

- Important to consider studies of the effectiveness of LPG in the field.
    - What are barriers to sustained usage? How can they be overcome?
    - Affordability strategies at the country level should be evaluated. Subsidies vs. Regulation
- Research on exposure / response is needed
- Identify countries with characteristics amenable to LPG as a cost-effective alternative to solid fuels.

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Indoor air pollution (IAP) is a major addressable health problem concentrated among the world's poor. Health hazardous indoor air pollution comes from solid fuels such as biomass (dung, woodfuel and agricultural residues) and coal, which are the predominant source of energy for heating and cooking for half of the world population. According to the WHO (2009), indoor air pollution was responsible for 2 million deaths and 41 million disability adjusted life years (DALYs) worldwide in 2008. Alternative modern fuel sources exist that could address this deadly health risk. Liquid Petroleum Gas (LPG) is a relatively clean and efficient alternative that could prevent deaths and create environmental and economic benefits for the developing world.

In Section I we describe the size of the health burden associated with indoor air pollution. In Section II we explain how this number is estimated. In Section III we review the changing landscape of the health burden from indoor air pollution. In Section IV we describe the potential of various interventions aimed at reducing the health risks from indoor air pollution with particular attention to LPG as a potentially effective alternative.

I. Context of Disease Burden from indoor air pollution

Health Burden

The health consequences of solid fuel use have been well documented. In a global assessment of avoidable health risks published in 2002, the World Health Organization (WHO) reported that in the year 2000 about 1.6 million people had died from indoor air pollution. In a subsequent 2009 report, the WHO raised the estimate to 2.0 million deaths. As shown in Table 1, indoor smoke from solid fuels is the 10th leading cause of avoidable deaths worldwide. It is the second most important environmental cause of disease after contaminated waterborne diseases (WHO, 2012).

Virtually all of the 2.0 million avoidable deaths from indoor air pollution are in low and lower-middle income countries (see figure 1). Within low income countries indoor air pollution is the sixth leading cause of avoidable death and among lower-middle income countries it is the fifth. Among these avoidable health risks, some tend to become relatively more important in lower income countries such as underweight children, unsafe sex, waterborne diseases and indoor air pollution. Other avoidable risk factors, such as high blood pressure and high blood glucose become relatively more important in countries with higher incomes. Therefore, among avoidable risks that are specific to lower income countries, indoor air pollution ranks fourth after malnutrition, unsafe sex, and waterborne diseases (Bruce et al, 2006). These are the health risks considered to be the "traditional" risks associated with poverty and limited development. Behavioral and technical interventions have been well established to prevent or treat these major developing world health risks and health conditions; the lack of basic infrastructure and appropriate nutrition account for the inability to reduce these types of risks. In addition, once a preventable disease or health condition is contracted in these countries, poor access to appropriate health care compounds the preventability of these deaths. Continued solid fuel usage exemplifies the complex socio-economic and environmental problems of developing countries.

The health burden from indoor air pollution can also be expressed in Disability Adjusted Life Years (DALYs). The WHO (2009) reports that 41 million DALYs were lost due to indoor air pollution (see figure 2). Indoor air pollution becomes relatively more important when expressed in DALYs because the DALYs include the fact that young children are at great risk from the health risks of indoor air pollution. DALYs also capture disabled years. In addition to impacts on mortality, indoor air pollution may have long lasting effects on general health and well-being through stifled lung development (Almond 2006).

Figure 3 and table 2 shows the fraction of deaths by country income group for the most frequent causes of disease in low income areas. Lower respiratory infections are the leading cause of death in low income countries causing 11% of all deaths (WHO 2012 and Wardlaw 2006). Moreover, in low income countries, more than half of lower respiratory infection deaths occur among children under the age of five. Death from lower respiratory infections is dramatically higher in low income countries where exposure to indoor air pollution is greatest. Multiple risk factors such as outdoor air pollution, smoking and malnutrition are associated with these three diseases but indoor air pollution is thought to cause about one-third of Acute Respiratory Infection cases.

Non-Health Burden

Collecting biomass takes time. For those who do the collecting – the majority being women and children— the time can be considerable. This takes children away from productive activities such as attending school and studying at home. The time of parents could otherwise be spent on childcare and potentially income generating activities.

Where biomass is not harvested sustainably, its use can lead to degradation or loss of tree resources. While expansion of agriculture, not use of woodfuels (firewood and charcoal), remains the primary driver of deforestation globally, concentrated consumption of woodfuels—typically in urban areas by residential users as well as by industry—can lead to loss of forest cover (FAO 2009; PREDAS 2009).

Mobilizing Resources to Tackle indoor air pollution

Despite the high burden of disease from indoor air pollution, it has not received the same attention as other diseases in the developing world. Over the last decade, significant financial resources from the global health community have been mobilized to tackle developing world health problems, almost doubling from $11 billion in 2000 to $22 billion in 2007. A large share of this assistance has gone toward preventing and treating specific diseases. Approximately a third of development assistance for health goes toward HIV/AIDs, Malaria and Tuberculosis (IHME 2009). In low income countries, these three disease groups together accounted for 1.6 million deaths, comparable to the 2 million deaths attributed to indoor air pollution health risks in 2008.

Estimates of worldwide expenditures for prevention and control are around $2 Billion for Malaria (WHO 2011) and $8 Billion for HIV/AIDS (Kates et al 2011). These two diseases account for 1.0 and 1.8 million deaths annually. If the same amount was spent on prevention and control for the 2.0 million deaths due to indoor air pollution, expenditures on averting this health risk would range from $4 - $8 billion. Spending on prevention and control of indoor air pollution is not available in a comparable way because the primary purpose of expenditure on clean fuels is for energy rather than prevention of disease. This comparison of health expenditure on diseases of major global health priority with the health burden from indoor air pollution is to suggest that the severe health risks from indoor air pollution have been relatively ignored by the global health community.

II. Health Effects of Solid Fuel Usage

The disease burden from indoor air pollution is a consequence of exposure to the extremely toxic pollutants produced by solid fuels burned in open fires or stoves in the home for cooking or heating. The most harmful of these pollutants include carbon monoxide and particulates. Evidence that exposure to these toxic particles at the levels of exposure from cooking indoors with solid fuels have come from numerous studies associating exposure to indoor air pollution with death from certain diseases. Strong associations have been found between indoor air pollution and acute lower respiratory infection (ALRI) (Smith et al 2000; Ezzati and Kammen, 2001a, 2001b), chronic obstructive pulmonary disease (COPD) (Bruce et al 2000; WHO 2002) and lung cancer in the case of coal smoke (Mumford 1987; Smith 1993). There is emerging evidence that indoor air pollution increases the risk of other child and adult health problems, including low birth-weight, perinatal mortality, asthma, tuberculosis, nasopharyngeal cancer, cataracts, blindness, and cardiovascular disease (WHO 2002).

The WHO estimates of 2.0 million deaths annually from indoor air pollution are produced by combining estimates of exposure to solid fuels with estimates of the risks associated with exposure. In this section we examine the quality of the evidence that goes into this calculation by examining exposure and risks of exposure in detail.

Exposure

Indoor air pollution from solid fuels can be hazardous for those exposed to harmful amounts. It has been well established that the pollutants emitted from indoor cooking is extremely hazardous. For example, we know that indoor cooking with solid fuels can regularly produce harmful levels of particulate matter over 10 times the accepted norm. In studies of PM_{10}, particulate matter with a diameter of less than or equal to 10µm, which is one of the particles that are widely believed to pose some of the greatest health risks, ambient concentrations sometimes exceeds $2000\mu g/m^3$ (Smith 2000) with averages of $600\mu g/m^3$ (Dasgupta et al., 2004) where $50\mu g/m^3$ cited as the accepted standard (EPA 2006).

Yet emission of toxic pollutants is not sufficient to measure exposure. Harm depends on human exposure to these pollutants. The level of exposure can depend on many factors including proximity to the source of the pollutants, the time exposed to the pollutants, and the intensity of the pollutants in the household. For example, women and children are typically more exposed than men since they are physically present for more hours and during the hours with the greatest intensity of pollutants. Finally, exposure includes the use of solid fuels by the household.

Proximity and duration: Exposure can depend on proximity to the stove during periods when the stove is in use. Studies using personal monitors recorded peak concentrations from 20,000 to 50,000 $\mu g/m^3$ in the immediate vicinity of the cooking fire (Ezzati et al 2000; Menon, 1988; and Saksena et al 1992). This suggests that women and children who are most likely to congregate near cooking stoves are exposed to the most intense indoor air pollution levels. The 2001 Ezzati et al. study of indoor air pollution in Kenya collected data on the location and activities of all household members as well as the spatial dispersion of indoor air pollution over 200 days for 14-15 hrs/day. Since one's exposure to indoor air pollution varies throughout the day, this study aimed to develop a continuous exposure-response relationship study. It then collected data on health outcomes, specifically the development of Acute Lower Respiratory Infections (ALRIs). This paper was able to demonstrate a log-linear relationship between PM exposure and relative risk of ALRI.

Because of the laborious process of collecting continuous exposure data as well as the few studies that are able to map exposure to health response, most only examine health outcomes and not degree of exposure to indoor air pollution. Instead, exposure is typically classified as a binary variable: individuals or households either cook with (exposing themselves to the risks of) solid fuels or they do not. This binary exposure classification is also appropriate given the fact that all other evidence on odds or relative risk ratios of disease are based on a binary exposure to solid fuel and cook stove types. But implicitly exposure is captured in the relative risks of disease. The higher relative risks for women and children are likely a result of their greater proximity to the pollutants and the longer duration of exposure.

Intensity of exposure: For any household using solid fuels, there can be variation in exposure to harmful particulates based on the type of cooking and heating appliances and on housing infrastructure. The WHO study uses a ventilation factor that falls within a range of [0,1] that accounts for these variations. With little household level data on ventilation that is comparable across countries ventilation factors were assigned to country sub-regions based largely on educated guesses. For example, countries with a per capita Gross National Product greater than $5,000 were assigned a VF=0 and Eastern Europe and former USSR countries received a VF=0.2. Further, this factor does not incorporate differences within the biomass fuel types. It does not account for variation between cook stove-fuel type combinations which has been demonstrated to be important (Grieshop et al 2011). Further, recent randomized control trials have demonstrated that cleaner cookstoves which improve ventilation may not actually reduce exposure to solid fuel pollution (Hanna et al 2012, Miller et al 2011). Even cooking on outdoor fires produces harmful exposure (Smith 2000).

Households using solid fuel: The first element in exposure is how many households use solid fuel. To determine the number of households, by country, the WHO relies on household surveys when available. For many countries, however, household usage is projected from national total use of energy by source which is often not as accurate. At the time of the original WHO study, accurate data were only available for 52 countries, but current estimates are now based on a database on household level solid fuel usage for 143 countries. Households also tend to use a mixture of different fuels. Households that may report usage of a modern fuel as their primary type of fuel may still continue to use solid fuels for a portion of their cooking and heating requirements. In such cases, households using solid fuels may be underestimated.

