SUSTAINABLE DEVELOPMENT

Household Energy, Indoor Air Pollution, and Public Health in Developing Countries

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Issue Briefs are short reports designed to provide topical, timely information and analysis to a broad nontechnical audience.

Globally, almost 3 billion people rely on biomass (wood, charcoal, crop residues, and dung) and coal as their primary source of domestic energy. Biomass accounts for more than half of domestic energy use in many developing countries and for as much as 95% in some lower-income nations. It has been hypothesized that with increasing income, households switch to cleaner fuels, moving up an "energy ladder." For details on worldwide energy usage, see Arungu-Olende (1984), Reddy et al. (1996), and the World Resources Institute (WRI, 1999) in Further Readings. Empirical research by Masera et al. (2000; see Further Readings), however, has illustrated a more complex picture in which, at any income level, households switch among various fuels. Various economic, infrastructure, and technological factors had probably created a declining trend in solid fuel use in many regions of the world in the 1970s and 1980s. Evidence from the World Health Organization and WRI (1997 and 1999, respectively; see Further Readings) now suggests that in some countries the decline in dependence on biomass has slowed or even reversed, especially among poorer households.

Health Effects

Biomass and coal smoke contain a large number of pollutants and known health hazards, including particulate matter, carbon monoxide, nitrogen dioxide, sulfur oxides (mainly from coal), formaldehyde, and polycyclic organic matter, such as benzo[a]pyrene, a carcinogen, as described in De Koning et al. (1985), Ezzati et al. (2000a), Smith (1987), Smith et al. (2000a), and Zhang and Smith (1996) in Further Readings. Exposure to indoor air pollution from the combustion of solid fuels has been implicated, with varying degrees of evidence, as a causal agent of several diseases in developing countries, including acute respiratory infections (ARI), otitis media (middle ear infection), chronic obstructive pulmonary disease (COPD), lung cancer (from coal smoke), asthma, nasopharyngeal and laryngeal cancer, tuberculosis, perinatal conditions and low birth weight, and diseases of the eye, such as cataracts and blindness; see Bruce et al. (2000), Ezzati and Kammen (2001a), Ezzati and Kammen (2001b), and Smith et al. (2000a) in Further Readings.

Most current studies on the health impacts of exposure to indoor air pollution in developing countries have focused on ARI, otitis media, and COPD; for examples, see Bruce et al. (2000) and Smith et al. (2000a) in Further Readings. Conservative estimates of global mortality due to indoor air pollution from solid fuels using only these three diseases show that in 2000, between 1.5 million and 2 million deaths were attributed to this risk factor by Smith and Metha and von Schirnding et al. (2000 and 2001, respectively; see Further Readings). This accounts for approximately 3% to 4% of total mortality worldwide. Approximately 1 million of the deaths were due to acute lower respiratory infections (ALRI) among children; the remainder were due to, in order, COPD, lung cancer among adult women, and other causes, according to Smith and Metha (2000; see Further Readings). Increasing evidence—for example, Boy et al. (2002; see Further Readings)—on the role of maternal exposure to indoor air pollution as a risk factor for low birth weight illustrates that perinatal and neonatal conditions associated with low birth weight are also likely to have large and long-term health effects and be an important source of burden of disease due to this risk factor.

The magnitude of the health loss associated with exposure to indoor smoke and its concentration among marginalized socioeconomic and demographic groups (women and children in poorer households and the rural population) have recently put preventive measures high on the agenda of international development and public health organizations. For more information, see Bruce et al. (2000), McMichael and Smith (1999), Rahman et al. (2001), von Schirnding et al. (2001), World Bank (1993), and WHO (2000) in Further Readings. Important knowledge gaps must be filled and detailed research questions answered, however, before successful preventive measures and policies can be designed and implemented.

Research to Date

Research on exposure to indoor smoke and its impacts on respiratory diseases in developing countries began in the 1960s and 1970s in India, Nigeria, and Papua New Guinea; examples include Anderson (1978, 1979), Clearly and Blackburn (1968), Rice (1960), Sofoluwe (1968), and Woolcock and Blackburn (1967) in Further Readings. Monitoring of pollution and personal exposures in biomass-burning households has shown concentrations many times higher than those in industrialized countries. The latest National Ambient Air Quality Standards of the U.S. Environmental Protection Agency, for instance, limit daily average concentrations of PM_{10} (particulates below 10 microns in diameter), which are considered a good measure of aggregate impacts of air pollution, to 150 mg/m3 (annual average, 50 mg/m3). In contrast, typical 24-hour average concentrations of PM_{10} in homes using biofuels may range from 200 to 5,000 mg/m3 or more throughout the year, depending on the type of fuel, stove, and housing; for details, see Ezzati et al. (2000a), Kammen (1995a), Smith (1987, 1988, 1993), and Smith et al. (2000a) in Further Readings. Levels of carbon monoxide and other pollutants also often exceed international guidelines, according to Ezzati et al. (2000a), Smith (1987, 1988), and Terblanche et al. (1994); see Further Readings.

