17

Indoor Air Pollution in Mexico

Iván Nelinho Pérez Maldonado, Lucia Guadalupe Pruneda Álvarez, Fernando Díaz-Barriga, Lilia Elisa Batres Esquivel, Francisco Javier Pérez Vázquez and Rebeca Isabel Martínez Salinas
Laboratorio de Toxicología, Facultad de Medicina, Universidad Autónoma de San Luis México

1. Introduction

General health conditions in Mexico have improved considerably over the last 50 years. This is clearly seen in life expectancy at birth. Between 1950 and 2000, the country added 25 years to this indicator. However, the respective differences among the states show the inequality prevailing in the country (SSA, 2005).

The differences found per region are an important fact to consider in understanding the Mexican situation. In the modern and industrialized northern region, the population is concentrated mostly in urban zones. The southern region is clearly traditional, unindustrialized and with a high indigenous population living in small, dispersed rural communities. This explains why the health indicators for the northern region are similar to those of developed countries, while the same indicators for the southern region are similar to those of developing countries with social and economic problems.

In 2002, there were 43,719,756 persons under 19 years of age in Mexico, representing just over 40 percent of the total population. The birth rate per 1,000 inhabitants has decreased from 45 in 1960 to 17 in 2000, while the child mortality rate in the first year of life decreased from 19.1 per 1,000 inhabitants in 1998 to 16.78 per 1,000 inhabitants in 2002. The leading causes of death also changed radically over the past 50 years. Transmissible diseases and congenital illnesses were displaced as the primary causes of death by non-transmissible diseases and injuries. In the same period, the percentage of deaths due to intestinal infections decreased by a factor of 14 (from 14.3 percent to 1 percent), while deaths from heart disease quadrupled (from 4 percent to 16 percent; SSA, 2005).

Another fact pointing to a clear epidemiological transition in the country is the changing pattern of causes of mortality among children under one year of age. Previously, infant deaths were concentrated in the postnatal period (between one month and one year of age), mostly caused by acute respiratory infections and diarrhea. Presently, infant deaths are concentrated in the first 28 days of life, due to perinatal causes and congenital anomalies requiring high-technology intervention (SSA, 2005).

Common infections and congenital events continue to cause major harm to health in highly marginalized groups. Over the last 10 years, deaths from diarrhea in children under five years of age have decreased by 85 percent. However, there are southern states with mortality rates from diarrhea above 40 per 100,000 inhabitants under five years of age, i.e., five times higher than the rates found in the more developed northern states. The same is found with deaths from acute respiratory infections, another clear example of the persistently lower quality of life (SSA, 2005).

Despite the major progress in health systems, the problems of poverty, social inequality, marginalization, the lack of services, and environmental air, water and soil pollution constitute important factors associated with a poor quality of life for a high percentage of the child population, primarily in the country's rural areas.

Air pollution is a generalized problem in Mexico's major metropolitan areas. However, current demographic growth, industrial concentration, greater numbers of vehicles, increased fuel consumption and inadequate urban mobility patterns have caused the problem to increase in other areas, such as medium-size cities.

Indoor air pollution caused by the burning of wood or charcoal used for cooking or heating constitutes a public health problem with repercussions for the population under five years of age and women of reproductive age, especially in the country's marginalized areas. In 1990, one of every three Mexicans (91 percent of rural inhabitants and 11 percent of urban inhabitants) used wood for cooking. In 1993, 25.6 million persons were estimated to use wood as household fuel, decreasing to 17.2 million inhabitants in 2000.

2. Biomass as energy source

The use of solid fuels for cooking and heating is likely to be the largest source of indoor air pollution on a global scale. Nearly half the world continues to cook with solid fuels such as wood, crop residues, agricultural wastes, and animal dung, with wood being the most commonly used (Bruce et al. 2000). When used in simple cooking stoves, these fuels emit substantial amounts of toxic pollutants. In households with limited ventilation (as is common in many developing countries), exposures experienced by household members, particularly women and young children who spend a large proportion of their time indoors, have been measured to be many times higher than World Health Organization (WHO) guidelines and national standards (Bruce et al. 2000; Smith 1987). In this regard, the number of annual deaths in developing countries associated with domestic biomass combustion is estimated at 1,849,000 (SSA, 2005).