Treatment of Health Risks from Solid Fuel Usage

The analysis bases the resulting solid fuel-related morbidity and mortality on the risks of developing three diseases: Acute Lower Respiratory Infections (ALRI) among children under the age of five, Chronic Obstructive Pulmonary Disease (COPD) among adults above the age of 30 and Lung Cancer among adults above the age of 30. The analysis acknowledges that it makes conservative assumptions about the types of diseases and age of disease onset associated with solid fuels in that it used only those diseases that could be conclusively linked to exposure to solid fuel usage. The state of the health risk evidence in the year 2000 was still inconclusive for diseases thought to be linked to solid fuel usage. Among children, solid fuel usage has been shown to have a relationship to low birthweight and nutritional deficiencies. Among adults, tuberculosis, cardiovascular disease and cataracts, and worsened health effects of HIV/AIDS may be caused by solid fuel usage. Since the study was conducted, additional and more conclusive studies have been conducted for these risk factors (Fullerton et al 2008). In a later section we consider this evidence in more detail.

The magnitude of the risks from exposure to indoor air pollution is captured by relative risk ratios (e.g. a ratio of 1.0 means that the likelihood of death is the same with exposure as without. A ratio of 1.2 means that the likelihood of death is 20% higher for those exposed to the risk.) These ratios for each of the 3 diseases used in the WHO calculation are displayed in Table 3. These ratios are derived from a meta-analysis of the literature.

As a result of applying these risk ratios to the exposure to indoor air pollution, the resulting estimates imply that, in low income countries, indoor air pollution is responsible for 21% of all deaths from lower respiratory infection, 35% of deaths from COPD, and 3% of deaths from lung cancer. Moreover, in low income countries, more than half of lower respiratory infection deaths occur among children under the age of five. Death from lower respiratory infections is dramatically higher in low income countries where exposure to indoor air pollution is greatest. Multiple risk factors such as outdoor air pollution, smoking and malnutrition are associated with these three diseases but indoor air pollution is one of the leading risks.

Underlying these estimates of relative risks of disease from indoor air pollution is an implication that if exposure to solid fuels were eliminated, the deaths attributed to exposure from the estimates of relative risk could be avoided. There are three important assumptions that allow for this strong implication.

Assumption of risk reversibility: When the estimates of the risk of disease from exposure are applied to estimating avertable health risks, it is based on the assumption of complete risk reversibility. That is, once individuals switch to cleaner fuels, their risks drop to zero. This implicitly assumes that there is no accumulated damage from a lifetime of exposure. While this assumption may overestimate the short-term affect of switching from solid cooking fuels to alternative clean fuels, it is an appropriate assumption for interventions that permanently change the fuel for cooking in at risk countries. A more refined assumption would include a dynamic treatment in which, following a switch to cleaner fuels, risk would decline but not necessarily to the baseline level associated with life time exposure to cleaner fuels. This would primarily impact risk assumptions related to COPD and lung cancer in which fuel switching would potential delay disease onset. Studies on smoking cessation and lung cancer could provide guidance as to how to address risk reduction after fuel switching.

Avoidable risk based on assumption of counterfactual exposure: Eliminating exposure to certain risks might not be theoretically possible so the exposure that goes into estimating deaths is based on an assumption of the exposure that would exist if the risk was addressed. This is referred to as the counterfactual exposure (Hoorn et al 2004). The health burden from indoor air pollution is based on an assumption that the counterfactual exposure to indoor air pollution after addressing the risk of solid fuel use would be zero. This is a safe assumption under the scenario of 100% switching from solid fuels to modern fuels. It is important to keep in mind that while this is theoretically possible, in practice, not all households will completely eliminate their use of solid fuels.

Assumption of causality: One important qualification for the evidence on the link between health and indoor air pollution is that it is based on observational studies (Bruce et al., 2000). It is possible that a factor correlated with solid fuel use may cause higher incidence of disease rather than the exposure to solid fuels. For example, households that do not take measures to improve indoor air quality may be those households that are also less likely to take other measures to improve their health. A stronger level of evidence would require testing the relationship between indoor air pollution and health through randomized interventions. The most comprehensive study on the impact of indoor air pollution on health to date is the RESPIRE study in Guatemala that is described in Smith-Sivertsen, et al (2004) and Diaz, et al (2007). The RESPIRE study, begun in October 2002, was the first randomized experiment of the provision of improved stoves. The study found that CO levels and the reported health symptoms were reduced among women who received the improved stoves; after about 16 months, twice as many women in the treatment group stated that their health had improved. However, measured health improvements were inconclusive.

III. The changing landscape of household air pollution

Changes in exposure: number of users of solid fuel

The opportunity for policies to reduce the burden of indoor air pollution comes from changing exposure to the pollutants from solid fuels burned in the home. Measuring and tracking exposure will be critical to achieving policy goals in this arena. The most comprehensive and accurate measure of exposure comes from estimates of the number of households using solid fuels for cooking. We acknowledge that solid fuel use is not sufficient to completely track exposure, but the comprehensiveness of this measure allows for tracking one of the most important measures of exposure. The proportion of households using solid fuels has been estimated by the WHO in 2007 and in 2000 for 143 countries. We have applied country population counts in 2000 and 2010 to the share of the country's households exposed to indoor air pollution to produce a total count of population exposed. We aggregate these totals by the region and by country income group and display the results over time in Figures 4-7.

In Figure 4, we see that total population exposed increased from 2.7 billion to 2.9 billion. This 6% increase can be attributed to world population growth of 13% because the share of the population exposed has declined slightly from 46% to 43%. Next we break out these totals by region in Figure 5. Most solid fuel use is in East Asia and the Pacific and South Asia, but the greatest share exposed is in Sub-Saharan Africa. Sub-Saharan Africa also experienced a 31% increase in population exposed; the greatest regional increase. This increase was driven by both larger than average population growth and an increasing share of households using solid fuel. The East Asia and the Pacific and Latin America and Caribbean regions experienced declines in exposure despite modest population growth. South Asia had a 5% increase in exposure as a result of large population growth.

We explore whether the higher and growing prosperity in East Asia and the Pacific and Latin America and Caribbean are related to the modest declines in population solid fuel use by analyzing the trends in exposure by country income group in Figures 6 and 7. Figure 6 shows the number exposed in 2000 and 2010 in low, lower-middle, and upper-middle income countries. We classify the country income groups based on income levels in 2000 in order to isolate changes in exposure over time for a fixed group of countries. Here we see that two-thirds of the worldwide total number of solid fuel users is concentrated within low income countries and nearly all the rest is in lower-middle income countries. Total use of solid fuels in low income countries grew from 1.8 to 2.0 billion people, a 13% increase. Higher income groups experienced a decline of 7% in lower-middle and 39% in upper middle.

The reason for the growth in total use of solid fuels in low income countries can be attributed primarily to fact that the fastest population growth is occurring in these countries. Population grew from 2.5 billion to 2.9 billion, or 18%. This was much faster than the world population growth of 13% in the last decade. The share of households using solid fuels in low income countries actually declined. The declines in share, however, were modest, only 5%. The declines in the lower-middle and upper-middle income groups were 14% and 46%, respectively.

Figure 7 examines the changes in low income countries more carefully by separating those countries that experienced large enough income growth to achieve at least a lower-middle income status. The 2000s were a decade when very large countries, such as India and China, escaped low income status. In fact 75% of the population lived in countries that moved from low income status to at least lower-middle income status. The reduction in the share of solid fuel using households was isolated among the countries with growing economies. The countries that did not experience income growth experienced an increase in the share of solid fuel using households. When compounded by large population growth, the total number of people using solid fuels in these countries grew by 45%.

Ultimately this analysis of trends suggests that two very different groups of countries are emerging from the perspective of addressing exposure to indoor air pollution. There are countries with growing economies that have a legacy of solid fuel use where assistance in moving the populations up the energy ladder could accelerate sustainable strategies for broad use of non-solid fuels. However, there are also many countries which do not have the incomes to sustain strategies involving modest assistance to move their populations up the energy ladder. Given the health burden of solid fuel use there is a moral imperative to exploring non-market-based strategies for reducing exposure to indoor air pollution in these low income countries.

New evidence on risks

More evidence has been developed that links additional health conditions to solid fuel usage. If this new evidence is included into the estimates of mortality from indoor air pollution, the estimate of the number of deaths attributable to indoor air pollution could double to 4.0 million.

Among children, solid fuel usage is linked to low birth weight, perinatal health conditions and nutritional deficiencies. Specifically, a study in Guatemala quantified the effects of low birth weight finding that the babies of women who cooked on open wood fires were 63 grams lighter compared to babies of women cooking with clean fuels. Another study of 30,000 children found a relationship between chronic nutritional deficiency such as anemia and child stunting and exposure to solid fuels (Fullerton et al 2008). Within the 3 diseases used in the WHO estimate there has been more recent research, such as an updated WHO meta-analysis on pneumonia among children under the age of 5, which should be incorporated into revised relative risk ratios (Dherani et al 2008).

Among adults, adverse health outcomes such as tuberculosis, cardiovascular disease and cataracts, and worsened health effects of HIV/AIDs may be caused by solid fuel usage (Fullerton et al 2008). Studies on exposure in Mexico and India have shown a causal link between solid fuel usage and TB. Biomass smoke exposure has been shown to increase diastolic blood pressure among women in Guatemala. A study in India found that exposure increased the odds of blindness 1.3 times. There is also a hypothesis that the mechanisms that lead to pneumonia among solid fuel usage may also exacerbate the pulmonary inflammation associated with HIV/AIDs (Fullerton et al 2008). Much more research is still needed to establish better evidence of causality and quantify the increased risk of contracting these specific health conditions due to solid fuel exposure. The current studies have difficulty accounting for possible confounding variables. Building concrete evidence on the causal effect of biomass fuels and specific health conditions is difficult because of the fact that users of solid fuels are primarily rural and impoverished women and children. It is possible that an uncontrolled characteristic of poverty other than solid fuel usage may be driving these adverse health effects.

IV. Reducing exposure to solid fuel

Addressing the health risks from indoor air pollution involves eliminating or dramatically reducing exposure to indoor air pollution. Exposure could be reduced through modifications to the living environment that might include improving the stove location or smoke ventilation, but switching from traditional to modern fuels such as liquefied petroleum gas (LPG), biogas, and ethanol, brings about the largest reductions in indoor air pollution. In many poor rural communities, however, access to these alternatives is limited by availability and affordability, and biomass remains the most practical fuel.

Economic development remains inextricably linked to household energy. As depicted by the energy ladder, more efficient and convenient fuels for cooking are more likely to be used with increasing amounts of income. We first review these non-solid fuel options and then we consider alternatives to reducing exposure to indoor air pollution that might not involve converting from solid fuels.

