Health and Environmental Effects of Cooking Stove Use in Developing Countries

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Introduction

Adoption of fire tens of thousands of years ago was surely one of the most powerful developments in all of human history. Fire for cooking made possible the consumption of a much wider variety of foodstuffs and greatly enhanced food safety. Fire for heating allowed us to expand our range to higher latitudes and elevations, and it fundamentally transformed our patterns of social development. But with fire also came the first anthropogenic pollution, evidenced by the soot still found in prehistoric caves. Over the past few centuries about half of humanity has been able to afford to transition from traditional biomass fuels (wood, animal dung, crop residues such as rice husks, etc.) to fossil fuels such as kerosene or gas, or to electricity. The remaining half of humanity, almost all in developing countries, continues to use biomass fuels or coal, often in open fires or in inefficient, smoky stoves. Consequently, the United Nations Environment Programme/World Health Organization Global Environment Monitoring System (GEMS) has confirmed that the worst overall air pollution conditions and the largest indoor pollutant concentrations and exposures are found in both rural and urban areas of the developing world.[1] The noxious and hazardous products of combustion from stoves, particularly indoors, in poorly ventilated houses, are a major source of health problems including acute and chronic respiratory diseases, malignancies of the aero-digestive tract and lungs, burns, eye diseases, low birth weights and increased infant mortality. The total population in developing countries subjected to excessively high indoor pollutants from poorly ventilated household stoves is probably several hundred million.[2] Women and young children bear the brunt of illness as a result of their exposure in the home. But cooking smoke also remains an occupational hazard, especially for food vendors and food preparers like fish-driers,[3] and it contributes significantly to outdoor pollution especially in densely populated areas.

Demand for traditional fuel also places significant pressure on local forests and woodlands, contributing to deforestation, soil erosion and desertification. Frequently, the need for wood is so great that reforestation attempts of badly degraded regions prove impossible because even young trees are rapidly harvested for cooking fuelwood or charcoal production. In the most severely affected regions, the poorest fuel sources, animal manures, grasses, crop residues, roots and shrubs are also harvested. Unfortunately, this increasingly common practice, especially in parts of Africa and South Asia, leads to a spiraling loss of soil fertility as natural fertilizers are not returned to the ground. In other areas, such as rural China, exhaustion of traditional fuels has prompted a switch to coal for household use with its own consequences. This review focuses on the enormous detrimental health and environmental impacts related to the use of cooking stoves in the developing world and examines some promising intervention strategies which may alleviate these burdens.

Background on Cooking Fuels

Compared to developed countries, developing nations use much less total energy per capita. However, because of their much larger populations, they still require a substantial portion of global energy. Less industrialized countries use energy differently, consuming a much higher proportion at the household level, principally for cooking and lighting, but also for heating in cooler climates. In fact, household fuel needs continue to make up more than half of total energy demands in more than 100 countries.[4]

Energy for cooking in less industrialized countries is provided by a heterogeneous mixture of fuels which vary in importance from country to country. These fuels are often conceptualized as forming an “energy ladder” (see Illustration 1, pg. 41) up which households ascend as soon as their economic circumstances permit because of the greater cleanliness, efficiency, storability and controllability of fuels at higher levels. In sub-Saharan Africa traditional fuels at the bottom of the energy ladder including wood, charcoal, grasses, animal dung and crop residues supply more than half of all energy needs, including transportation and industrial requirements.[5] In the Sahel these fuels typically provide more than 90% of household energy needs.[6]

Wood and Charcoal

Total average annual fuelwood production in developing countries increased approximately 16.5% over the past decade to about 1.55 billion cubic meters.[7] Worldwide, it is estimated that nearly 3 billion people use fuelwood as their primary source of energy.[8] In developing countries, especially in rural areas, 2 billion people rely solely on fuelwood for heating and cooking.[9] In addition, for much of Africa and South America, wood fuel and charcoal remain important energy sources for a large number of industries including tea, tobacco and coffee drying, brick making, sugar-curing, baking, fish-smoking and beer-brewing.

Charcoal is a renewable resource made from wood that is baked in a kiln. But the baking process requires 1_ - 3 times as much wood to deliver the same amount of energy for cooking. It thereby exacerbates the demand for wood. When burned in inefficient stoves, losses are further multiplied. Even so, it is a preferred cooking fuel in many countries because it is lightweight, easy to transport and store, resists attack by insects, burns in a controlled fashion without much smoke or flame, can be made in uniform sizes to fit conveniently into inexpensive stoves, and often costs much less than fossil fuels. Moreover, it can be made locally and contributes to the national economy. Representing an advancement along the energy ladder above wood, charcoal probably has lower respiratory health risks to the user than some other traditional fuels. Therefore, demand for charcoal can be quite high. For example, in Burkina, wood from approximately half of all land cleared between 1988 and 1993 was used for the production of charcoal to meet the energy needs of the capital Ouagadougou.[10]

Coal

In China, South Africa, North Korea, Iran and other countries, coal is also a major source of energy for domestic cooking needs. It represents an intermediate step on the energy ladder. But the quality of coal deposits varies considerably, and as a result coal smoke can contain considerable amounts of pollutants not ordinarily found in most traditional fuels including sulfur oxides, inorganic ash particles and heavy metals including lead. Coal can also contain high amounts of fluorine which has lead to fluorosis through respired air and from vegetables grown in the presence of coal emissions.[11] Naturally low-volatile coal such as anthracite, processed (devolatized) coal and charcoal produce less irritating hydrocarbon emissions than most other traditional fuels. Ironically, this benefit also contributes to carbon monoxide (CO) poisoning and death because without the accompanying irritants, victims are not alerted to the presence of odorless CO.