In México currently, biofuels represent about 8% of the total energy demand (SE, 1998), 46% of residential energy use (Figure 1) and more than 80% of the energy demand in the rural sector (Masera, 1996b). The three main types of biofuels used in the country are: bagasse, which is used in the sugar cane industry, fuelwood and charcoal. Fuelwood is by far the dominant woodfuel, with charcoal being used mainly in street industries and for barbecues. Total fuelwood use accounts for 3 times the total commercial timber legally harvested in the country (Masera, 1996a). In this regard, in 1990, one of three Mexicans used fuelwood for cooking, including 91 percent of rural residents and 11 percent of urban residents. It is estimated that 25.6 million people used this fuel in their homes in 1993 and that by 2000 this number had declined to 17,256,471. Fuelwood is also used in many small (cottage) industries, like pottery making, "tortilla" making, brick making, and others. The use of fuelwood is concentrated in rural areas and small towns. Fuelwood markets are mostly of a local nature. Most fuelwood comes from forest areas (including here all degraded lands and semi-arid forests); many of the species used are of no commercial value, and the use of agricultural residues and dung is not widespread (Masera, 1996a; Masera et al, 1997). Among the states in México with the highest use of fuelwood are Oaxaca and Chiapas, where it is estimated that 50–60 percent of the

population uses this type of fuel (Figure 2). The general pattern is that a higher proportion of people are exposed to fuelwood and charcoal in the southern part of the country. These are largely rural states with some of the poorest populations; thus, exposure to fuelwood-related pollutants is more prevalent here.
The heaviest biomass fuel usage by household is in southern and north central Mexico, where utilization may approach 90 to 100 percent in some localities (Figure 3). These are largely rural states with some of the poorest populations.
The majority of households using solid fuels in México burn them in open fires or simple stoves that release most of the smoke into the home (Figure 4). The resulting indoor air pollution is a major threat to health, particularly for women and young children, who may spend many hours close to the fire. Furthermore, the reliance on solid fuels and inefficient stoves has other, far-reaching consequences for health, the environment, and economic development (Reddy et al., 1997; WHO, 1997).

3. Indoor air pollution

The current dominant pattern of household fuelwood use presents several problems. People depend mostly on
open fires, leading to very high indoor air pollution levels, particularly for women and children. Fuelwood combustion emits a complex mixture of organic compounds and gases, which include carbon monoxide (CO), nitrogen and sulphur oxides (NOx and SOx), aldehydes, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), chlorinated dioxins, breathable particulate matter (PM) with diameters < 10 microns (PM10),

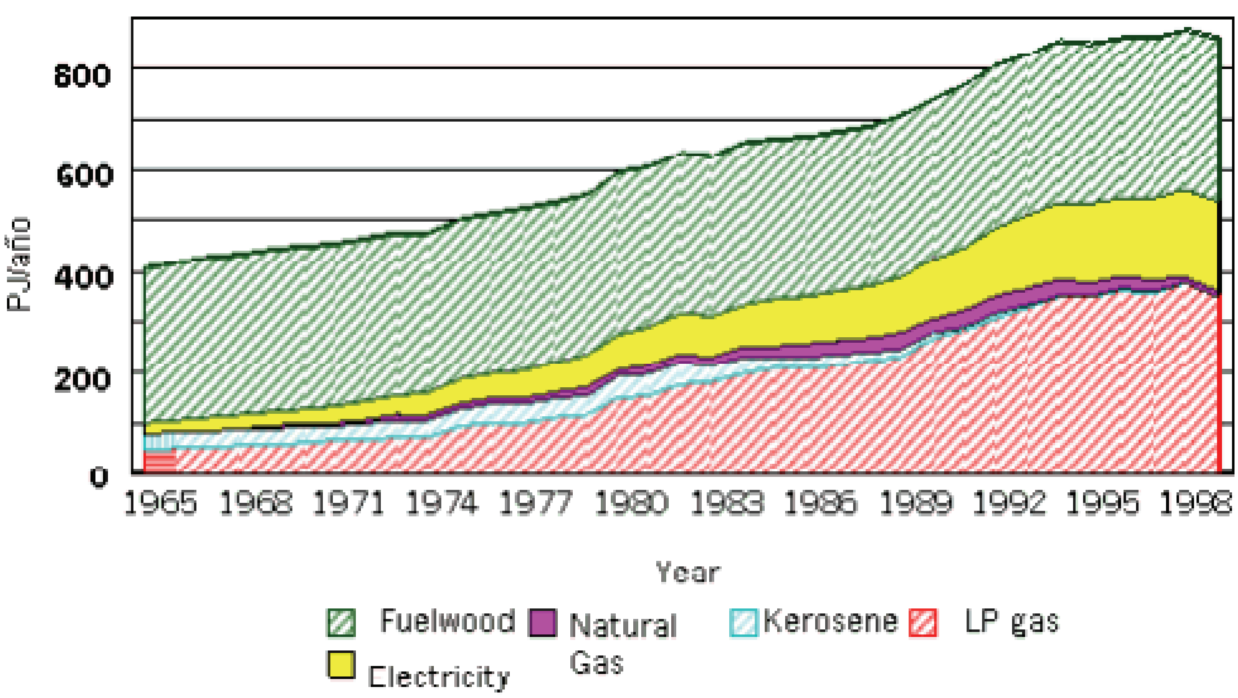


Fig. 1. Residential Energy Use in Mexico 1965-1998. **Source:** Masera O.R, Drigo R., and Trossero M.A. 2003. Woodfuels integrated supply/demand overview mapping. Universidad Autónoma de México, FAO-EC Partnership Programme. Food and Agriculture Organization of the United Nations.

and free radicals (Albalak, 2001; Mishra, 2003; Table 1). Moreover, wood users rely on simple and rustic stoves such as open "three-stone" fires and mud, clay, or metal stoves that result in incomplete and inefficient combustion (Reddy et al., 1997; WHO, 1997).