Non-solid fuels

Cleaner energy inputs include kerosene, gaseous fuels (biogas, LPG and natural gas) and electrification. When non-solid fuels are used in low income countries LPG, natural gas, and kerosene are the most common options as shown in Table 4. The benefits of these cleaner fuels include direct health benefits, time-savings, and environmental benefits. We consider each of the major non-solid fuel types and their pros and cons.

LPG: Liquid Petroleum Gas (LPG) is comprised of butane or propane and can be purchased in cylinders of various sizes for cooking. It burns efficiently and cleanly and is very easy to use. LPG is generated either automatically as an associated gas from natural gas extraction or as a by-product of the crude oil refining process. It is most commonly used as a cooking fuel in urban areas amongst middle or high income groups. In some countries where there are extensive distribution networks, LPG is also used in rural areas.

LPG usage is considered a feasible clean alternative to solid fuels, both in terms of costs and environmental impact. There are several barriers to increased use. There is a high initial cost of purchasing appliances and cylinders, the technology is relatively sophisticated, supply may be irregular, access to replacement cylinders may be poor, and there is a risk of explosion. The safety risks can be effectively addressed with certified and tested equipment which are most effectively implemented in more developed LPG markets.

Kerosene compared to LPG: Kerosene is sold for cooking in liquid form by the liter or bottle and is the most common modern fuel used in low income countries. With an appropriately designed kerosene stove, it can be efficient and cook quickly. Kerosene is viewed as convenient, but kerosene stoves give off an unpleasant smell and can be dangerous when handled improperly or when faulty equipment is used. Lighting a kerosene stove can be tedious and they can be noisy when running. When comparing the tradeoffs between kerosene and LPG (Budya et al. 2011), the advantages of kerosene include cheaper stoves and easier access to fuel given more convenient purchasing and storage options as well as a less sophisticated supply system and distribution network. The advantages of LPG include less time for cooking and kitchen cleaning, a cleaner burning fuel, less air pollution, no health risk from poisoning and fewer greenhouse emissions. While kerosene is generally less expensive for the minimum quantity available for purchase, the greater efficiency of LPG can make it less expensive to cook a meal. However, there are several variables at play so the fuel with the lowest variable cost will depend on the context. There are safety concerns from both types of fuel. Kerosene has a higher probability of household fire and fire injuries while LPG has potential safety problems that arise from leaking equipment and improper storage and handling.

Natural gas and electrification: Natural gas, when available is a superior option to both LPG and kerosene. Electricity is also a superior option for cooking from a health perspective, but the availability of electricity does not necessarily imply that households have access to clean cooking methods. (While 1.3 billion people lack access to electricity IEA, 2011), 3 billion still use solid cooking fuels.) The use of electricity for cooking is not common in developing countries although in some, such as South Africa and several countries in Eastern Europe and the former Soviet Union, many households use electricity as the primary source of energy for cooking. The consideration of LPG as a public health issue is mostly for households for whom LPG is the potentially cleanest form of household energy (that is, households who do not have access to natural gas and who would not consider electricity for cooking and heating). Therefore we do not expand on natural gas and electrification further.

Drivers of Adoption of LPG over solid fuel

Unless heavily subsidized, cleaner fuels are typically more expensive than solid fuels, particularly biomass, which can be acquired at no financial cost through collection by household members in many parts of the developing world. While collection of solid fuels can be time consuming, when entry of these household members into the labor force is difficult, biomass collection is typically the more financially attractive choice. For households with cash income, which is necessary for regular fuel purchase, this income can also be irregular, particularly in rural areas. Thus it is not surprising that many low income rural households choose biomass as their main cooking fuel and rarely use these cleaner options even when it is available. Urban households face different circumstances and thus are more likely to use cleaner fuels than their rural counterparts. Because incomes tend to be higher and more regular and because biomass may no longer be free but has to be purchased, modern fuels are relatively more attractive.

Thus, affordability is a key driver of LPG adoption. The factors that drive the cost of LPG can vary greatly between countries and even within countries. As mentioned earlier, LPG is generally more affordable in urban environments where distributing tanks to customers is less costly simply due to density and because solid fuels are more difficult to obtain without cash. LPG is sold in cylinders, and delivery of bottled LPG requires good road infrastructure. There are economies of scale in cylinder management, so the LPG market requires a critical mass of regular consumers to be able to gain from scale effects.

The drivers of cost between countries are similar, but also include the cost of the LPG itself. Historically, the cost of LPG has been highly correlated with the world oil prices. This is because LPG is a byproduct of crude oil refining. But since it is also an associated gas from natural gas extraction, as natural gas extraction increases worldwide, the correlation of price with world oil prices will be reduced. As a result, this element of the full cost of using LPG as a cooking fuel in the developing world tends to vary over time, but this variance may decline over time. A world price also means that this element of the cost of LPG does not vary between countries. However, costs related to shipping and storage of the fuel can be a major driver of fuel costs. For oil or natural gas producing regions, however, costs of providing LPG may be substantially less. For countries with sufficient capacity and infrastructure for shipping and storing fuel there is also a great potential to minimize these costs. Many of these drivers of affordability are not constant. As countries develop sufficient scale for shipping, storage, and distribution, costs will go down.

Affordability, however, is not the only factor that determines adoption. On the consumer side, LPG availability, reliability of LPG supply, issues of safety, and familiarity of cooking with LPG all play important roles (Kojima, Bacon and Zhou, 2011). They also found that rising prices of firewood and kerosene, which compete with LPG, increased LPG selection and cultural preferences and inadequate information about different fuel options—including fear of explosion and fire—influence fuel use. LPG consumption and selection increased with education level of both male and female household members.

Among lower-middle income countries, there are many that have already widely adopted LPG such as Belize, Ecuador, Egypt, Iraq, and Syria. There are many other lower-middle income countries that have several favorable factors for increasing LPG penetration, but still predominantly use solid fuels for cooking. Pursuing LPG as an alternative to solid fuel use will involve identifying the country-level factors that drive adoption and determine which countries demonstrate the greatest potential for LPG as a solution for switching from solid fuels. For some countries, LPG may not be the best alternative. Most low income countries do not exceed 10% LPG penetration rates (Kojima 2011) as income remains an important barrier to adoption. What is critical is to acknowledge that there is no one solution to the problem of indoor air pollution.

There are several examples of countries that subsidize LPG to encourage fuel switching. These policies have met with mixed success that often correlates with fluctuations in price of LPG as sustainability of these policies are important for their success. Strategies to address affordability would have to be considered on a country-by-country basis given the differences in access to sustainable and affordable supplies of LPG. For some countries, targeting households that have an income high enough to start using LPG without subsidies may be a viable starting point. Education is likely to be a proxy for the level of awareness about the benefits and costs of LPG. In persuading households to start using LPG, raising awareness about the benefits of LPG use and providing basic training on safety features of LPG, especially among women, might be effective in shifting households away from solid fuels to LPG.

Box 1. Promoting LPG through Subsidies: Successes and Pitfalls in Senegal's Solid Fuel Usage

Senegal is a lower-middle income country in West Africa with a population of over 12.4 million people. Through series of policies focused around LPG subsidies, it has successfully scaled up the use of LPG as an alternative to wood and charcoal for cooking. By current estimates, LPG is used as a primary fuel by 41% of the population, with concentrated usage in the major cities. Nearly all households in the capital, Dakar (90%) use LPG. The scale up of usage occurred rapidly, increasing 10-15% over the span of two decades. But in recent years after subsidy reductions, the country has been dealing with LPG supply shortages and inequalities among the beneficiaries of the subsidies.

Beginning in the 1970s, the government of Senegal introduced its *Butinisation* program to alleviate the country's rapid deforestation for charcoal cooking. First, the government tried to incentivize the adoption of an LPG-compatible stove through import duty exemptions to lower the costs of the stoves. Then in 1976, the government implemented a fuel subsidy on small LPG fuel cylinders financed through taxes on other petroleum products, allowing the costs of LPG to be within reach of poorer households. This was followed by further removal of taxes on imported LPG stoves and another increase in subsidies by 1988.

In 1998 the government began to reduce the size of its subsidies in phases while concurrently liberalizing the LPG market to eliminate monopolies and price regulation. Despite the lower subsidies, fluctuating prices led to spikes in government obligations. In 2009, Senegal was unable to pay for imports leading to a lengthy LPG supply shortage and a doubling of LPG prices.

Further, recent analyses have shown that the subsidies do not proportionally benefit the poorest members of the population. The International Monetary Fund estimated in 2008 that the two poorest quintiles benefited from only 19% of the LPG subsidies, while the two wealthiest quintiles received 61%. Senegal's success story through subsidies comes with caveats. While universal subsidies have been able to rapidly reduce solid fuel usage in favor of LPG, they fail to be a sustainable solution for the poorest members of its population.

(Kojima et al. 2011, Fall et al. 2008, and Schlag et al. 2008)

Box 2. Targeting LPG subsidies to the Poor in Brazil

Brazil is an upper-middle income country in South America with a population under 195 million people. About 87% of the population uses LPG as a primary cooking fuel (WHO 2012). Nearly all urban residents but less than half of rural residents use LPG. LPG has had a long history of usage in the country. Through subsidies, it has been widely accessible through much of the 20th century. But because of fluctuations in fuel prices, the subsidies and high LPG usage were under threat. Brazil offers lessons for other developing countries that are considering the use of subsidies to scale up LPG usage; it also provides lessons on ways to maintain usage among the poor under fiscal constraints.

LPG usage began in 1937 when surplus propane canisters were distributed to 160 households after the *Graf Zeppelin* trips to South America were cancelled. In 1955, Petrobras, the national oil company started producing LPG. But, despite domestic production, Brazil still imports about a third of the LPG consumed. LPG retail prices were heavily regulated throughout the second half of the 20th century. Through cross-subsidies from other petroleum products and regulated end-prices, LPG became highly affordable for the broad population. These policies meant that competition among LPG distributors was discouraged, the government bore high subsidy costs and consumers were using LPG for unintended purposes. For example, the government was spending $100 million a year on LPG subsidies when there were reports that LPG was being used to heat swimming pools and fuel vehicles.

In 2002, under the weight of the subsidy costs, the government ended their universal subsidy program and deregulated the LPG market. As a consequence, the costs of LPG increased 20%. But in order to keep LPG prices within reach for poorer households, the government incorporated vouchers for LPG to the poor into their social welfare program, *Bolsa Familia*. This has been relatively successful in improving the progressivity of these subsidies. According to the World Bank, LPG consumption rates across wealth quintiles are fairly consistent with poor households consuming amounts comparable to the rich ones.