Cooking Smoke Pollutants

Empirical studies have shown that cooking stove smoke can contain hundreds of chemicals components. The most well-studied products include total suspended particulates (TSP), polycyclic aromatic hydrocarbons (PAH), and carbon monoxide (CO). These substances have repeatedly been found arising from stoves in alarming concentrations in many developing countries like Kenya[12] as well as in poorer areas of moderately developed nations like Chile.[13] Human health risks relate to specific pollutants, their concentrations and to exposure as a function of time spent in contaminated domestic micro-environments.[14] Although only the best-studied pollutants are reviewed here, it is important to note that many other potentially harmful substances have been identified in cooking stove smoke such as phenolic antioxidants.[15]

Polycyclic Aromatic Hydrocarbons

Many traditional fuels emit polycyclic aromatic hydrocarbons (PAH) such as benzo(a)pyrene (BaP), naphthalene, fluorene, phenanthrene and acenaphthene, which have been identified as priority pollutants by the International Agency for Research on Cancer (IARC) owing to their carcinogenic potential. Urinary 1-hydroxypyrene (1-OHP) has become a standard biological indicator for overall PAH exposure. Indoor inhalation of PAH from cooking appears to pose a substantial health hazard. In Burundi, for example, villagers in two rural areas with traditional mud and thatch homes had average geometric mean urinary 1-OHP levels 30 times that found among inhabitants of the capital Bujumbura.[16] BaP exposure among urban poor exposed to cooking wood smoke has been estimated to compare with an exposure of more than two packs of cigarettes per day.[17]

Carbon Monoxide

A substantial literature from developed countries describes many adverse effects of carbon monoxide on cardiovascular and respiratory systems, fetal development, and the nervous system. The toxicity of CO lies at least in part in its ability to bind strongly with hemoglobin and interfere with oxygen transport. Acute CO poisoning can have a range of toxicities leading to death. Even low level exposures (17-100 PPM), well within the range found inside rural kitchens, have been shown to cause neuropsychological impairment.[18]

Particulate Matter

Standard measurements of exposure to particulate matter (PM), are described in terms of particle size, for example, less than 10 microns in diameter (PM10), or less than 2.5 microns (PM2.5). The factors governing size, composition and health implications of these combustion aerosols have recently been reviewed. [19] Adverse outcomes relate largely to site of deposition within the respiratory tract. Excessive levels of particulates from domestic (predominantly cooking) sources have been repeatedly documented and are summarized in Tables 1 and 2 (pages 37 and 38). Such exposures routinely exceed US standards which call for a maximum of 250 $\mu g/m^3$ not to be exceeded more than once per year.

Health Effects

The adverse health effects of cooking stove smoke in developing countries has been much less studied than the effects of tobacco or outdoor air pollutants affecting the populations of developed nations. Epidemiological studies have been limited by the fact that both short-term outcomes such as acute respiratory infections (ARI), and long-term outcomes like cancer and obstructive lung diseases can have multiple determinants. Long latency periods between exposure and disease outcomes have also clouded the picture. Some studies on respiratory health in developing countries have also been hampered by more subtle household and socio-economic confounding factors such as arrangement of rooms, floor type and ownership of a television or radio.[20] Nonetheless, a growing body of literature has begun to document a variety of health problems of enormous proportions.

Acute Respiratory Infections

Acute respiratory infections (ARI) are the leading cause of burden of disease worldwide and account for the deaths of 4-5 million children under five in developing countries each year. A recent review examined the relationship between indoor air pollution from domestic biomass fuels in developing countries and acute lower respiratory infections, the major killer of children.[21] The authors concluded on the basis of nine case control studies (n=4311, OR 2.2-9.9), four cohort studies (n=910, OR 2.2-6.0) and one case fatality study (n=206, OR 4.8), that pneumonia/ARI is probably the largest disease outcome from air pollution exposure worldwide. More minor symptoms such as cough, cold, congestion and phlegm have been associated with kerosene and mixed fuel use in India.[22] Among Jordanian[23] and Indian[24] school children, exposure to wood and kerosene cooking smoke was associated with sharp reductions in pulmonary function. In Turkey[25] and Malaysia[26] children in households cooking with wood had similar reductions in lung function.

Chronic Airway Diseases

Evidence for a causal role of domestic cooking smoke in chronic lung diseases is also strong. Multiple cross-sectional studies in developing countries have shown high rates of chronic respiratory diseases including chronic obstructive pulmonary disease (COPD) among populations who were exposed to indoor cooking smoke, but not to tobacco or atmospheric pollution.[27,28] In cross-sectional surveys in Turkey,[29] India[30] and among Nigerian soldiers,[31] the prevalence of chronic bronchitis was found to be much higher among people exposed to domestic biomass fuel combustion. In a case-control study in Mexico, exposure to wood stove smoke showed a crude odds ratio of 3.9 (95% CI, 2.0-7.6) for chronic bronchitis alone and 9.7 (95% CI, 3.7-27) for chronic bronchitis and chronic airway obstruction (CAO).[32] In Bogota, Columbia , another case-control study showed an odds ratio of 3.43 associating cooking with wood and obstructive airways disease (OAD).[33]

Tuberculosis

Tuberculosis (TB) is a leading cause of morbidity and mortality, particularly in developing nations. Tobacco smoke and other pulmonary irritants such silica dust have been repeatedly shown to be risk factors in the development of pulmonary TB and plausible biological mechanisms have been identified. Bronchial irritation from smoke exposure appears to disrupt the mucociliary defenses of the lungs, and decrease both cellular immunity and humoral immunity.[34] Now, an emerging body of literature has begun to implicate biomass cooking smoke from traditional wood stoves as a major determinant of this disease. A recent case-control study in Mexico City supports a causal role with a crude odds ratio of 5.2 (95% CI, 3.1-8.9) for current exposure and 3.4 (95% CI, 2.4-5.0) for past or present exposure.[35] Likewise in India, biomass cooking fuels (wood or dung) have been strongly linked to tuberculosis (even after correcting for a range of socioeconomic factors) leading the authors to conclude that in subjects over 20 years of age 51% of the prevalence of active tuberculosis is attributable to cooking smoke.[36] If these findings continue to be borne out, the burden of disease attributable to cooking activities may be much higher than previously estimated.

Asthma

Evidence regarding a causal role of indoor cooking smoke in asthma has been mixed. A possible reason for this is that defining asthma for epidemiological studies can be problematic, and criteria vary from study to study. It is often difficult to separate acute infections from asthmatic disease in children, and other chronic obstructive pulmonary diseases from asthma in adults. Increasingly, however, studies are using specific criteria such as those in the International Study of Asthma and Allergies in Childhood (ISAAC), and there is much research underway.

A recent review summarized findings of fourteen studies which looked at asthma and biomass smoke from indoor combustion.[37] Overall, seven studies found a significant association with biomass smoke exposure, four found no association, and one found mixed results (no asthma association with kerosene or wood fire smoke, but an association with mosquito coil smoke). Two studies showed a protective effect, but these were done in Australia and Germany, where exposure was possibly quite different from that of the other studies in developing countries.