Compound	Major indoor sources
Carbon monoxide	Fuel/tobacco combustión
Nitrogen oxides	Fuel combustión
Sulphur oxides	Coal combustion
Aldheydes	Furnishing, construction materials, cooking
Polycyclic aromatic hydrocarbons	Fuel/tobacco combustión, fumes from food being cooked.
Volatile and semi-volatile organic compounds	Fuel/tobacco combustión, consumers products, Furnishing, construction materials, fumes from food being cooked.
Chlorinated dioxins	Fuel/tobacco/ coal combustión
Breathable particulate matter	Fuel/tobacco combustión, cleaning, fumes
free radicals	Indoor chemistry

Table 1. Toxic compounds generated during fuelwood combustion.

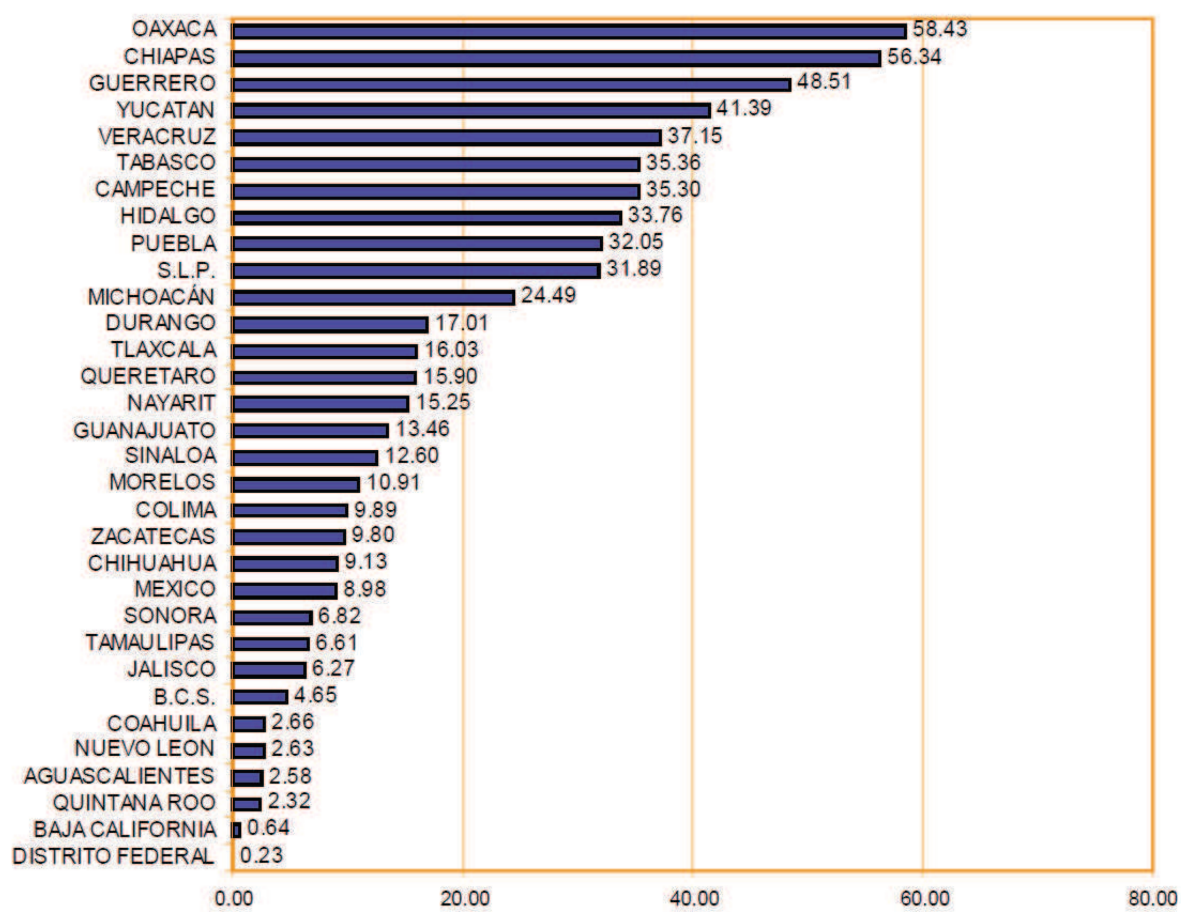


Fig. 2. Percentage of Mexico's General Population Exposed to Biomass Smoke, by Region, 2000. Source: Diagnóstico Nacional de Salud Ambiental y Ocupacional 2002. Dirección General de Salud Ambiental.