(Lucon et al 2004, Kojima et al 2011)

Reducing Exposure through Improved Cookstoves – Behavior Matters

Under laboratory conditions, improved cookstoves for solid fuels when used properly have been found to have beneficial energy efficiency and emissions outputs. As a result, they have been widely disseminated to promote cleaner cooking. In 2009, $70 million in capital investments were made to provide 7 million people with advanced biomass cookstoves (IEA 2011). However, more recent evidence from two randomized control trials found no statistically significant improvement of health outcomes. One of the studies also measured long-term effects and found no emissions reductions from introducing cleaner cookstoves.

The RESPIRE study randomized the distribution of one type of clean cement cookstove along with intensive training of usage and maintenance across villages in Guatemala and followed up on health outcomes and emissions output from the stoves after 12 and 18 months. It found that while $PM_{2.5}$ and CO decreased by 60% among women in the treatment group relative to the control, there was little or no statistical significance among the targeted health outcomes. A separate study in India randomized distribution of a lower end cookstove and provided less intensive training that would approximate a more realistic setting for cookstove dissemination. It followed households for a longer period of time, over the course of four years and found that while there was a significant 12.5% decrease in inhaled CO in the first year, the difference in CO emissions among households randomized to receive stoves relative to the control group disappeared by the third year after the introduction of the stove. Further, there were also no significant differences in measured health outcomes during the course of the study.

The reduction in the improvements in CO after a year were attributed to household behavior such as reduced overall usage, reduced proper usage and limited maintenance by the end of the study. Many treatment households continued to use traditional cooking methods, using the improved cookstove only 20% more often (or 3 more meals out of 14 meals a week) than households who were not randomized to receive an improved stove. Further, only 60% of treatment households self-reported using the stoves properly and only about 20% properly cleaned and maintained the stoves in good condition. Improper usage such as failing to cover a second pot opening would continue to allow smoke into the cooking area (Hanna et al. 2012).

Behavior matters for non-solid fuel interventions as well: As the randomized-control trials on clean cookstoves have demonstrated, there are stark differences between emissions outputs in the lab and health outcomes in the field. Underlying these differences is the behavioral component. Sustained usage of clean cookstoves or clean fuels may be undermined by unforeseen circumstances – either at the household level where inappropriate usage of stoves or improper maintenance of stoves may have been the cause of the insignificant impacts on health or at the market level where high fuel prices or fluctuating supply may put access to clean fuels out of the reach of the poor. Policy interventions that may ease the introduction of clean fuels will be ineffective without a means of ensuring continued use of these cleaner alternatives.

V. Cost-effectiveness of indoor air pollution risk-reduction interventions

Cost effectiveness or cost benefit analyses provide tools for decision makers to decide between competing investments. A cost benefit analysis which incorporates the benefits of not just improving health but impacts on the environment found that by reducing reliance on clean fuels for 50% of current solid fuel users, $90 billion a year in benefits would be achieved (Hutton et al. 2006). A cost effectiveness analysis found that targeting 50% would result in $542 to $1,695 per healthy year gained (Bruce et al, 2006).

In Table 5 we compare these figure to the cost-effectiveness of interventions of major diseases as compiled by the Disease Control Priorities Project. Keep in mind that these are population averages and the cost effectiveness varies widely depending on type of intervention, the units used, circumstances in which the intervention is introduced, and region where the intervention is introduced. But looking at interventions for IAP, cost effectiveness of interventions range from a low of $13-15 per healthy year gained for introducing improved cookstoves in South Asia to a high of $1258 – 1361 per healthy year gained in Eastern Europe. Similarly, preventing malaria in Sub-Saharan Africa through insecticide treated bed nets costs as low as $5-17/DALY compared to a range of $1,974-6,390/DALY for improving water and sanitation to avoid diarrhea.

The lost lives and DALYs averted, as discussed above, would on humanitarian grounds provide sufficient justification for interventions that advocate for transitioning to cleaner fuels. From an economic standpoint, these health and time-saving benefits of transitioning would have structural impacts on the productivity gains for developing economies. Significant time, specifically from women, is expended on the collection of biomass fuels. By introducing access to market accessible fuels, women's time could be redeployed to other economically productive activities. There are also potential environmental benefits from using cleaner fuels. Incomplete combustion of global solid fuel use contributes about 3 % of total carbon dioxide flows to the atmosphere (McDade 2004). However, the choice of energy source from the energy ladder may have different implications for environmental benefits.

Tables and Figures

Table 1. Deaths and DALYs lost (in Millions) from Attributable Health Risks by Risk Factor and by Country Income Group

	World		High		Upper-Middle		Lower-Middle		Low	
	Deaths	DALYs	Deaths	DALYs	Deaths	DALYs	Deaths	DALYs	Deaths	DALYs
High blood pressure	7.5	57.2	1.4	7.5	1.3	9.9	2.9	21.5	2.0	18.3
Tobacco use	5.1	56.9	1.5	13.1	0.7	10.1	1.9	21.3	1.0	12.4
High blood glucose	3.4	41.3	0.6	6.0	0.4	5.3	1.1	14.2	1.3	15.8
Physical inactivity	3.2	32.1	0.6	1.6	0.5	2.5	1.1	6.2	1.0	5.7
Overweight and obesity	2.8	35.8	0.7	7.9	0.6	8.1	1.0	12.7	0.5	7.0
High cholesterol	2.6	29.7	0.5	4.1	0.5	5.3	0.8	8.9	0.9	11.4
Unsafe sex	2.4	70.0	0.0	1.1	0.4	10.7	0.2	6.6	1.7	51.5
Alcohol use	2.3	69.4	0.1	8.2	0.5	13.9	1.0	29.8	0.6	17.5
Underweight	2.2	90.7	0.0	0.1	0.0	0.9	0.2	7.8	2.0	81.8
Indoor smoke from solid fuels	**2.0**	**41.0**	**0.0**	**0.0**	**0.0**	**0.2**	**0.7**	**7.3**	**1.3**	**33.4**

Source: WHO Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks. 2009.

Table 2: Deaths (in Millions) by Leading Causes and by Country Income Group

	World	High	Upper-Middle	Lower-Middle	Low
Lower respiratory infections	4.18	0.31	0.15	0.78	2.94
Ischemic heart disease	7.20	1.33	1.15	2.24	2.47
Diarrheal diseases	2.16	0.01	0.04	0.31	1.81
HIV/AIDS	2.04	0.02	0.34	0.16	1.51
Tuberculosis	1.46	0.02	0.10	0.44	0.91
Neonatal infections	1.14	0.01	0.03	0.20	0.90
Malaria	0.89	0.00	0.00	0.03	0.86
Prematurity and low birth weight	1.18	0.02	0.04	0.28	0.84
Birth asphyxia and birth trauma	0.86	0.01	0.02	0.17	0.66

Source: WHO Global Health Observatory

Table 3. Relative Risk Ratios of Key Diseases

Disease	Relative Risk Ratio
Lower respiratory infection among Children < 5 years	2.3 (1.9-2.7)
COPD among Women > 30	3.2 (2.3-4.8)
COPD among Men > 30	1.8 (1.0-3.2)
Lung cancer among coal using Women > 30	1.9 (1.1-3.5)
Lung cancer among coal using Men > 30	1.5 (1.0-2.5)

Source: Bruce et al. 2006

Table 4. Clean Fuel Users by Country Income Group

	Total	Low	Lower-middle	Upper-middle
Electricity	6%	17%	1%	10%
LPG	65%	25%	67%	64%
natural gas	17%	29%	14%	24%
Biogas	1%	2%	0%	1%
Kerosene	12%	27%	17%	1%
# OF COUNTRIES	131	34	48	37

Source: WHO Fuel Usage Database 2012Note: Available data represents 61% of world population

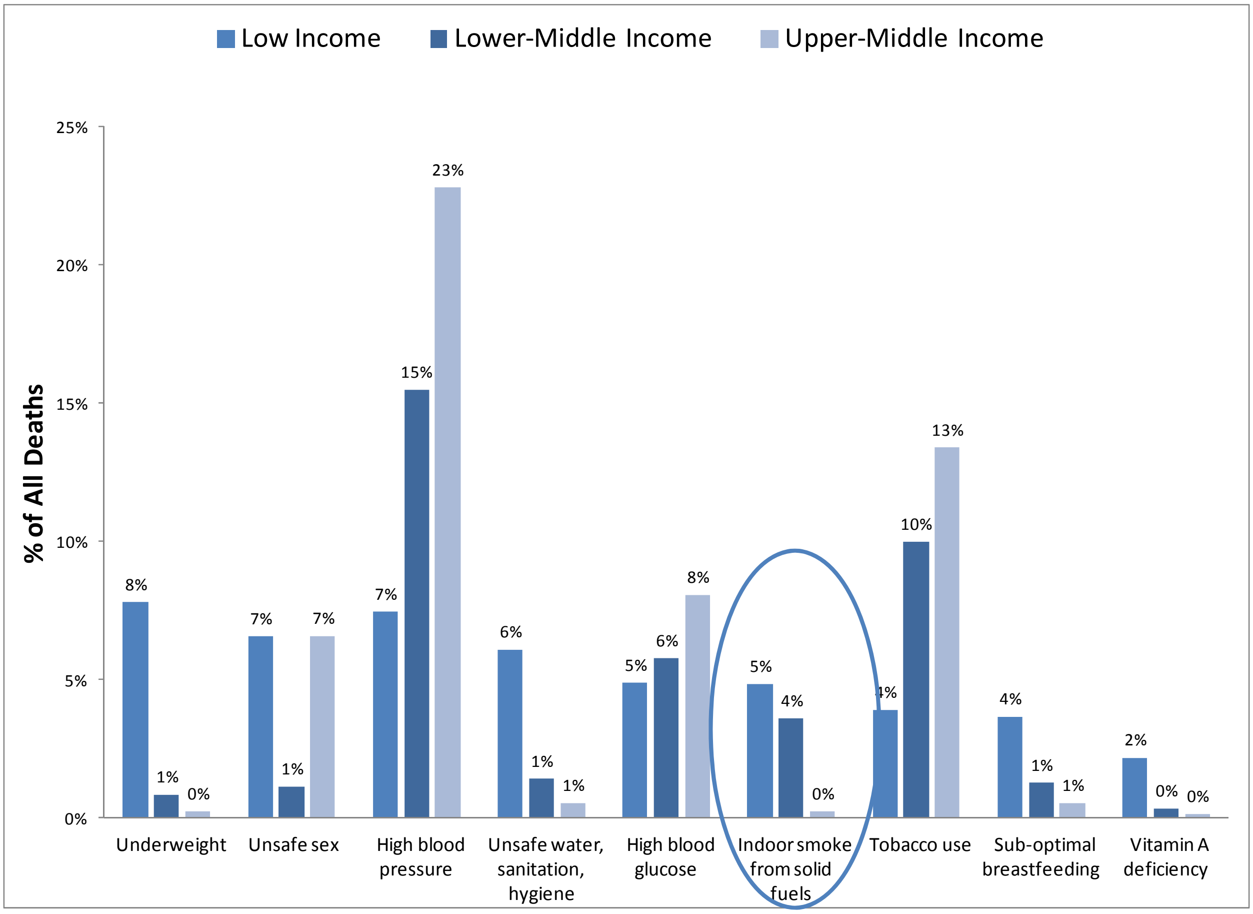
Table 5. A comparison of various cost-effective interventions