Pneumoconioses

The combined respiratory insults of domestic cooking smoke and other respiratory exposures such as tobacco or occupational exposures in developing countries has thus far received little attention, but may have significant dimensions. Indoor cooking smoke probably contributes to domestically acquired pneumoconioses. For example, among rural South African women, “Transkei silicosis” appears to have a significant smoke inhalation component, prompting the study authors to suggest renaming the condition “hut lung.”[38]

Sarcoidosis

Although we are not aware of any investigations in developing countries examining a possible relationship between the use of wood stoves and sarcoidosis, a recent case-control analysis from the United States showed a dose-response gradient for exposure to wood stoves and fireplaces.[39]

Lung Cancer

In most developed nations, the majority of lung cancers are attributable to tobacco use. However, observational studies in many developing countries show cancers occur much more often there among non-smokers, particularly women. Extracts of biomass fuels have shown significant mutagenicity in the laboratory.[40]

In China, where coal is used widely in the home, case-control studies have strongly implicated indoor cooking smoke in the development of lung cancer among women.[41,42] The use of "smoky" coal in unventilated fire-pits has been of particular concern.[43] Not all cooking-related lung neoplasms however can be attributed to fuel combustion products. For example, in Taiwan,[44,45] and Gansu Province, China,[46] un-vented cooking oil fumes have also been implicated. Among women in Chandigarh, India, cumulative exposure of more than 45 years to indoor air pollution from coal or wood for cooking or heating showed an OR for lung cancer of 1.43 (CI 0.33-6.30).[47]

Aero-Digestive Tract Cancers

Upper aero-digestive tract (UADT) cancers involving the oral cavity, pharynx and larynx are the third most frequent forms of neoplasms found in males and the fourth most frequent in females in developing countries.[48] Tobacco, alcohol, dietary deficiencies and consumption of specific beverages like *maté* have been identified as important UADT determinants. Recently, in Brazil, case-control studies have strongly implicated wood stove use as well.[49,50] Similarly, in Guangxi, China, exposure to firewood was also associated with a strong risk for nasopharyngeal carcinoma (OR 5.4, P = 0.01)[51] and in Shanghai, a moderate association was found between cancer of the nasal cavity and sinuses and use of wood and straw as cooking fuels.[52]

Eye Diseases

Tobacco smoke has been shown to cause or accelerate numerous eye disorders including acute and chronic conjunctivitis, cataract, macular degeneration, retinal ischemia and optic nerve damage.[53] Less research has been done focusing on the effects of indoor cooking smoke and eye disease. Common sense would suggest that the ocular effects seen with tobacco smoke might also relate to indoor biomass smoke as well. Data are now beginning to accumulate which support this assumption, especially for cataracts.

Cross sectional surveys indicate that cataracts are the most common cause of blindness worldwide, responsible for over 19 million cases.[54] In most countries in Africa and Asia, cataracts account for half of all blindness.[55] Interestingly, cataract formation tends to occur 10-20 years earlier in persons in developing countries,[56] and the reason for this remains unknown. However, in an *in vitro* system, fuel smoke condensates cause opacification of rat lenses. This effect is partially inhibited by the use of antioxidants.[57] These findings are consistent with the current theory of smoke induced cataract formation, which suggests that toxins are absorbed and stored in the lens and cause oxidative damage.[58] In India, a study involving 170,000 people, which controlled for socioeconomic, housing and geographic differences, showed that partial or complete blindness was more strongly associated with use of biomass fuel than other fuel types (OR 1.32, 95% CI ,1.16-1.50).[59] Also in India, a recent case-control study of senile cataract found cooking with inexpensive fuels to be a risk factor (OR 1.8).[60] If indeed cooking smoke is proven to be a causal factor, the public health implications may be large given the size of the populations at risk.

Low Birth Weight and Perinatal Mortality

About 95% of all low birth weight (LBW) infants are born in developing countries. LBW is considered to be a major determinant of perinatal and infant mortality, and is a significant risk factor for subsequent malnutrition and infectious disease. Determinants of LBW include premature delivery, maternal malnutrition, anemia, malaria and other infections, placental insufficiency, and pre-eclampsia. In addition, studies from all over the world have now established a clear relationship between LBW and both outdoor air pollution and smoking. The mechanisms involved in this process are not yet clear. Data on the role of ambient[61,62,63] CO and smoking-related[64,65] CO have so far yielded conflicting results.

The relationship between cooking stove smoke (by whatever mechanism) and LBW in developing countries is also being studied. A recent WHO report found that Guatemalan infants born to women using wood to cook weighed 63g less on average compared to those using gas or electricity.[66] A possible relationship to perinatal mortality is also beginning to be examined. In Ahmedabad, India, indoor air pollution was associated with stillbirth (OR 1.5, 95% CI, 1.0-2.1).[67] The same level of risk for stillbirth was also observed in Ghana among mothers cooking with wood.[68]

Meningitis

Studies over the past several decades from developed countries have identified tobacco exposure, including passive exposure in children, as a risk factor for meningococcal disease. Now, a case-control investigation conducted in northern Ghana has very strongly implicated (OR 9.00, CI, 1.25-395) firewood cooking with meningococcal meningitis, which sweeps the "meningitis belt" of sub-Saharan Africa in epidemics every 8-12 years.[69] Prior to this study risk factors for the disease in this setting had been largely unknown. Biological plausibility may relate to increased *Neisseria meningitidis* nasopharyngeal carriage rates such as those found among personal smokers (OR 2.5) and passive smokers (OR 1.6) in New Zealand.[70]

Immunological Function

Immunologic mechanisms may be responsible for many of the health problems described above. Both tobacco smoke and wood smoke[71] have been shown to depress cellular and humoral immunity. Whether or not these immunologic effects contribute to other diseases in developing countries has not yet adequately been investigated. Such associations may have large additional health implications. For example, a role in HIV transmission is implicated by studies that demonstrate a tripling of the rate of vertical HIV transmission among women who smoke during pregnancy.[72]

Burns

A number of observational studies from developing countries indicate that burns and scalds related to cooking are major sources of injury, but under-reporting has hampered full quantification of their impact. These injuries are of concern both because of their frequency and because of the limited treatment options available in many countries. Open flames which catch loose clothing and hair, and open fires at ground level into which people, usually children, fall, are particular hazards.[73] Therefore, burn prevention is an important consideration in the design of improved stoves. Elevating the cooking surface height and reducing exposure to open flames are important measures.