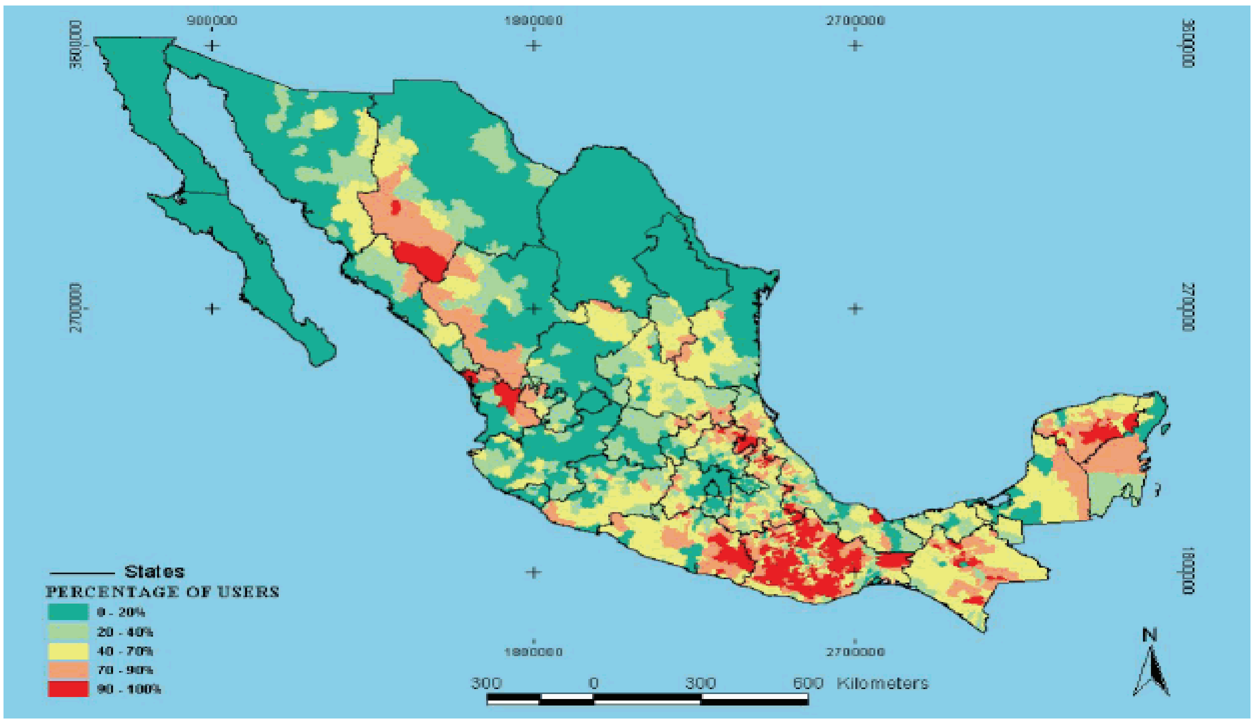


Fig. 3. Percentage of Fuel Wood Users, at the Municipal Level, in Mexico, 2000. **Source:** Masera O.R, Drigo R., and Trossero M.A. 2003. Woodfuels integrated supply/demand overview mapping. Universidad Autónoma de México, FAO-EC Partnership Programme. Food and Agriculture Organization of the United Nations.

Fig. 4. Traditional wood-burning cookstove.

For example, studies carried out in rural households belonging to different regions of Mexico report average concentrations of respirable suspended particulates ranging between 537 and 1020 µg/m³ (Table 2). Per capita fuelwood use averages 2.0 kg/day, with large variations depending on the specific region.

Study location	**Reference**	**PM10 mean concentration**
Michoacán, México	Masera et al. 2007	1020 µg/m³
Michoacán, México	Saatkamp et al. 1999	995 µg/m³
State of México, México	Brauer et al. 1996	768 µg/m³
Chiapas, México	Riojas, et al. 2001	537 µg/m³

Table 2. Mean PM10 concentration in Mexican households that use fuelwood as energy source.

A more recent study in Michoacán, México report average concentrations of PM10 particles of 1020 µg/m³ with maxim levels of 4230 µg/m³ (Masera et al. 2007; see Table 2). Saksena et al. 2004, have compiled data on several of the main pollutants associated with various household fuels from studies of homes in a wide range of developing countries. Concentrations of PM10, averaged over 24-hour periods, were in the range 300 to 3,000 (or more) micrograms per cubic meter (µg /m³). By comparison, the U.S. Environmental Protection Agency's annual air pollution standard for PM10 is 50 µg/m³, one to two orders of magnitude lower than levels seen in many homes in developing countries.