Disease/Condition	Intervention	Intervention description	Cost effectiveness estimate
Indoor air pollution-related illness	Improved stove	Replacement of traditional open stoves with enclosed stoves that are more efficient and/or have flues for ventilation	306-605 per healthy year (EAP); 975-1134 per healthy year (LAC); 379-471 per healthy year (MNA): 13-15 per healthy year (SAR); 21-26 per healthy year (SSA)
Indoor air pollution-related illness	Improved stove with kerosene or LPG	Replacement of traditional open stoves with enclosed stoves that use kerosene or LPG	26-85 per healthy year (EAP); 522-1416 per healthy year (ECA); 305-784 per healthy year (LAC); 227-624 per healthy year (MNA): 27-182 per healthy year (SAR); 46-304 per healthy year (SSA)
Indoor air pollution-related illness	Kerosene	Substitution of wood, dung, and crop residues with kerosene for cooking and heating	12-232 per healthy year (EAP); 172-188 per healthy year (ECA); 109-650 per healthy year (LAC); 98 per healthy year (MNA): 37-65 per healthy year (SAR); 62-87 per healthy year (SSA)
Indoor air pollution-related illness	Liquefied petroleum gas	Substitution of wood, dung, and crop residues with liquefied petroleum gas for cooking and heating	103-1746 per healthy year (EAP); 1258-1361 per healthy year (ECA); 806-1447 per healthy year (LAC); 779-785 per healthy year (MNA); 321-558 per healthy year (SA); 534-736 per healthy year (SSA)
HIV/AIDS	Antiretroviral therapy	Combination therapy with multiple antiretroviral drugs associated with prolonged survival in treated patients	350-1,494 (SubSaharan Africa)

HIV/AIDS	Condom promotion and distribution	Targeted distribution and placement of condoms in locations such as bars or brothels; distribution linked to voluntary counseling and testing and sexually transmitted infection care to ensure universal access; information, education, and communication, including education through literature, classroom, and clinical settings and radio, newspapers, and television	52-112 (SubSaharan Africa)
HIV/AIDS	Home care	Home visits providing basic care to sick AIDS patients or comprehensive schemes that provide palliative care, nutrition, psychosocial support and counseling, and links to primary and secondary health care	--
HIV/AIDS	Peer and education programs for high-risk groups	Targeting community members (for example, students or commercial sex workers) to disseminate information and teach specific skills	6-68
Malaria	Insecticide treated bednets	Impregnation of bednets with deltamethrin, one treatment of permethrin, or two treatments of permethrin, with the bednets either purchased or subsidized	5-17 (SubSaharan Africa)
Tuberculosis (endemic)	BCG vaccine	Live attenuated vaccine, BCG; recommended at birth or at first contact with health services in areas of high incidence	55-82
Tuberculosis (endemic, infectious or noninfectious)	Directly observed short-course chemotherapy	Short-course chemotherapy of infectious or noninfectious tuberculosis (with or without transmission, non-HIV-positive), diagnosed via directly observed treatment strategy	84-551
Tuberculosis (endemic, latent)	Isoniazid treatment	Isoniazid treatment of latent infection (with or without x-ray exclusion of active cases; nonHIV-infected population)	9,450-16,867
Tuberculosis (epidemic, infectious)	Directly observed short-course chemotherapy	Short-course chemotherapy of infectious TB (allowing for transmission, non-HIV positive) carried out for epidemic TB	15-189
Tuberculosis (epidemic, latent)	Isoniazid treatment	Isoniazid treatment of latent infection (x-ray exclusion of active cases; non-HIV-positive population) is	45-348

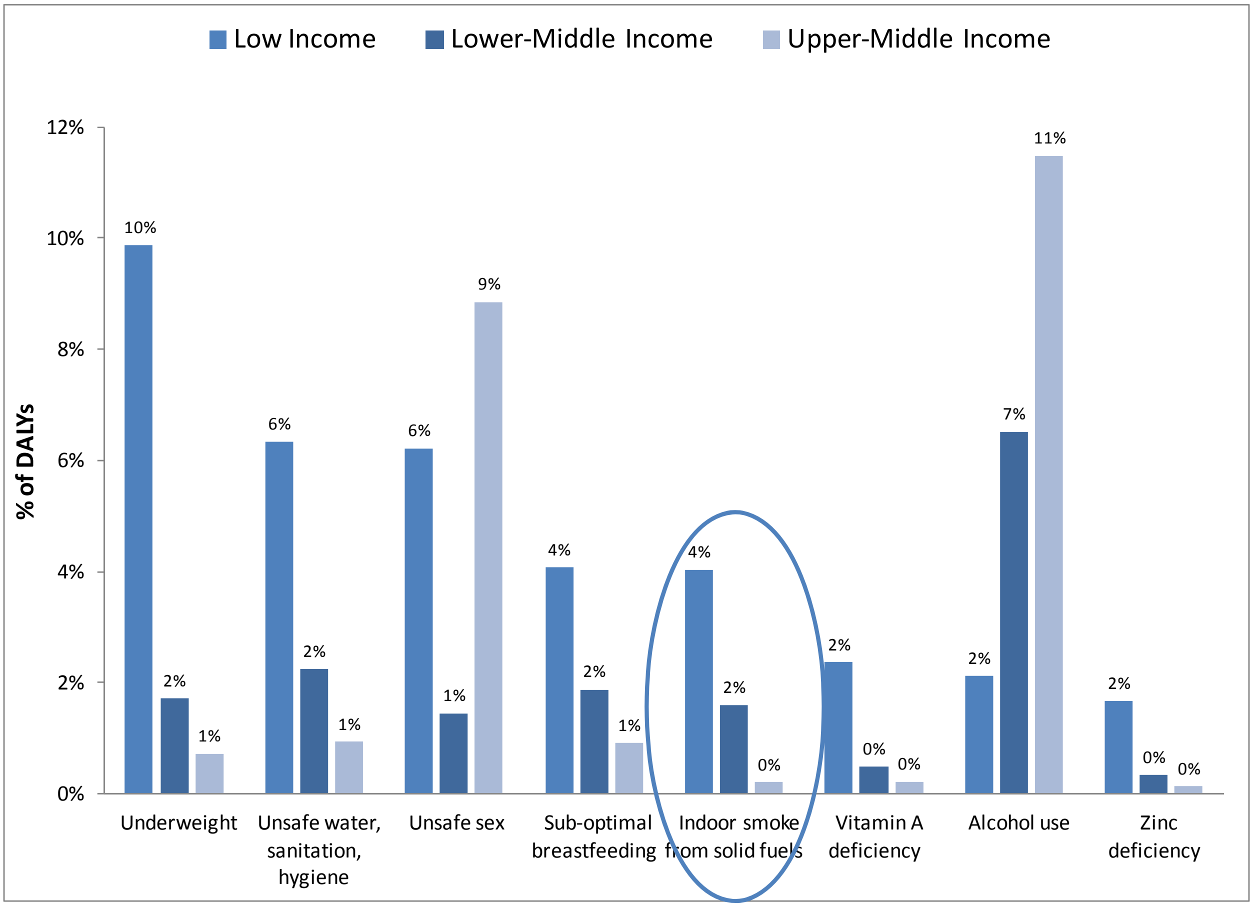
		conducted for epidemic tuberculosis	
Diarrheal disease	Improved water and sanitation at current coverage of amenities and other interventions	Improved water supply and excreta disposal where established infrastructure currently exists, in urban or rural settings for at least five years	1,974-6,39

Figure 1. Deaths by Leading Health Risks in Developing Countries



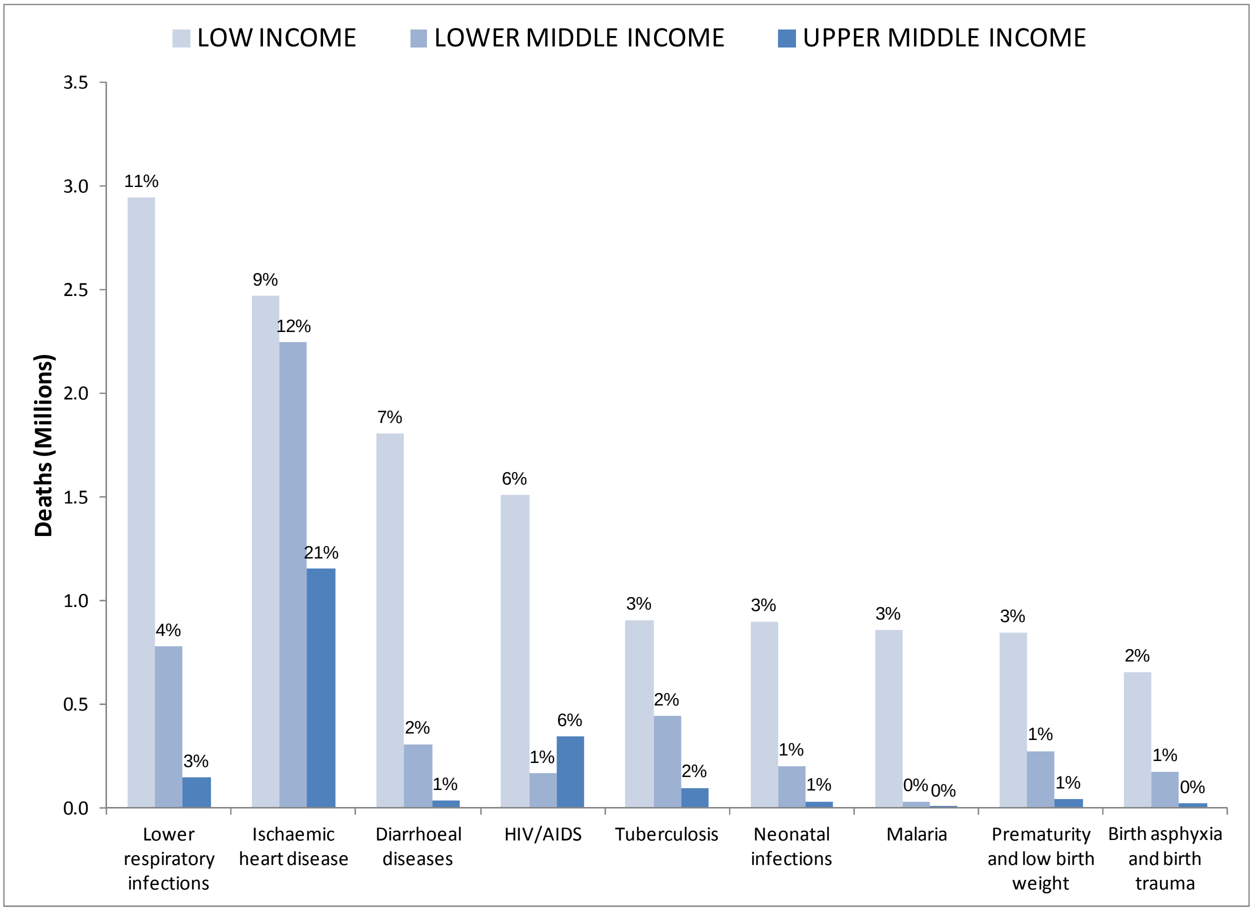
Source: WHO, Global Burden of Disease: 2004 Update. WHO, Geneva.