Burns are also an important consideration in the choice of cooking fuels. Kerosene and LPG are common causes of explosions and fires particularly when they are used in poor-quality and ill-maintained stoves. The importance of proper liquid fuel formulation was tragically illustrated in Rajasthan, India in 1994 when petrol was inadvertently added to kerosene oil creating an excessively flammable mixture. Over 300 burn cases and 37 deaths resulted.[74]

Eye Irritation

Not surprisingly, eye irritation from cooking smoke has been associated with high particulate levels and respiratory symptoms in Lusaka, Maputo, and Hanoi. "Tears while cooking" therefore has been proposed as a simple, non-intrusive survey indicator to identify groups at risk of high indoor air pollution exposures.[75]

Fuel Collection and Storage

Clear health risks are associated with obtaining and storing fuel for the domestic cooking stove. Collection of biomass fuels is associated with a variety of mechanical injuries from felling, carrying and splitting wood, encounters with animals such as snakes and scorpions, violence, and exposure to vectors of a number of infectious diseases. For example, a case control study in Uganda demonstrated a significant risk of contracting sleeping sickness associated with firewood collection.[76] Similarly, fuel storage can place humans at risk from infectious diseases. For example, in Costa Rica, removal of stored firewood was identified as an important method of controlling Chagas disease by depriving triatomine bugs of refuge in proximity to dwellings.[77] Liquid and gas fuels are associated with fires and burns. Poisoning among children with stored kerosene cooking fuel has been repeatedly reported from several countries including India.[78]

Effects of Fuel Shortages

Humans have adopted cooking as a fundamental means of improving water potability and food safety. This practice remains especially significant today among populations that lack adequate means of refrigeration. An important, though very little studied issue relates to the ill-health effects of cooking fuel shortages. Rural households adapt to cooking fuel shortages in a number of ways which can jeopardize nutrition.[79] Increased time and energy spent on fuel collection often means time and effort diverted from food production and preparation, income generation, child care and rest. Economizing on fuel use can render food less digestible or contaminated. For example, inadequate firewood to reheat food was identified as a strong risk factor for disease (OR 8.0) in a cholera epidemic among refugees in Malawi.[80] Such findings may be only the tip of the iceberg, hinting at a much larger burden of diarrheal and other food and water borne diseases that could be ameliorated by providing households with adequate means of cooking.

Impact of Health Effects

Considerable evidence has been accumulated linking indoor air pollution from biomass cooking stoves to a variety of different diseases. Tobacco research suggests that cooking smoke might also cause peptic ulcer disease, cardio-vascular diseases, otitis media and other ailments. Although further work is needed on many fronts, there is already sufficient evidence to warn of a major public health hazard on a global scale. Given that approximately 3 billion people are exposed to indoor biomass combustion, and given that average daily indoor concentrations of pollutants often exceed WHO guidelines by factors of 10 or 20 (and during cooking by as much as 100 fold), the burden of diseases caused or exacerbated by this exposure is presumably very large.

At least two estimates of this global burden have been made, and though each used a different methodology, the final results were very similar.[81] The estimates of the number of deaths attributable to indoor particle air pollution in developing countries is nearly 2.44 million per year. Including indoor pollution in industrialized countries, the total approaches 2.8 million per year, which would translate to about 6 percent of all deaths annually worldwide.[82] Another study conducted in India used the disability adjusted life year (DALY) approach, and estimated that cooking fuel smoke accounted for 4-6 percent of the national burden of disease.[83] Justifiably, then, the World Bank has designated indoor air pollution in developing countries one of the four most critical global environmental problems (along with clean water, urban air pollution and deforestation).[84] Yet, such estimates may in fact still considerably under-estimate the overall disease burden associated with cooking stove use because they do not account for all likely adverse outcomes.

Possible Beneficial Effects of Traditional Stoves

Interventions that improve domestic cooking stoves are sometimes unexpectedly resisted by local communities, suggesting that some beneficial effects of traditional methods are being overlooked. Some indigenous populations believe that smoke is a useful, natural insect and rodent repellent or that it prevents traditional houses from rotting. Studies from several developing countries including Guinea Bissau[85,86] and Papua New Guinea[87,88] confirm that smoke from specific plants can indeed have insect-repelling properties and may be important in the prevention of arthropod-borne diseases. However, the efficacy of ordinary domestic cooking smoke in disease reduction and rodent control has not been adequately evaluated, and the relative health risks even for selected areas where arthropod disease transmission is high are unknown.

Another area where more traditional cooking practices may have some limited benefit relates to ambient humidity. Evidence from Australia suggests that the indoor air of homes equipped with solid fuel fires may have fewer harmful total fungal propagules.[89] These benefits may be related to enhanced air flow and reduced household dampness which has been implicated in a variety of respiratory health symptoms.[90] Household dampness may be associated with increased food spoilage rates and toxic aflatoxin production.

Environmental Effects

Shortages of wood and other biomass cooking fuels have forced communities to make significant changes to their local ecosystems. As populations increase and the demand for fuel rises, the surrounding environment is increasingly exploited resulting in marked reductions in tree cover. Particularly in arid and semiarid regions of the world, the need for fuelwood results in significant deforestation, with all its detrimental consequences. In fact, in arid and semiarid parts of West Africa, fuelwood shortages limit the carrying capacity of the land more so than do low crop and livestock yields.[91]

This fuelwood shortage does not just affect rural areas. In many developing nations, electricity services in urban areas are irregular and often do not reach poor sectors. Since many households can not afford kerosene and liquefied petroleum gas (LPG), a substantial portion of the urban poor continue to rely on fuelwood and charcoal.[92] Some have argued that urban fuelwood demand is more destructive of forests than rural needs, because of the intensity of cutting around cities, along roads and later from more distant sources. Urban demands are more often met by commercial entities that have equipment like chain saws and log splitters capable of harvesting larger diameter trees. It is projected that in the Sahel, urban fuelwood use will soon exceed that of rural areas.[93]

Global Deforestation

Worldwide, over the last twenty years, roughly 300 million hectares (ha; 100 x 100 meters, or 10,000 square meters or 2.47 acres) of forest (an area six times the size of France) have been cleared to make way for farming, grazing, and large scale plantations of oil palm, rubber, bananas and other cash crops.[94] The United Nations Food and Agriculture Organization (FAO) reports that during the 1990s, global loss of natural forests was 16.1 million hectares per year, and 15.2 million of these hectares were in the tropics.[95] Deforestation was highest in Africa and South America; in Asia, deforestation was somewhat compensated for by new plantation forests. Generally, the three major causes of deforestation are expansion of agricultural activities, logging and fuelwood collection; the relative contribution of each varies by region. In Africa, it is primarily expansion of subsistence farming. In forestry terminology, there is transition from closed forest systems, through intermediary stages of depletion, to shrub and fallow lands. In Latin America deforestation is typically due to large economic development programs involving resettlement, agriculture and infrastructure. There one sees more abrupt change from closed forest to other land cover, such as permanent agriculture, cattle grazing or water reservoirs. In Asia, both processes take place, with more gradual depletion resulting from rural population pressure, and abrupt changes from centrally planned resettlement schemes and plantation programs.[96] In all regions, over-harvesting of industrial wood and fuelwood is an important factor. Other factors also contribute to global deforestation, such as overgrazing, fire, insect pests, diseases, storms, air pollution, and poor harvesting practices.