Figure 1. *Household members involved in cooking are exposed to episodes of high pollution when they work directly above the fire.*

Recent work on exposure to indoor smoke under actual conditions of use by Ezzati et al. (2000a and 2000b; see Further Readings) has shown that stove emissions are highly episodic and that peaks in emissions concentrations commonly occur when fuel is added or moved, the stove is lit, the cooking pot is placed on or removed from the fire, or food is stirred, as seen in Figures 1 and 2. Quantitative and qualitative data on time-activity budgets also indicate that some household members are consistently closest to the fire when the pollution level is the highest. Other individuals may be outside at such times, especially during the hours when the fire is lit or extinguished.

Figure 3 shows exposure estimates that account for the episodic nature of indoor air pollution as well as the activities of individual household members. Figure 4 compares these values with the exposure estimates obtained using only average pollution concentration at a single point and time spent inside (i.e., without taking into account either the spatial distribution of pollution or the role of activity patterns).

Ignoring the role of activity patterns in exposure could not only result in inaccurate estimates of exposure but also—and possibly more importantly—bias the relative exposure levels of demographic groups. The exposure of women, who cook and are most affected by high-intensity pollution episodes, would be underestimated most severely by using average pollution alone. This

Figure 2. *Day-long monitoring of pollution and cooking activities. PM_{10} concentration (at a distance and height of 0.5 meter) was measured in a household that used a three-stone stove inside. The uses of the stove are indicated above the horizontal lines. Ugali is a common food in rural East Africa made from maize flour. The lower horizontal line indicates the mean pollution for the day. As seen, mean concentration is a poor indicator of the patterns of exposure.*

could in turn result in systematic bias in assessing the health impacts of exposure and benefits from any intervention strategy.

Although reducing exposure to indoor air pollution from solid fuels can be achieved through interventions in emissions source, energy technology, housing, ventilation, behavior, and time-activity budgets, as shown by von Schirnding et al. (2001; see Further Readings), most current research has focused on improved stoves and fuels, which provide more affordable options in the near future than a complete shift to nonsolid fuels.

The initial emphasis of research on household energy in developing countries was on the environmental impacts of biomass use, such as deforestation and desertification, with increased efficiency as the goal. For more information, see Kammen (1995a, 1995b), Karekeizi (1994), Krugmann (1987), and Manibog (1984) in Further Readings. The public health benefits from reducing exposure to indoor smoke became the subject of attention soon after. The promise of a double dividend—improving public health while reducing adverse environmental impacts—encouraged efforts to design and distribute improved stoves, as described in Barnes et al. (1994), Kammen (1995b), and Smith et al. (1993); see Further Readings). Research and development, however, often proceeded without detailed data on stove performance. Efficiencies and emissions, for example, were measured in controlled environments with technical experts using the stoves under ideal conditions; see, for example, Krugmann (1987) and Manibog (1984) in Further Readings. Other researchers, such as Agarwal (1983) and Ravindranath and Ramakrishna (1997) (see Further Readings), began monitoring stove performance under actual conditions of use, taking into account social and physical factors that would lower performance or limit the use of these stoves altogether. As a result of these studies, the initially large potential benefits from improved stoves have been questioned by Ballard-Tremeer and Jawurek and by Wallmo and Jacobson (1996 and 1998, respectively; see Further Readings).

More recent studies—see Albalak et al. (2001); Ezzati and Kammen (2002); Ezzati et al. (2000a); Ezzati et al. (2000b); Lan et al. (2002); and McCracken and Smith (1998) in Further Readings—have quantified the benefits of improved stoves under actual conditions of use with proper maintenance . For example, in a study in rural Kenya, energy- or behavior-based interventions can reduce exposure to PM_{10} by an estimated 35% to 95% for different demographic subgroups. This would mean that on average, the range of interventions considered could reduce the incidence of acute respiratory infections among infants and children below 5 by 24% to 64%, and the incidence of the more severe acute lower respiratory infections by 21% to 44%. The range of reductions was larger for those older than 5 and highly dependent on the time-activity budgets of the individuals. These reductions in infant and childhood ALRI are of similar magnitude to those achieved by more costly medical interventions, according to Bang et al. (1990); Kirkwood et al. (1995); Lye et al. (1996); Mtango and Neuvians (1986); Pandey et al. (1989); and van Ginneken et al. (1996) (see Further Readings). Although limited data on exposure prevent direct extrapola-