Figure 2. Morbidity of Leading Health Risks in Developing Countries



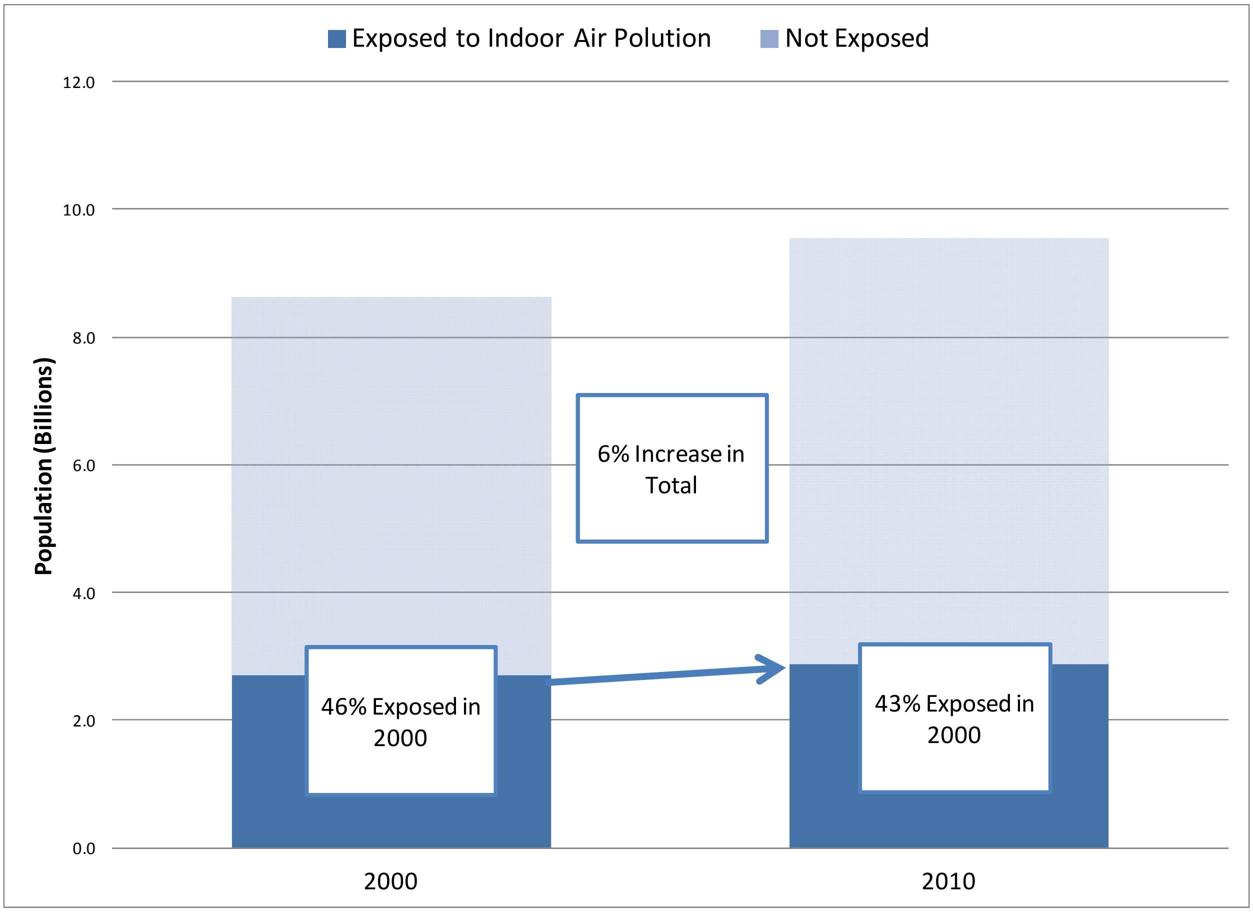
Source: WHO, Global Burden of Disease: 2004 Update. WHO, Geneva. Accessed 2012.

Figure 3. Leading Causes of Death by Income Group



Source: WHO, Global Health Observatory Database: 2004 Data. WHO, Geneva. Accesse d 2012.

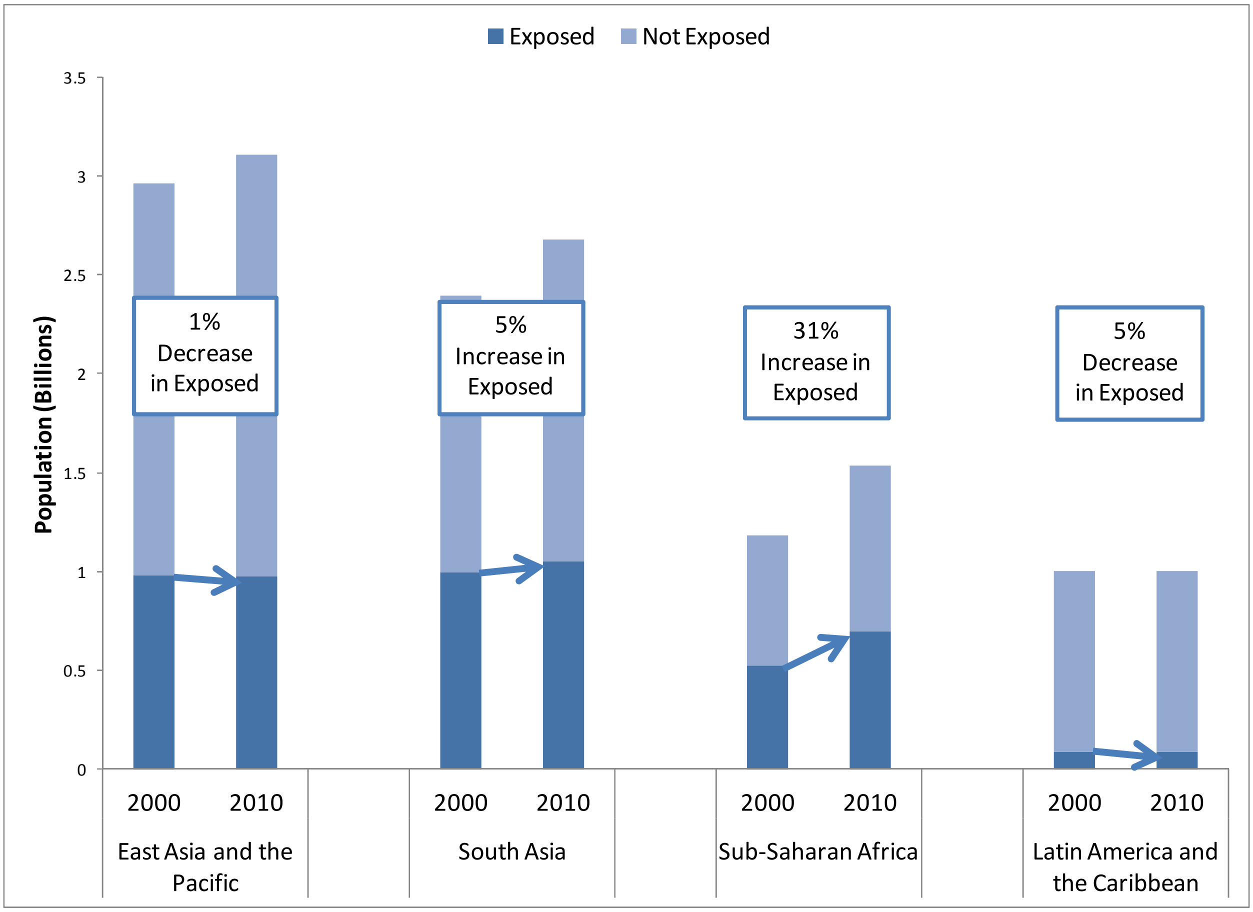
Figure 4. Changes in Global Exposure to Indoor Air Pollution



Sources: WHO Solid Fuel User Database, World Bank World Development Indicators

Note: Estimates for countries with missing solid fuel user data in 2000 were imputed based on the regression analysis outlined in Smith et al. 2004.

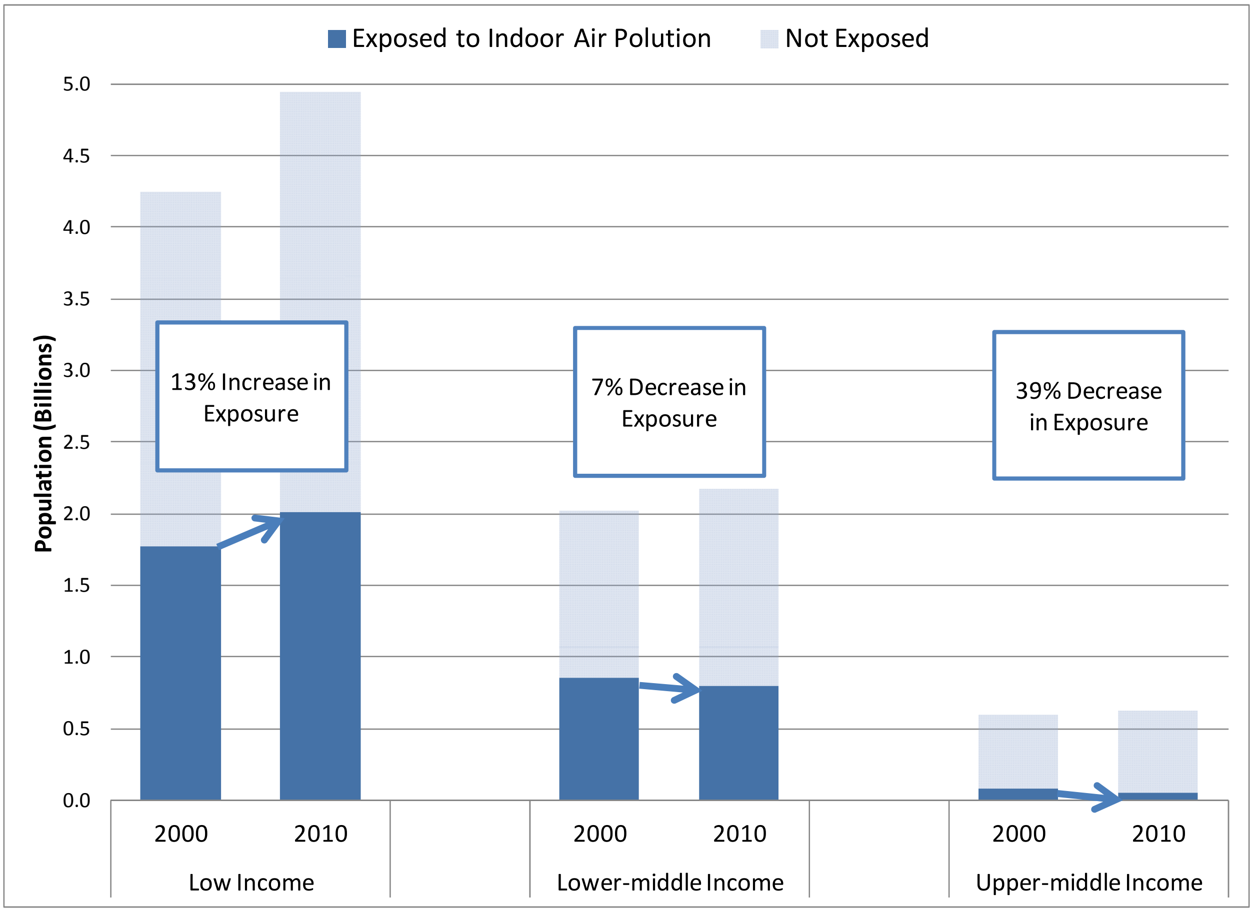
Figure 5. Change in Regional Solid Fuel Usage