Recently, the FAO reported that the global rate of deforestation may have slowed for the years 2000-2001, to approximately 9 million ha per year (i.e., still a net loss). This trend is based on preliminary figures obtained by satellite imaging, but does not pertain to Africa, where deforestation rates continue to rise.[97] In terms of percentages, the world's forest cover decreased annually by 0.2% during the 1990s. In contrast, Africa's rate was 0.8%, the highest worldwide (South America was next, at 0.4%). Within Africa, the rates vary greatly from country to country. Extremely high rates are seen in Burundi (9.0%), Comoros (4.3%), Rwanda (3.9%), Niger (3.7%), Togo (3.4%), Cote d'Ivoire (3.1%), and Sierra Leone (2.9%). Of these top seven, six are nations in the midst of economic and political turmoil and suffer extreme poverty. On the other hand, countries known for their rich forests and aggressive timber cutting, such as Cameroon and the Democratic Republic of the Congo, actually manage with much lower rates of 0.9% and 0.4% respectively. Thus, the great pressure exerted on forest lands by populations in poverty and conflict (subsistence farming, displaced populations without sense of land ownership, land mine disruption of forest management) can be as important as timber harvesting itself.

Fuelwood Demand and Deforestation

The relative contribution of fuelwood collection to this process varies across the developing world, and can be difficult to assess. In China, it appears to account for 30% of land clearing.[98] In Africa fuelwood collection may be second only to agricultural extension by subsistence farmers as a cause of deforestation.[99] Actual relative contributions to deforestation based on studies of plants cut down has been difficult to assess because the end use of the wood collected by households is often unclear, and because there is generally simultaneous use of land for farming and wood collection. Moreover, daily wood fuel collection deforests an area gradually via degradation, and statistics regarding what land is actually considered "deforested" are often unclear. It is conclusive, however, that in Africa, most of the wood harvested (in whatever fashion) goes to meet local energy needs. For example, in Cameroon (Africa's leading timber exporter), four times more wood was harvested for fuel than for industrial roundwood in 1998. Biomass fuels (mainly firewood and charcoal) accounted for 80% of the entire energy usage for Cameroon in 1995.[100]

In most areas of the developing world, the demand for fuelwood outstrips supply. For example in parts of western and sub-Saharan Africa, fuelwood consumption is 30-200% greater than the average tree replacement rate.[101] In India, consumption exceeds sustainable wood production six-fold.[102]

The demand for fuelwood is expected to increase in the coming decades, as the population of developing countries increases by 3 billion over the next forty years. By 2050, the world's population will be approximately 9 billion, with roughly 8 billion residing in less developed nations.[103] Meeting the energy needs of this increasing population puts tremendous pressure on already strained and damaged forest ecosystems, and encourages continued harvesting of virgin forests. Together with the expansion of agricultural activities to support the expanding population, it is no surprise that globally, forests are disappearing at a rate faster than they are replenished.

Effects of Deforestation

The term deforestation often conjures up images of mountainsides and vast tracts of tropical forest clear cut by heavy equipment. While some commercial wood traders who sell fuelwood operate in this fashion, taking live trees as well as deadwood and debris, the type of deforestation resulting from the daily collection of fuelwood for household use takes a different form. Serious environmental damage occurs long before an area is left completely bare. Such damage includes loss of biodiversity, soil depletion and erosion, decreased agricultural yields, and in many areas desertification and climate change.

Biodiversity Loss

Loss of biodiversity begins gradually, as the most available preferred fuel species are cut selectively. Subsequently there evolves a change in tree species composition, with a reduction in stem size distribution, plant densities and leaf area index.[104] The resulting habitat destruction causes loss of animal species diversity as well. Selectively removing the more easily handled younger trees decreases the regenerative capacity of the forest, and excessive pruning of remaining trees often reduces their individual growth capacity. As the forest canopy is opened, the area becomes more susceptible to wind and sun effects, and as humidity is reduced, more susceptible to fire. Eventually, less preferred fuel sources such as saplings, shrubs, litter, deadwood and even stumps and roots are recruited as fuels. Finally, the land is often left denuded but for sparse and thorny shrubs.

Soil Depletion

As shade, the litter layer, and root systems are removed, the ability of the soil to retain moisture is greatly reduced. The drier soil supports fewer plants, fewer plants means less organic matter to retain moisture, and a vicious cycle ensues. As the soil itself dries, it is eroded by wind, and with the decreased ground cover to anchor it, the soil is much more easily washed away by rains. Effects of such soil erosion are not only felt locally, but can be seen downstream in distant ecosystems as rivers and lakes become clogged with silt. Thus depleted, the ground is left acidified and compacted.[105]

Not surprisingly, agricultural yields from such soil systems are continuously diminished. Deprived of recycled plant debris, or “green manure,” the same land simply cannot produce as much per unit area. In addition soil fertility and conditioning is further reduced by lack of traditional manure, as local inhabitants, desperate for fuel, turn to burning animal dung for energy. One study has estimated, for example, that in Ethiopa in 1983, if the animal dung used for fuel had been left as soil fertilizer, grain production could have been increased by one to fifteen million tons.[106]

Hydrologic Changes

Local hydrology is also affected by the process of deforestation. Loss of the forest canopy and litter layer results in more rapid water runoff. Consequently, the local ground water is not replenished as efficiently, and water tables drop. The rapid water runoff is often accompanied by landslides and flooding. River and stream volumes shrink or even dry up for one or more seasons of the year. With the overall loss of surface water, humidity and plant transpiration, the water cycle is altered, and in many areas annual rainfall actually decreases, effecting a climate change for the region and hastening desertification.