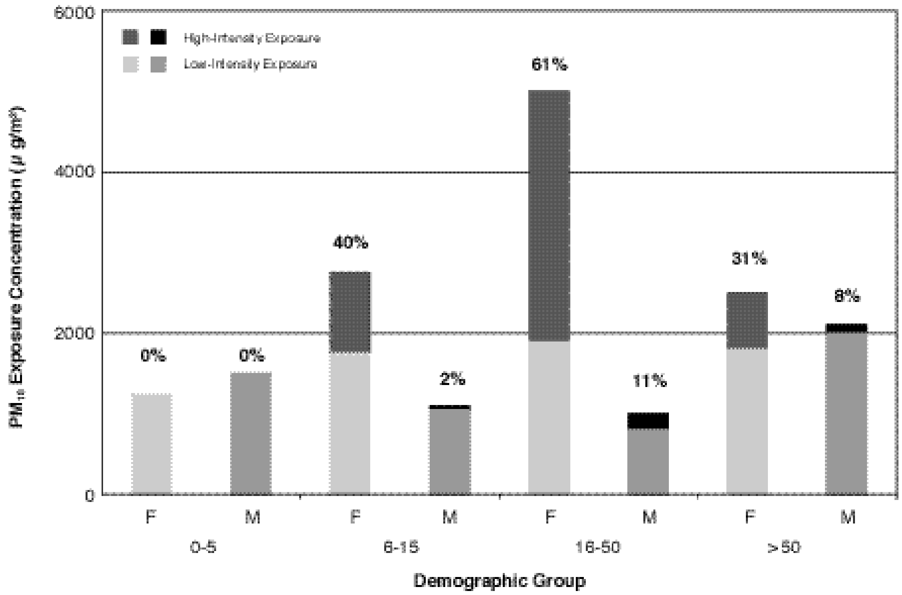

Figure 3. *Breakdown of total daily exposure to PM_{10} into high-intensity (dark) and low-intensity (light) exposure. For each demographic subgroup the total height of the column is the average exposure concentration divided into average high- and low-intensity components. The percentages indicate the share of total exposure from high-intensity exposure. The high-intensity component of exposure occurs in less than one hour. See Ezzati et al. (2000b, in Further Readings) for details.*

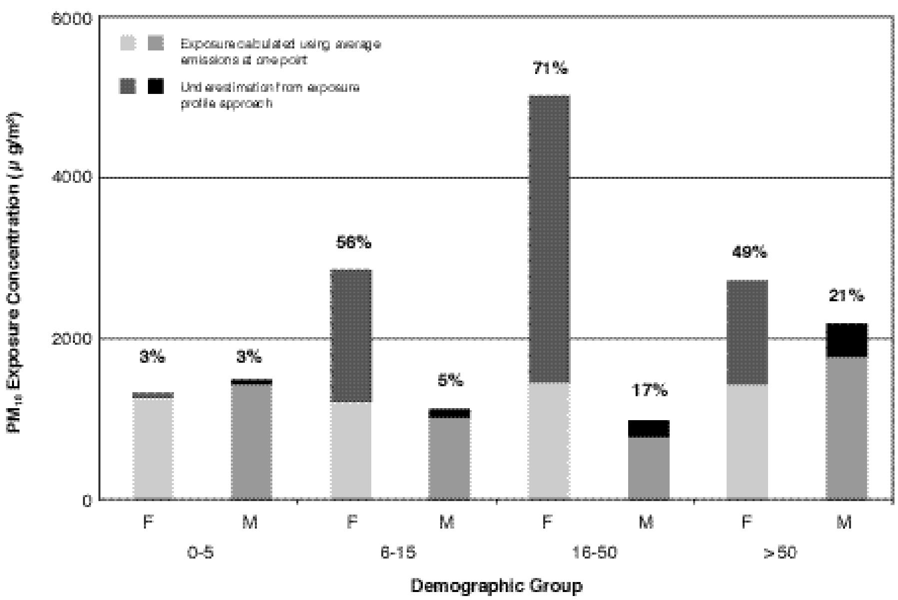

Figure 4. *Comparison of exposure values based on temporal and spatial characteristics of pollution concentration and individual time-activity budgets with average exposure values (light) based on emissions at a single point and time spent inside (without accounting for spatial dispersion and activity). For each demographic group the height of the column is the group average (from Figure 3). The darker shade is the underestimation of exposure using this method relative to the exposure profile approach, also shown as a percentage. See Ezzati et al. (2000b, in Further Readings) for details.*

tion of these results to a global scale, the consistency of epidemiological studies in different settings and the important role of ALRI in developing countries' mortality and burden of disease would imply large expected health benefits from the transition to cleaner fuels (or alternatively, combinations of energy, housing, and behaviors that would reduce exposure equivalently); these benefits would arise from reductions in childhood ALRI and other diseases not quantified here.