Sources: WHO Sold Fuel User Database, World Bank Development Indicators

Note: Estimates for countries with missing solid fuel user data in 2000 were imputed based on the regression analysis outlined in Smith et al. 2004.

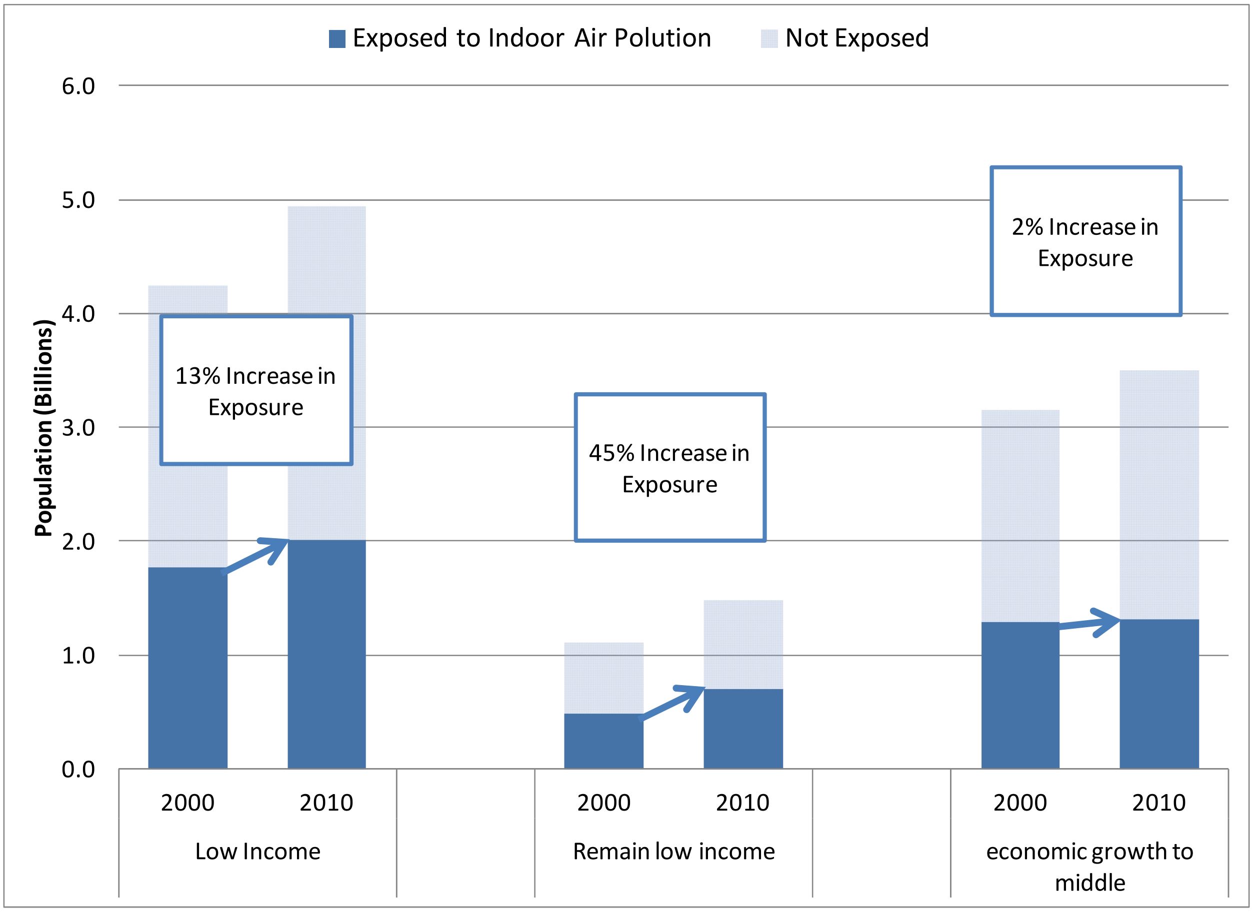
Figure 6. Changes in Exposure to Indoor Air Pollution by Country Income Group



Sources: WHO Solid Fuel User Database, World Bank World Development Indicators

Note: Estimates for countries with missing solid fuel user data in 2000 were imputed based on the regression analysis outlined in Smith et al. 2004.

Figure 7. Changes in Exposure to Indoor Air Pollution for Low Income Groups in 2000 by Economic Growth



Sources: WHO Solid Fuel User Database, World Bank World Development Indicators

Note: Estimates for countries with missing solid fuel user data in 2000 were imputed based on the regression analysis outlined in Smith et al. 2004.

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APPENDIX. New Research on the Health Effects on Solid Fuel Usage: A Recent Review

Study	Design	Dependent Variable Observed	Population Studied	Location (Year)	Confounding Adjusted	Observation/Comments	OR (95% CI)
K. Smith, J. Samet, I. Romieu, N. Bruce. Indoor air pollution in developing countries and acute lower respiratory infections in children, Thorax. (2000); 55(6): 518–532.	Case-Control	Incidence of ALRI	Children < 5 years old	Rural South Africa (1980)	Examined, but not adjusted data: # of siblings and economic status	Only 63% of 123 x-rayed had pneumonic changes. Control group was small. Exposure assessment was vague.	4.8 (1.7-13.6)
	Cohort	Incidence of ALRI	Children < 5 years old	Rural Nepal (1984-85)	Confounding not taken into account as homes were 'homogeneous'	Dose response relationship found Exposure assessment not validated	2.2 (1.6-3.0)
	Cohort	Incidence of ALRI	Children < 5 years old	Rural Gambia (1987-1988)	Adjustment made for: birth intervals, parental ETS, crowding, socioeconomic score, nutritional indicators, vaccination status, number of health center visits, ethnic group, maternal education, other.	Father's ETS only other significant factor. Cautious about interpretation, ability to deal with confounding, and to establish causation where exposure and incidence high	2.8 (1.3-6.1)
	Case-Control	Incidence of ALRI	Children < 5 years old	Urban Argentina (1984-1987)	None	Risk assessment on charcoal heat use in inpatients	9.9 (1.8-31.4)
		Incidence of ALRI	Children < 5 years old		None	Risk assessment on any heating fuel usage in inpatients	1.6 (1.3-2.0)
		Incidence of ALRI	Children < 5 years old		None	Risk assessment on gas cooking usage in outpatients	2.2 (1.2-3.9)

Smith et al. cont.	Case-control	Incidence of ALRI	Children < 5 years old	Rural Zimbabwe (?)	Maternal ETS, overcrowding, housing conditions, school age siblings, paternal occupation not adjusted(only difference was number of school age sibs, but not adjusted)	None	2.2 (1.4-3.3)
	Cohort	Incidence of ALRI	Children < 5 years old	Rural Gambia (?)	Factors included in questionnaire: parental ETS, crowding, socioeconomic index, number of siblings, number sharing bedrooms, vitamin A intake, number of wives, number of clinic visits; adjusted in MLR	Effect of IAP in males	0.5 (0.2-1.2)
			Children < 5 years old		Factors included in questionnaire: parental ETS, crowding, socioeconomic index, number of siblings, number sharing bedrooms, vitamin A intake, number of wives, number of clinic visits; adjusted in MLR	Effect of IAP in females	1.9 (1.0-3.9)
	Case-control (case fatality)	Incidence of ALRI	Children < 5 years old	Urban Nigeria (1985-1986)	None	Risk assessment on those exposed to wood smoke compared to those exposed to kerosene and gas.	12.2 ($p<0.0005$)
	Case-control	Incidence of ALRI	Children < 5 years old	Rural Tanzania (1986-1987)	Village, age, maternal education, parity, water source, child nutrition, whether mother alone decides treatment	All deaths for sleeping in a room with air pollution coming from biomass fuel smoke	2.8 (1.8-4.3)
						Deaths from pneumonia	4.3
						All other deaths	2.4

Smith et al. cont.	Case-control	Incidence of ALRI	Children < 5 years old	Rural Gambia(?)	Adjusted for significant factors in univariate analysis: socioeconomic score, crowding, parental ETS, and nutrition indicators plus maternal education. No significant factors for cases vs. dead controls	For cases vs. live controls	5.2 (1.7-15.9)
	Case-control	Incidence of ALRI	Children < 5 years old	Urban Brazil (1990)	Cigarettes smoked, housing quality, number of children in household, income/education levels, day care center attendance, history of respiratory illness, other; Hierarchical Model/ MLR	Risk assessment for indoor smoke exposure	1.1 (0.61-1.98)
		Incidence of ALRI	Children < 5 years old		History considered: number of smokers in the house, number of siblings, household characteristics, socioeconomic conditions, education and birth weight	Risk assessment for those usually found in the kitchen	0.97 (0.75-1.26)
	Case-Control	Incidence of ALRI	Children < 5 years old	Urban & Rural India (?)	History considered: number of smokers in the house, number of siblings, household characteristics, socioeconomic conditions, education and birth weight	Risk assessment on exposure to smokeless stove	0.82 (0.46-1.43)
		Incidence of ALRI	Children < 5 years old				
	Prospective Case-control	Incidence of ALRI	Children < 5 years old	Rural Gambia (1989-1991)	Adjusted for mother's income, maternal ETS, child's weight slope, recent illness, significant illness in the last six months	No effect of bednets, crowding, wealth, parental education, paternal occupation, age of weaning, and nutritional status.’	2.5 (1.0-6.6)