Cultural Consequences

Finally, it must be added that this gradual destruction of local forests deprives local inhabitants not only of fuelwood for household use and income-earning activities (e.g., pottery making, food processing), but a myriad of other important forest products as well. Foods such as nuts, fruits, berries, tubers, leaves, honey, and mushrooms can be important supplements in the diets of farmers and serve as traditional medicines. Wood and plant stuffs are needed for construction and the making of household wares, and many traditional customs require forest products such as bark, seeds, resins and animal products (for garments, masks, dyes, musical instruments, etc.). For many forest communities, their culture and identity are intricately linked with the forest ecosystem, and loss of this environment profoundly and perhaps irreversibly transforms these cultures.

Interventions

There is a consensus that demand for traditional biomass fuels in less industrialized nations will continue to increase, although probably not as fast as population growth; and demand for fossil fuels will continue to accelerate. How best to meet the energy needs of the fast-growing developing world in a more sustainable, carbon neutral and healthy manner has been the subject of much debate. Supply-side issues with the most direct relevance to cooking needs include improved forest management and agro-forestry practices, expanded liquid biofuel and biogas production, improved charcoal production efficiency, and some solar applications such as solar cookers and ovens. Developments in photovoltaic, wind, hydroelectric, nuclear and geothermal sources are also crucial because of their potential to produce electricity for cooking. On the demand side, safer, more efficient biomass fueled cooking stoves, expanded rural electrification, and domestic behavioral changes are of chief interest.

Forest Management

Fuelwood supply shortages have already been partially alleviated in China, India, Indonesia and elsewhere by a combination of forest management and tree farming strategies on national and commercial tree farms. Agroforestry, an approach that encourages farmers to devote a portion of their land to tree planting and community forest projects that encourage community participation in the sustainable management of local communal woodlands have also been helpful in slowing environmental damage.

Charcoal Production

Traditional pit kilns are often inefficient and require more wood per unit of charcoal produced. Culturally acceptable but more efficient kilns have been successfully introduced in Madagascar, Rwanda, Thailand and elsewhere. These programs may be most successful when integrated with forestry management programs which give charcoal producers a direct stake in conserving local woodland resources. Wood fuel use is also closely related to the manner of kiln operation. Training in more efficient production practices with existing kilns may also improve efficiency.

Biofuels

Biofuels like alcohols and biogas have been an important source of energy for decades. Brazil has used ethanol/gasoline mixtures in vehicles since the 1930s. These fuels are expected to play a greater role in future global energy needs, including for use in domestic cooking stoves, in part because they have two advantages over other renewable sources. Unlike solar, wind or small hydro sources, energy is stored and can be drawn at any time. Biofuels are also more versatile and can meet all forms of energy needs like gas and liquid fuels which solar, wind and hydro do not. In addition, they can be formulated to produce less domestic indoor air pollution than many traditional fuels. Biofuels hold particular promise for developing nations by providing rural jobs, increasing the profitability of agriculture and restoring degraded lands.

In a recent review of biofuel prospects and potential, preliminary calculations suggest that in Africa and Latin America alone, bioenergy resources are available equivalent to more than 890 million tons of oil equivalent (Mtoe).[107] These calculations consider the two primary biofuel resources to be energy crops, such as trees, grasses or tubers planted specifically for fuel production and biomass wastes and residues including animal wastes, urban organic wastes and agricultural and forest residues. Crops which usually yield the most liquid biofuels (like alcohol) per hectare are sugarcane, cassava, fodder beets, sugar beets, sweet potato, and Nipa palm. For some of these crops ethanol yields of over

10,000 (liters/ha/yr) are achievable. Energy uses of biofuels extend far beyond the kitchen to include the village level, exemplified by the Pura, India 5kW biogas-diesel generator project, to 30-100MW plants under investigation by large corporations like Shell.

Biogas

Biogas has already shown great utility as a clean, affordable, renewable, cooking gas that can also serve lighting, heating, welding, crop drying and electricity production needs. It is produced in air-tight and water-tight digesters of various sizes ranging from individual steel drums to community-wide sewerage digestion plants. Biogas generation relies on the anaerobic bacterial decomposition of organic matter to produce both liquid fertilizer and biogas fuel composed of methane (50-75%), carbon dioxide (30-40%) and small amounts of hydrogen, nitrogen, ammonia and hydrogen sulphide. Its calorific value can be enhanced by removal of carbon dioxide and water vapor by filtration through lime water (calcium hydroxide) and calcium oxide respectively.

While theoretically any biodegradable material can be digested for biogas production, most systems operate best on animal dung. India alone has an estimated 987 million tons (mt) of cow dung available annually.[108] Each 25 kg of dung, the daily product of 2-3 cattle, can produce about 1 m^3 of biogas, which is equivalent to 2.44 kg of coal or 3.98 kWh of electricity, and can serve the cooking needs of 3-4 people. China has claimed remarkable success with biogas production which began in the 1930's and resulted in more than 7 million family and community scale biogas plants. But, attempts to reproduce their success elsewhere have met with uneven results. Capital investments, training and maintenance are cited as common obstacles. Even Chinese plants are now falling into disrepair as rural electrification proceeds. In the near future biogas use will likely remain limited to areas with sufficient dung supplies and no practical alternatives. However, technological advances allowing better gas generation using leaves and other organic matter may expand the utility of this method considerably.

Improved Stoves

Stoves occupy a central place in the health, environmental, economic, and social lives of families in developing countries. Improved cookstoves therefore can provide a number of benefits. They can reduce indoor and outdoor air pollution by providing more complete combustion, decrease indoor exposure by providing better ventilation, and decrease burns by elevating the cooking surface off of the floor. Improved stove efficiency can boost household economics and empower women by reducing the time, dangers, drudgery and expense involved in obtaining and preparing fuel, leaving more time for childcare or economic activities. Reducing fuel consumption can also serve to improve soil fertility and reduce deforestation, soil erosion and desertification. Local economies benefit from jobs associated with stove construction and repair, and national economies from reduced dependence on importation of fossil fuels like kerosene and LPG. Improved stoves can also have subtle but important social benefits like improved cooking convenience because they can be made to any height and require less attention to tend the fire.