With use of biomass, CO levels are generally not as high in comparison, typically with 24-hour averages of up to 10 parts per million (ppm), somewhat below the World Health Organization (WHO) guideline level of 10 ppm for an eight hour period of exposure. Much higher levels of CO have been recorded, however. For example, a 24-hour average of around 50 ppm was found in Kenyan Masai homes (Bruce et al. 2002), and one Indian study reported carboxyhemoglobin (COHb) levels similar to those for active cigarette smokers (Behera et al. 1988). In this regard our group, demonstrated in a rural community in San Luis Potosí, Mexico that use biomass as the principally energy source, mean COHb level of 4.93% and moreover, 55% of those people presented COHb levels above 2.5% considered a safe level (Kleinman, 2000). Moreover, this 55% of people had geometric mean COHb levels of 8.39% (Torres-Dosal et al. 2008). In this study also was monitored exposure to PAH´s in urine of people using 1-hydroxypyrene (1-OHP) as exposure biomarker to PAH´s. Because PAH exposure occurs as a mixture of compounds, and because pyrene is almost always found in this mixture, pyrene and its metabolite 1-hydroxypyrene (1-OHP) are considered appropriate surrogate markers of total PAH exposure (Jacob and Seidel, 2002). Results show that the geometric mean level of 1-OHP ranged between 1.1 to 17.8 µmol/molCr (mean ± SD; 6.71 ± 3.58 µmol/molCr; (Torres-Dosal et al. 2008). The levels of 1-OHP found in this study are higher than the mean urinary 1-OHP concentrations from people throughout the world (range: 0.03–0.76 µmol/mol creatinine; Levine, 1995; Zhao et al., 1992). These values are also higher than levels observed in people living in traditional houses from rural districts in Burundi (1.50 µmol/mol creatinine, range: 0.26–15.62), that use wood as the principal fuel (Viau et al., 2000). We don't know the type of wood burned in Burundi, but it is possible that the difference in exposure between Mexico (our study) and Burundi is the type of wood used. It has been shown that different emission rates of PAHs and other compounds are dependent on fuel and burning conditions (Jenkins et al., 1996; Zhang and

Smith, 1999; Mcdonald et al., 2000). In a more recent study performed in México, our group evaluated PAHs exposure in children in different residential categories (sites included in the study are recognized for their industrial activity, indoor wood combustion, waste disposal and brick manufacturing using different materials as fuel sources). We performed a random sampling in nine communities in Mexico (Table 3). The participant group consisted of 65 children living in communities with brick furnaces (communities of San Vicente and Tercera in San Luis Potosí (SLP), state); 105 children who live in houses where firewood is the domestic fuel (communities of Ramonal in Quintana Roo state, Ventanilla in Oaxaca state, Victoria in Chiapas state and Tancuime in San Luis Potosí, state); 32 children living next to a municipal landfill in San Luis Potosi city with waste combustion (community of Milpillas) and 56 children living in areas next to highways with moderate and high vehicular trafficc (communities of El Centro and Domingo in San Luis Potosí, state, respectively). The highest levels of 1-OHP in this study were found in Victoria, Chiapas (mean, 4.4 ± 3.7 µmol/mol creatinine; 5.9 ± 5.1 µg/L), in this community, children are exposed to biomass combustion. Interestingly, the communities that also are using biomass combustion as Victoria (i.e., Ramonal, Ventanilla and Tancuime) had children with urinary 1-OHP mean levels, similar to those found in Victoria (Martínez-Salinas et al. 2010). When grouped by exposure scenario, (a) moderate vehicular traffic; (b) heavy vehicular traffic; (c) fumes from a municipal landfill; (d) fumes from brick kilns and (e) indoor air pollution by biomass combustion, the highest levels of urinary 1-OHP were found in children exposed to indoor air pollution (approximately one order of magnitude higher than the other scenarios; Table 4). Children living in communities with brick kiln industry, children living in Milpillas (landfill) and children living in Domingo (heavy vehicular traffic) were the next communities in order (Table 4), leaving the community of El Centro (moderate vehicular traffic; Table 4) at the end (Martínez-Salinas et al. 2010). Moreover, Jongeneelen (2001) proposed a benchmark guideline for occupational exposure to PAHs, taking into account urinary 1-hydroxypyrene levels. Following this guideline, the reference value as a 95th percentile in non occupational exposed controls is 0.24 µmol/mol creatinine and 0.76 µmol/mol creatinine for non-smokers and smokers, respectively (first level). A no-biological-effect-level of 1-hydroxypyrene in urine for exposed workers was fixed at 1.4 µmol/mol creatinine. It is the lowest reported level at which no genotoxic effects were found and therefore the estimate for the second level of the benchmark guideline. Finally, two reference values for the third level were proposed 2.3 µmol/mol creatinine and 4.9 µmol/mol creatinine, in two types of industry, coke ovens and primary aluminum production, respectively, and it was designated occupational exposure limit (OEL). When our results in children were compared with this guideline for adult workers, only in El Centro did we find a low risk condition; in the rest of the communities, an important percentage of children were found at risk (Table 5). It is important to note that the guideline values proposed by Jongeneelen (2001) are derived for workers and for adult populations. Thus, our results are more important in terms of public health as we studied children in non-occupational scenarios.