Some other issues surrounding the success of intervention programs have been discussed by various researchers—see Agarwal (1983); Barnes et al. (1994); Ezzati (1999); Kammen (2001); Hoiser and Dowd (1987); Manibog (1984); Smith et al. (1993); and von Schirnding et al. (2001) in Further Readings—all using a limited number of case studies in various countries. The lack of systematic studies may stem, in part, from energy technology's central role in the household: adoption of new technology is likely to vary from setting to setting and even household to household, according to Masera et al.

(2000; see Further Readings). Although the benefits of adopted interventions may be known, there is little systematic evidence on what factors motivate households to adopt any intervention or suite of interventions and what institutions are required; this point is illustrated by the variable success of stove programs, as detailed by Agarwal (1983); Barnes et al. (1994); Ezzati (1999); Hoiser and Dowd (1987); and Manibog (1984) in Further Readings. Moreover, the long-term performance of improved stoves has not been monitored, with two exceptions: the recent work of Albalak et al. (2001; see Further Readings), which ensured proper maintenance over an eight-month period, and the important retrospective cohort study of Lan et al. (2002; see Further Readings), which considered the long-term health benefits over a 16-year follow-up period. Finally, knowledge is scarce about the wider environmental and socioeconomic implications and sustainability of proposed interventions. For example, encouraging a shift to charcoal, which offers significant health benefits over wood—for details, see Ezzati and Kammen (2002)—could lead to more severe environmental degradation because of inefficiencies in charcoal production: more wood may be needed per meal when cooking with charcoal, according to Dutt and Ravindranath (1993), with increased greenhouse gas emissions, as Bailis et al. (2002) and Smith et al. (2000b) explain; see Further Readings. Further, Ribot (1995; see Further Readings) has found the political economy of charcoal production and markets to be complex, influencing access to this fuel for different sectors of the society.

Future Directions

Solid fuel combustion and other determinants of exposure to indoor smoke are complex phenomena and involve many social and physical variables. Unless explicitly related to and calibrated with local parameters, simple indicators are likely to overlook important information about exposure and the benefits of interventions. Answers to six research questions are needed:

1. What is the quantitative relationship between exposure to indoor air pollution and the incidence of disease (i.e., the exposure-response relationship)?

2. What factors determine human exposure and what are the relative contributions of each factor to personal exposure? Household energy use is complex, and researchers need to consider energy-housing-behavior combinations, including energy technology (stove-fuel, multistove, and multifuel combinations), housing characteristics (size and material, number of windows, and arrangement of rooms), and behavioral factors (amount of time spent indoors or near the cooking area).

3. Which determinants of human exposure will be influenced, and to what extent, through any given intervention strategy? The conditions of exposure must be addressed in intervention design and evaluation. For example, the design of improved stoves should address peak emissions—while lighting, extinguishing, or moving fuel—as well as average emissions levels.

4. What are the impacts of any intervention on human exposure and on health outcomes, and how would these impacts persist or change over time? Longitudinal monitoring of both technical performance and adoption, including the role of community networks in facilitating or impeding technology adoption, is needed.

5. What factors facilitate or impede the development of entrepreneurial networks for designing and marketing locally manufactured energy technology or housing designs?
6. What are the broader environmental effects of each intervention, its costs, and the social and economic institutions and infrastructure required for its success? The social, economic, and environmental implications of each intervention strategy should be anticipated and monitored.

Substituting clean energy sources is the most effective way to reduce exposure to indoor air pollution. Without a complete fuel transition, however, affordable and effective interventions for reducing exposure to indoor smoke are limited in developing countries. Problems include the complexities of household energy and exposure and a lack of infrastructure to support technological innovations, marketing and distribution, and maintenance. Too little is known about combinations of technologies that may be used by a household and the factors that motivate people to adopt them.

An important implication is that research and reliable data on even the most quantitative variables, such as exposure, require an integration of methodology and concepts from numerous disciplines, from quantitative environmental science and engineering, to toxicology and epidemiology, to the social sciences. Given the fundamental interactions of the variables, integration of tools and techniques should take place early in the design of studies as well as in data collection, analysis, and interpretation.

Research on health risks and interventions should be motivated by the need to improve human health in ethical, sustainable, and cost-effective ways. The data needs go beyond simply identifying those most affected by exposure to indoor smoke; we must now describe the complex mechanisms of impact and measures for reducing negative health effects. By conducting research at various scales and from different angles, from epidemiology to risk analysis to intervention assessment, we can build the knowledge base for expanding the limited number of current interventions and creating effective programs to reduce disease from indoor air pollution in developing countries.

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