Improved stoves have been a major element of the appropriate technology movement for decades. Hundreds of designs have been produced, adapted and field tested across the developing world. Several compendia have been made available to facilitate introduction into new areas.[109,110] Efficient stove designs and cooking systems have come from both developed and developing worlds.[111] Improvements can entail many technical considerations in addition to user satisfaction. Combustion is maximized by keeping temperature high within the firebox. Designs also attempt to maximize radiative, convective and conductive transfer of heat to the food pots. These designs can frequently accomplish more than a doubling of percentage of heat utilized. Unfortunately, many improved stove projects have not reached their maximum potential because they focused either on fuel efficiency or on reduced smoke, but often not both. Both the cost and efficiency of improved stoves varies considerably. Efficiency tends to go up considerably as stoves move up the energy ladder. Gas stoves have thermal efficiencies in the range of 50-70% in comparison to dung and crop residues of only 11-17% (see Table 3, pg. 39).

Improved stoves have been promulgated by a variety of non-governmental organizations (NGO) with varying degrees of success. Programs working in areas with fuel shortages and high fuel prices have often proved most successful. National programs have also been conducted including the largest to date, the Chinese National Improved Stove Program which resulted in the installation of over 129 million stoves in rural areas. These have included some remarkable designs including the Kang-Lianzao bed stove which circulates heat underneath the sleeping surface for use in cold climates.[112] More recently China has produced more than 500,000 coal stoves designed to be located in the kitchen and distribute heat to living areas through hot water pipes which do not require electricity to circulate.

The National Programme on Improved Chulhas (NPIC) of India was started in 1983 and has become the second largest stove program in the world. Chulhas are a common form of cooking stove found throughout the Indian sub-continent and parts of central Asia. Traditional chulhas are typically simple U-shaped constructions of mud without chimneys. Improved chulhas can conserve fuel and decrease indoor smoke. Recognizing these potential benefits, the program first targeted fuel-scarce, poorer areas of the country and used subsidies as high as 90% to help finance the stove purchase. The improved chulhas have usually been made and installed by trained, self-employed individuals. Improved designs may be portable or not, they may be constructed of pottery-lined mud, metal, or ceramic-lined metal, and they may or may not have a chimney (see Illustration 2, pg. 42). The NPIC however has met with some difficulties. Critics claim that as many as 50-60% of installed stoves are no longer in use, and they cite problems relating to bureaucracy, inadequate funding, and lack of sensitivity to gender and stove design issues.[113] Expanded commercialization is viewed by some as a means of improving dissemination.[114] Nevertheless, by 1996, more than 8 million improved chulhas had been introduced.

Unlike India and China where national programs were in place, East Africa has been the scene of a variety of improved stove programs funded by NGOs and multilateral and bilateral development agencies. The Kenya Ceramic Jiko (KJC) stove has gained most popularity, and over 700,000 are reportedly in use. Although more efficient than traditional East African stoves or open fires, they are not vented, and thus their impact on health is lessened (see Illustration 3, pg. 43). However, their environmental impact has been considerable, and much has been learned about stove dissemination methods.

Solar Cookers and Ovens

Many different models of solar cookers and ovens have been introduced in developing countries. In India, more than half a million have been sold since the early 1980s. Their attractiveness lies in the fact that they require no fuel and little maintenance. However, introduction has been hampered by high initial costs, their limited use during cloudy periods and cultural unacceptability because they are too different from traditional methods and are not useful where the main meals may be eaten early or late in the day. Solar ovens, although limited to baking are relatively inexpensive and can fill a useful cooking niche. Communal solar ovens can for example provide for the baking needs of the entire village.

Climbing the Energy Ladder

Stoves which use fuels which are higher on the "energy ladder" can both reduce health risks and lessen environmental impacts. Crude biomass stoves can release 50 times more pollutants and consume 6-7 times as much fuel than gas stoves in cooking the same meal. In Qalabotjha, South Africa, switching from coal to low-smoke fuels for domestic cooking and heating resulted in sharp reductions of airborne particulates.[115] Likewise in Guatemala, cooking method had a marked effect on a variety of other emissions.[116] A beneficial health effect of advancing along the cooking fuel "ladder" is supported by a cross sectional study of urban slum dwelling women in Pondicherry, India, where women using biomass fuels experienced more respiratory symptoms (23%) than those using kerosene (13%; $p < 0.05$) or liquid petroleum gas (LPG) (8%; $p < 0.05$). Lung functions FVC, FEV1, and PEFR were also significantly lower in biomass fuel users compared with both kerosene ($p < 0.01$) and LPG users ($p < 0.001$). Lung functions in kerosene users also were significantly poorer when compared with LPG users ($p < 0.01$).[117] Similarly, in Maputo, Mozambique, more modern cooking fuel use was associated with both reduced particulate exposure and cough.[118]

Progression up the fuel "ladder" does not necessarily result in across the board reduction in emissions depending upon combustion device used. For example, certain wick type kerosene stoves have been shown to emit more hydrocarbons than wood or charcoal stoves.[119] Nor does progression up the energy ladder have consistent environmental impacts. As mentioned previously, charcoal, a step above wood on the energy ladder, requires a great deal of wood in its production. It is thus overall less energy efficient than wood. However LPG, a non-renewable, fossil fuel carbon source, has a much greater caloric efficiency than wood. This is due in part to the fact that some of the heat produced in wood combustion is used in producing steam from the moisture within the wood. Therefore, less total energy is required to cook the same meal. Another important consideration in comparing fuels relates to their greenhouse gas emissions. Wood and other biomass fuels low on the "energy ladder"also usually emit more kinds of greenhouse gases, which further diminishes their advantage over LPG or other "cleaner" fossil fuels. Of course, it is hoped that clean-burning renewable liquid and gas biofuel can soon replace LPG.

Barriers To Stove Dissemination

Many small and large scales projects have failed for both cultural and technical reasons. Sometimes the causes have been quite subtle, a pot that doesn't fit, burnt meals before learning how to control the flame, local clay that cracks or adds grit to the tortilla, or the loss of open flame as a source of light or ritual focus. Firewood suitable for an open fire, may need additional cutting to fit into the firebox. Loss of smoke can change the flavor of food and allow insects in the home. Cooking may normally be done at several locations, demanding stove portability which was not planned for.

Although many early improved cooking stove programs anticipated efficiency improvements of 75 per cent or more, such gains were rarely achieved. Many failed to meet their energy conservation goals because stoves often perform relatively poorly under field conditions depending on variables such as fuel type and moisture content, and atmospheric conditions. Failure to perform basic stove maintenance can also severely affect performance over time and result in adverse events such as chimney fires. Overall fuel savings in practice reported by the UNDP tend to follow a distribution, as shown in Table 4 (pg. 40) and are closer to 20-25 per cent per stove overall, still an important achievement.