Finally, taking account the above results mentioned assessed in children, our group performed a study to evaluated 1-OHP levels in women (aged 15-50 years) in two exposure scenarios: 1) People living in an indigenous community in La Huasteca in San Luis Potosi state that use fuelwood as the principally energy source and 2) People living in the city of San Luis Potosi that use gas LP as the principally energy source. As expected the levels of 1-OHP in urine were higher in people that use fuelwood (table 6).

Community	Characteristics
Victoria, Chiapas	Rural community with fuelwood combustion
Ventanilla, Oaxaca	Rural community with fuelwood combustion
Ramonal, Quintana Roo	Rural community with fuelwood combustion
Tancuime, SLP	Rural community with fuelwood combustion
San Vicente, SLP	Community with 50 brick kilns using different materials as fuel source
Milpillas, SLP	Community living next to municipal landfill in the city of San Luis Potosí
Tercera, SLP	Community with 75 brick kilns using different materials as fuel source
Domingo, SLP	Community in San Luis Potosí state exposed to heavy vehicular traffic
Centro, SLP	Urban community in the city of San Luis Potosí with moderate vehicular traffic

Table 3. Characteristics of studied sites

Residential Group	Mean ± SD 1-OHP (µmol/mol creatinine)
moderate vehicular traffic	0.08 ± 0.2
heavy vehicular traffic	0.20 ± 0.2
fumes from a municipal landfill	0.30 ± 0.4
fumes from brick kiln	0.35 ± 0.3
indoor air pollution by biomass combustion	2.26 ± 2.8

Table 4. Urine concentrations of 1-OHP in children by exposure scenario in México.

4. Health effects associated with indoor air pollution

The adverse effects on respiratory health of products of incomplete solid-fuel combustion are summarized in Table 7, which also includes some of the known or proposed mechanisms of damage. Exposure to solid fuel smoke can be lifelong, beginning before birth and early infancy, and continuing during adulthood, especially in women, who are traditionally charged with the task of cooking. Exposure is longer in cold communities that require fire-related heating, and may adversely impact lung growth and development, both directly and through an increase in lung infections. Indoor air pollution from indoor burning of solid fuels has been associated with an increased risk of several diseases and health conditions (Table 7). In general, studies are scarce, and show varied health outcomes. Moreover, they commonly lack a quantitative exposure assessment, and rely instead on qualitative or semi-quantitative indicators, such as the use of open fire indoors. The amount of time that children and/or women spend in proximity to fires is the crucial determinant of the health impact of indoor air pollution (Barnes et al. 2005). For other health outcomes, the adverse effects of exposure to solid fuel smoke from coal or biomass is expected, as from exposure to tobacco smoke, but information is lacking or scarce about other consequences such as low birth weight and adverse perinatal outcomes (stillbirth), among others (WHO, 2007) For example, biomass smoke in Guatemalan women has been shown to increase diastolic blood pressure (McCracken et al. 2007) According to World Health Organization estimates, worldwide exposure to solid fuel smoke produces 1.6 million deaths yearly, 693 000 due to COPD and 910 000 due to acute lower respiratory infections (ALRI), as well as 38.5 million disability adjusted life years (DALYs), most due to ALRI, being the eighth overall cause of DALYs in the world and the eleventh cause of death (Smith et al. 2004). This is likely an underestimation, as only diseases with a strong evidence base, i.e., COPD, ALRI, and lung cancer from coal burning, are considered.

Residential Group	**<0.24 μmol/mol creatinine (%)**	**0.24-1.39 μmol/mol creatinine (%)**	**1.4-2.3 μmol/mol creatinine (%)**	**>2.3 μmol/mol creatinine (%)**
moderate vehicular traffic	95.0	5.0	0.0	0.0
heavy vehicular traffic	53.0	47.0	0.0	0.0
fumes from a municipal landfill	66.0	32.0	2.0	0.0
fumes from brick kiln	51	47.0	2.0	0.0
indoor air pollution by biomass combustion	7.0	14.0	25.0	54.0

Table 5. Percentage of children in each range of 1-OHP urinary levels.

Community	**Mean ± SD 1-OHP (μmol/mol creatinine)**
La Huasteca in San Luis Potosi state	3.97 ± 5.51
City of San Luis Potosí	0.44 ± 0.70

Table 6. Urine concentrations of 1-OHP in women (aged 15-50 years) in San Luis Potosi state.