Schei M, Hessen JO, Smith KR, Bruce N, McCracken J, Lopez V. Childhood asthma and indoor woodsmoke from cooking in Guatemala. (2004). J Expo Assess & Environ Epi 14(S-1):110-117.	Randomized Field Trial	Asthma	Children < 5 years old	Guatemala	None: Sex, age and number of siblings not significantly related to any of the symptom categories	Occurrence of wheezing symptom 'ever in life' due to use of open fires for cooking.	2.0 with p<0.05 (1.1-3.7)
						Occurrence of wheezing in the last 12 months	3.4 with p<0.005 (1.3-8.5)
						Asthma Diagnosed	1.8 with unknown p (0.76-4.19)
						Exercise induced wheeze in the last year	3.5 with p<0.05 (1.4 -8.6)
						Speech limit of 1-2 words	3.4 with p<0.05 (1.1 - 11.3)
						1-3 wheezing episodes last year	2.0 (0.5- 9.9)
						> 12 wheezing episodes last year	2.7 (0.8-10.8)
						Woke up more than once per week	1.8 (0.5-5.4)
Agrawal S. Effect of Indoor Air Pollution from Biomass and Solid Fuel Combustion on Prevalence of Self-Reported Asthma among Adult Men and Women in India: Findings from a Nationwide Large-Scale Cross-Sectional Survey. (2012) J Asthma.	Observational	Asthma	Men between 20 and 49 years of age	India	Tobacco use, age, and 12 socioeconomic factors	Adult men living in households using biomass and solid fuels	0.98 with p = 0.846 (0.77 - 1.24)

Agarwal cont.	Observational	Asthma	Women between 20 and 49 years of age	India	Tobacco use, age, and 12 socioeconomic factors	Adult women living in households using biomass and solid fuels	1.26 with p = .010 (1.06-1.49)
						Combined effects of biomass and solid fuel use and tobacco smoke on the risk of asthma	2.16 with p < .0001 (1.58 - 2.94)
Desai M, Mehta S, Smith KR. Indoor smoke from solid fuels: Assessing the Environmental Burden of Disease at National and Local Levels. (2004) In: Pruss-Ustun A, et al, editors. Environmental Burden of Disease, Series No 4. Geneva: WHO.	Case Control	Asthma	Children 5-14 years of age	Not specified	None	None	1.6 (1.0 - 2.5)
			Population > or = to 15 years of age	Not specified	None	None	1.2 (1.0 - 1.5)
			children of 1 month to 5 years of age	Malaysia, Kuala Lumpur	History of allergy, asthma in 1st degree relatives, low birth weight, coughing sibling		ETS: 1.91 (1.13 - 3.21) ; Coil: 1.73 (1.02 - 2.93)
			children of 9 to 11 years	Kenya, Nairobi	Damp damage in child's bedroom; furniture, rugs and carpets in child's bedroom, extra salt intake of the child, matched age, sex controls.	None	2.5 (2.0 - 6.4)
	Cross sectional	Asthma	Children older than 15 years	China (rural)	Age, education, occupation, and marital status	None	Females: 1.15 (0.66 - 2.07); Males:1.86 (1.15-3.01); Both: 1.51 (1.05-2.17)

Rinne ST, Rodas EJ, Bender BS et al., Relationship of pulmonary function among women and children to indoor air pollution from biomass use in rural Ecuador. (2006) Respir. Med.;100:1208–1215 & R.J. Dennis, D. Maldonado, S. Norman, E. Baena, et al. Woodsmoke exposure and risk for obstructive airways disease among women. (1996) Pontificia Universidad Javeriana 109 (1), pp. 115–119	Hospital-based Case control	COPD	Elderly women of low socioeconomic status	Bogotá, Colombia	None	Woodsmoke exposure associated with the development of OAD or Obstructive Airwave Disease	3.43 with p<0.001
						Gasoline smoke exposure associated with the development of OAD or Obstructive Airwave Disease	0.52 with p=0.02
Desai M, Mehta S, Smith KR. Indoor smoke from solid fuels: Assessing the Environmental Burden of Disease at National and Local Levels. (2004) In: Pruss-Ustun A et al., editors. Environmental Burden of Disease, Series No 4. Geneva: WHO.	Case Control	COPD	Women > or = to 30 years	India	No adjustments were made for rural households versus urban households, nor for households using solid fuels versus other fuels. Percentage of any age/sex group exposed to SFU was the same as the percentage of households exposed to SFU.	None	3.2 (2.3 - 4.8)
Ekici A, Ekici M, Kurtipek E, Akin H, Arslan M, Kara T, Apazdin Z, Demir S. Obstructive airway diseases in women exposed to biomass smoke. (2005) Environ Res;99:93–98.	Randomized Control Trial	CAD (Chronic Airway Diseases)	Village women > or = to 40 years of age	Kirikkale, Turkey	Age	Risk assessment on exposure Group C (Low/Disadvantaged group) after age adjusted	0.9 with p = 0.3 (0.9 - 1.0)

Ekici A et al cont.	Randomized Control Trial	CAD (Chronic Airway Diseases)	Village women > or = to 40 years of age		Passive Smoking	Risk assessment on exposure Group C (Low/Disadvantaged group) after adjustment of passive smoking habit	0.8 with p = 0.6 (0.4 - 1.5)
					Income	Risk assessment on exposure Group C (Low/Disadvantaged group) after adjustment of income	1.4 with p = 0.2 (0.8-2.5)
					Education	Risk assessment on exposure Group C (Low/Disadvantaged group) after adjustment of education	0.5 with p = 0.1 (0.2 - 1.1)
Zhang J, Smith K. Household air pollution from coal and biomass fuels in China: measurements, health impacts, and interventions. (2007). Environ Health Perspect;115:848-55	Observational	Lung Cancer	Women	China	Smoking and Chronic Respiratory Diseases	N/A	1.94 (1.09 - 3.47)
			Men		Smoking and Chronic Respiratory Diseases	N/A	1.5 (0.97 - 2.46)
Desai M, Mehta S, Smith KR.Indoor smoke from solid fuels: Assessing the Environmental Burden of Disease at National and Local Levels. (2004) In: Pruss-Ustun A et al, editors. Environmental Burden of Disease, Series No 4. Geneva: WHO.	Case-controlled	Lung Cancer	Women > or = to 30 years	India	None	Exposure to coal smoke	1.9 (1.1 - 3.5)
					None	Exposure to biomass smoke	1.5 (1.0 - 2.1)

	Survey Based/Observational	Tuberculosis	260,162 persons age 20 and over (from India’s 1992-93 National Family Health Survey)	India	None	Risk assessment on households primarily exposed to biomass fuels from cooking	3.56 (2.82 - 4.50)
					Availability of a separate kitchen, house type, indoor crowding, age, gender, urban or rural residence, education, religion, caste or tribe, and geographic region statistically controlled	Risk assessment on households primarily exposed to biomass fuels from cooking	2.58 (1.98 - 3.37)
					None	Risk assessment on men primarily exposed to biomass fuels from cooking	2.46 (1.79 - 3.39)
					None	Risk assessment on women primarily exposed to biomass fuels from cooking	2.74 (1.86 - 4.05)
					None	Risk assessment on urban households primarily exposed to biomass fuels from cooking	2.29 (1.61 - 3.23)
					None	Risk assessment on rural households primarily exposed to biomass fuels from cooking	2.65 (1.74 - 4.03)
Desai M, Mehta S, Smith KR. Indoor smoke from solid fuels: Assessing the Environmental Burden of Disease at National and	Case-controlled	Tuberculosis	Population > or = to 15 years of age	Not specified	None	None	1.5 (1.0 - 2.4)

Local Levels. (2004) In: Pruss-Ustun A et al, editors. Environmental Burden of Disease, Series No 4. Geneva: WHO.							
Brook RD, Franklin B, et al Air Pollution and Cardiovascular Disease: A Statement for Healthcare Professionals From the Expert Panel on Population and Prevention Science of the American Heart Association **Circulation. (2004);109:2655-2671**	Observational	Congenital Heart Disease	Delivered neonates and fetuses	Southern California	None	Birth records from California (1987–1993); data collected by the California Birth Defects Monitoring Program for four counties: 1990–July 1993 for Los Angeles, 1989 for Riverside, 1988–1989 for San Bernardino, and 1987–1989 for Orange counties; ORs for cardiac ventricular septal defects increased in a dose-response fashion with increasing carbon monoxide exposure	Second quartile: 1.62 (1.05 - 2.48) Third quartile: 2.09 (1.19 - 3.67) and Fourth quartile: 2.95 (1.44- 6.05)
Mishra V and Retherford R. Does biofuel smoke contribute to anaemia and stunting in early childhood? Int. J. Epidemiol. (2007) 36(1): 117-129	Survey Based/Observational	Anemia & Stunting (Nutritional Deficiency)	Children under aged 0–35 months living in the sample households	India	None	Risk of biofuels relative to children in households using only cleaner fuels	2.18 (1.90 - 2.52)
						Risk of biofuels and clean fuels (e.g. LPG) relative to children in households using only cleaner fuels	1.53 (1.31 - 1.58)

Mishra et al cont.					20 Controls of socioeconomic type (e.g. income) introduced	Risk assessment of moderate to severe anemia on children in households using a only biofuels relative to children in households using only cleaner fuels	1.58 (1.28 - 1.94)
						Risk assessment of moderate to severe anemia on children in households using a mix of biofuels and clean fuels (e.g. LPG) relative to children in households using only cleaner fuels	1.36 (1.13 - 1.63)
Pokhrel, A, Smith, KR, Khalakdina, A et al. Case–control study of indoor cooking smoke exposure and cataract in Nepal and India' (2005) Int. J. Epidemiol. 34(3): 702-708 first published online February 28, 2005	Hospital-based Case control	Cataracts	Cases (n = 206) were women patients, aged 35–75 years with confirmed cataracts.	Border between Nepal and India	Controls (n=203)--i.e., without cataract disease-- frequency matched by age, were patients attending the refractive error clinic at the same hospital.	Risk assessment of flued solid fuel stove usage with ventilation; • Cases were more likely to live in rural areas (p<0.01) and less likely to be literate (p<0.01)	1.23 with p = 0.69 (0.44- 3.42)
					Controls (n=203)--i.e., without cataract disease-- frequency matched by age, were patients attending the refractive error clinic at the same hospital.	Risk assessment of unflued solid fuel stove usage; • Cases were more likely to live in rural areas (p<0.01) and less likely to be literate (p<0.01) .	1.9 with p = 0.05 (1.0 - 3.61)
					Controls (n=203)--i.e., without cataract disease-- frequency matched by age, were patients attending the refractive error clinic at the same hospital.	Risk assessment of flued solid fuel stove usage without ventilation; Cases were more likely to live in rural areas (p<0.01) and less likely to be literate (p<0.01) .	1.96 with p = 0.003 (1.25 - 3.07)