Domestic Behavioral Changes

Domestic behaviors can influence both health and conservation practices. Studies in The Gambia showing a significant risk of acute lower respiratory tract infection in children carried on their mothers back while cooking, suggest that simple child care modifications have the potential to reduce childhood exposure in such settings.[120],[121] Likewise, a reduction of exposure to smoky interiors by pregnant women may be beneficial. Another strategy is to encourage the use of outdoor cooking when possible. This concept is supported by studies like one conducted in highland villages in Bolivia, where cooking done primarily outdoors was associated with a 60% lesser risk of bronchitis compared to similar villages with exclusive indoor cooking.[122] To what extent populations are even aware of the health risks posed by cooking smoke is unknown. We have not found even a single study examining the issue. Other simple measures, such as improving ventilation by opening a window or door, or performing some cooking tasks in communal stoves seems to be dependent upon awareness of risks.

Important, simple domestic fuel conservation practices such as putting out fires with sand and retrieving partially consumed sticks for later consumption, or learning how to bundle a clump of local grass to control its rate of combustion in a given stove are matters largely of traditional wisdom. As such they may not be very amenable to scientific scrutiny or promulgation in development programs unless perhaps when conducted in culturally appropriate forums such as village women's associations.

Cookware

The importance of pots and pans in cooking energy consumption is easily overlooked. Using lids is a basic energy conserving measure. Pots which are able to be stacked one atop another and pressure cookers can also significantly reduce fuel expenditure although such simple equipment is not generally available to poor households and may not work well with local food preparation customs. In many improved stove designs, pots are specifically matched to stove design, often fitting snugly into a depression on the cooking surface and thereby minimizing loss of heat and fumes.

Economic Considerations

Fuel choice and cooking methods are closely associated with poverty. In countries with per capita incomes of $300 or less, at least 90% of the population uses traditional fuels like wood and dung for cooking. However, by the time per capita income reaches only $1000 –1500, almost the entire population has moved up the "energy ladder" to cleaner more convenient sources.[123] It is anticipated that with technological advances such as more efficient biofuel production, the income level at which this transition takes place can be significantly lowered.

Economic analysis of cooking fuel use also needs to take into account the important role that the marketing and manufacture of traditional fuels plays in national economies. In Africa for example, charcoal and fuelwood businesses employ more than 400,000 people, with sales of some $5 billion annually.[124] Governments clearly have important roles to play in the development of policies affecting cooking energy policies. However, optimum strategies have been difficult to formulate. For example, some economists argue that energy subsidies, which are common in many developing countries, should be largely avoided because they can discourage investment in alternative energy sources and often predominantly benefit richer segments of society who consume disproportionately more energy. Subsidies can also have unintended consequences and fail to benefit the poor. For example, kerosene subsidies in Ecuador which were intended to lessen the cost of cooking and lighting for the poor, resulted in diversion of fuel by retailers to sale for automotive use which was more profitable.[125] Conversely, in Haiti, taxes on kerosene may have hurt the poor (and the local environment) as the middle class purchased more charcoal.[126]

Market liberalization can clearly work to the advantage of the poor such as was experienced in Hyderabad, India where relaxation of importation and production restrictions on LPG has permitted many more middle and low income families access to this energy source.[127] On the other hand certain subsidies and government sponsored microcredit schemes also can work well in helping the poor meet their basic energy needs. For example, diminished tariffs on low volume electricity use, which are offset by higher charges for higher use customers, appear to benefit the poor without adversely affecting distribution companies. Subsidies and microcredit loans targeted at alleviating “first costs” may also be successful such as those associated with connecting to the electricity grid, installing a community photovoltaic microgrid and other home and community solar investments.

Conclusion

The slow pace of development in many countries indicates that dangerous, smoky cooking stoves will remain in widespread use for decades throughout much of the developing world. Much more remains to be learned about their adverse health, economic and environmental effects. Most of the studies on the respiratory effects of cooking stoves have focused on indoor air, but cooking stoves also contribute significantly to local outdoor air pollution even in rural areas, particularly depending upon stove density. Little or no attention has been given to the possible interaction of indoor air pollution from cooking smoke and other factors potentially related to the pathogenesis of respiratory diseases among the poor, such as protein-energy malnutrition, vitamin and other micronutrient deficiencies, HIV and smoking.[128] Tobacco research suggests that cooking smoke might also cause peptic ulcer disease, cardio-vascular diseases, otitis media and other ailments. The disease contribution made by fecal-oral and skin infections acquired while collecting and processing animal dung is also largely unknown and many other health and environmental aspects remain under-studied.

However, despite such gaps in knowledge, abundant health, environmental, economic and development data have already defined the existence of clear hazards to both human health and the environment from inefficient, smoky cooking stoves. Moreover, a range of practical interventions has been formulated over the past several decades that can ameliorate many of these problems at moderate costs. Yet, progress has proceeded too slowly.

Since most workable interventions have come from the developing nations themselves, particularly India and China, one may call into question whether the slow progress in this area may be in part due to a different set of environmental health priorities between more and less developed nations. Environmentalists, health workers and development specialists should have a common interest in promoting more rapid implementation of solutions to the stove smoke problem. Yet many other issues, of far less demonstrable impact on health and the environment, receive much more funding and attention in the global environmental forum. Perhaps one reason for the industrialized nations' lack of action commensurate to the scope of this problem might relate to an unrecognized bias toward issues involving higher technologies. Certainly the science surrounding cooking stoves is less glamorous than its genetic or space-based counterparts. However, slow progress cannot be attributed solely to a disparity in culturally defined priorities within the global health and environmental communities. Rather, it is more likely a symptom of the prevailing apathy evident on the part of wealthier societies as a whole toward the problems of the developing world. The challenge here appears to be more a matter of commitment by policy makers and concerned individuals rather than of further scientific inquiry.

Although we were unable to find a single study evaluating risk perception from cooking smoke in any developing nation, we believe that it is very likely that many populations are not well informed about the hazards involved. It is highly likely that millions of people are unaware of the hazard in their homes, just as millions of smokers were unaware of the hazards of tobacco until the 1960s. It appears to be a matter of social justice that populations at least be informed about these risks so that they may take whatever action they choose. Such actions may be as simple as opening a door while cooking or keeping the children outside more when the house is smoky.

We earnestly recommend that governments, international bodies and academic centers act more urgently and decisively on this vital issue.

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