In México information regarding health effects associated with indoor air pollution is scarce. However, in a study conducted in the rural village of Solis, composed of 13 small communities, located 200 km northwest of Mexico City and at an elevation of 2,600 m above sea level. Women in Solis have cooked with wood, crop residues, and corn cobs as fuel, but now some of them also use natural gas either alone or supplemented with biomass fuel. When compared with those cooking with gas, current use of a stove burning biomass fuel was associated with increased reporting of phlegm (27 vs. 9%) and reduced FEV1/FVC (79.9 vs. 82.8%). Levels of FEV1 were 81 ml lower and cough wasmore common (odds ratio, 1.7;

95% confidence interval, 1.0–2.8) in women from homes with higher PM10 concentrations. All women found with moderate airflow obstruction were cooking with biomass stoves (Regalado et al. 2006). Similar results were found by Romieu et al. 2009.

In order to study other health effects associated with indoor air pollution, our group evaluated blood carboxyhemoglobin (% COHb) and DNA damage in blood cells (with comet assay) in a community in San Luis Potosi state exposed to wood smoke (Torres-Dosal et al. 2008). Since carbon monoxide (CO) is probably the most important single contaminant emitted during combustion of wood (Viau et al., 2000), A marker use to indirectly assess CO exposure is carboxyhemoglobin (COHb) that reflects binding of CO to the hem portion of hemoglobin. A concentration of COHb <2.5% is currently considered safe (Kleinman, 2000). The lowest level of COHb, at which adverse effects are observed, ranges from 2.9 to 3% (Estrella et al., 2005). Moreover, COHb concentrations >5% are associated with effects, such as neurobehavioral function, impaired visual function, task performance, and maintaining alertness (WHO, 1999; EPA, 2000; Raub and Benignus, 2002). All studied individuals had a geometric mean COHb level of 4.93% and 55% of those people presented COHb levels above 2.5% considered a safe level. While, DNA damage in people exposed was 5.8 ± 1.3 of Tail Moment. In this study also was monitored 1-OHP in studied individuals and significant positive correlation was obtained between urinary 1-OHP and DNA damage in blood cells. Our data suggest that DNA damage in lymphocytes is at least partially related to exposure to wood smoke, as a relationship was found between DNA damage in lymphocytes and levels of 1-OHP in urine of people studied (Table 8).

Compound	Potential health effect
Breathable particulate matter	Wheezing, exacerbation of asthma, respiratory infections, chronic bronchitis, and chronic obstructive pulmonary disease.
Carbon monoxide	Low birth weight, increase in perinatal deaths
Polycyclic aromatic hydrocarbons	Lung cancer, cancer of mouth, nasopharynx and larynx.
Nitrogen oxides	Wheezing, exacerbation of asthma, respiratory infections, reduced lung functions in children.
Sulphur oxides	Wheezing, exacerbation of asthma, Exacerbation of chronic obstructive pulmonary disease, cardiovascular disease.

Table 7. Adverse effects on respiratory health associated with indoor air pollution

5. Interventions programs

Far from a relatively simple problem with fixed technical solutions, the ''biofuel problématique'' in developing countries has turned out to be a very complex issue with multiple implications. The patterns of household biofuel use are very heterogeneous, as are also the people, the environment and the cultures that depend on these fuels to solve their essential cooking needs. The uses of energy in the home—for example, for cooking and keeping warm and as a focus of social activities—have important attributes that are specific to the locality, culture, and individual households and are often associated with established traditions and deeply held beliefs. Encouraging the use of cleaner and more efficient energy technologies by populations that are among the poorest in the world has not been easy, but recent years have seen progress being made with respect to suitable technology that meets the needs of households and with respect to the development of supportive policy.

There is limited experience with improved wood-burning cookstove programs in Mexico (Olguín, 1994; Arias and Cervantes, 1994; Navia, 1992; Dutt et al., 1989). The government launched a large-scale effort at the beginning of the ’80s, with poor results, and basically abandoned the field (Vargas, 1990). In recent years, a number of initiatives have been started in different regions of Mexico, particularly within the states of Michoacan, Chiapas, Oaxaca and San Luis Potosí, working with a diversity of stove designs and dissemination schemes (RETA, 2004; Cayetano, 1997). Most groups still work with massive Lorena-type improved stoves, but there are groups now disseminating ‘‘Justa’’ and portable ‘‘Rocket’’ stoves in southern Mexico. Most of the improved cookstove programs are local (village- level) or micro-regional in scope, they are generally part of larger initiatives directed at restoration of local forests or conservation of biodiversity, or they are part of the portfolio of well-established peasant organizations. Efforts are still concentrated on the construction of stoves with little or no follow-up; stoves are entirely or mostly subsidized; there is still emphasis on stoves being constructed by users themselves. Some institutions promoting these stove programs have become more aware of users’ priorities and needs, resulting in higher stove acceptance rates.

	Before program intervention	**After program intervention**
% COHb (mean ± SD)	4.9 ± 4.3	1.0 ± 0.2
1-OHP (µmol/mol creatinine; mean ± SD)	6.7 ± 3.6	4.8 ± 3.3
Tail moment (comet assay; mean ± SD)	5.8 ± 1.2	2.4 ± 1.3

Table 8. A risk reduction program using biomarkers of exposure (COHb and 1-OHP) and a biomarker of effect (DNA damage).

In this regard, several intervention programs have been implemented. For example, the Grupo Interdisciplinario de Tecnología Rural Apropiada (GIRA) has recently disseminated 4,000 improved Patsari cookstoves, most of them in the Purépecha region of Michoacán state, Mexico. In paired comparisons in a subset of kitchens in a single community before and after installation of an improved Patsari cookstove, 48-hour average kitchen concentrations of carbon monoxide (CO) and fine particulate matter (PM2.5) were reduced by 66 % (n = 32) and 67 % (n = 33), respectively (Masera et al. 2007). The results are excitants; however health concerns are now a major focus of the new initiatives. A randomized study was conducted in the Central Mexican state of Michoacan. Households were randomized to receive the Patsari stove or keep their traditional open fire. A total of 552 women were followed with monthly visits over 10 months to assess stove use, inquire about respiratory and other symptoms, and obtain lung function measurements. Women who reported using the Patsari stove most of the time compared with those using the open fire had significantly lower risk of respiratory symptoms (relative risk [RR], 0.77; 95%confidence interval [CI], 0.62–0.95 for cough and RR, 0.29; 95% CI, 0.11–0.77 for wheezing) adjusted for confounders. Similar results were found for other respiratory symptoms as well as for eye discomfort, headache, and back pain (Romieu et al 2009). Our group performed a study to evaluate a risk reduction program using biomarkers of exposure (COHb and 1-OHP) and a biomarker of effect (DNA damage) in a community in San Luis Potosí state. An initial census survey of the study area was used to identify homes with open fires stoves, indoor soot adhered to roofs and internal walls and dirt floors. Thus, for the intervention we offered 1) removal of indoor soot adhered to roofs and internal walls, 2) paving dirt floors, and 3) an improved stove (the Patzari stove),which is constructed using sand, clay and cement; it also has a metal chimney that expels the smoke outdoors (Masera et al., 2007; Figure 5). The complete 3-stage risk reduction program was applied in all houses studied. We applied a questionnaire to confirm that the improved stove was well accepted by people in the community. The program was introduced in ten indigenous houses during August 2005; we assessed exposure to carbon monoxide, PAHs (1-OHP) and DNA damage previously and one month after the intervention program. Table 8 shows the geometric mean COHb level in all subjects studied before and after intervention. Before intervention all individuals had a geometric mean COHb level of 4.93% and 55% of those people presented COHb levels above 2.5% considered a safe level. Moreover, this 55% of people had geometric mean COHb levels of 8.39%. However, in all the studied individuals the levels of COHb were reduced to below 2.5% (mean level 1.0%) one month after intervention. Urinary 1-OHP was used to assess the exposure to PAHs (Table 8). Results show that the geometric mean level of 1-OHP before intervention was significantly higher in studied people (6.71±3.58 μmol/molCr) than after the program (4.80±3.29 μmol/ mol Cr). The amount of DNA damage in the studied people is depicted in Table 8. When compared, DNA damage in people exposed before the intervention was higher (5.8±1.3 of Tail Moment) than when the program was introduced (2.8±0.9 of Tail Moment). When the studied population was divided by gender or age groups, we did not observe differences in Tail Moment. Usually, risk reduction programs for indoor air pollution caused by biomass combustion only include the installation of a stove with a chimney (Chapman et al., 2005; Smith-Sivertsen et al., 2004; Khushk et al., 2005; Naeher et al., 2000). Those programs were evaluated either through a decrease of indoor air pollution (Riojas-Rodriguez et al., 2001; Naeher et al., 2000; Khushk et al., 2005; Zuk et al., 2007) and/or by a reduction in the incidence of diseases related with this kind of contamination (Riojas-Rodriguez, et al., 2001; Chapman et al., 2005; Boy et al., 2000; Smith-Sivertsen et al., 2004). We believe that our study represents an improvement in this area, as we installed a stove with a metal chimney that expels smoke outdoors, but also indoor soot adhering to roofs and internal walls was removed, and dirt floors were paved (it has been shown that biomass burning might be the major origin of PAHs in rural soil; Zhang et al., 2006). It is important to mention that soot is a sink of several chemicals generated during combustion (Jonker and Koelmans, 2002a, 2002b) and moreover, an extremely slow desorption of PAHs from soot has been demonstrated (Jonker et al., 2005). Therefore, although we do not have information regarding the importance of each stage in risk reduction, the elimination of soot sources (in roofs, walls and dirt floor) is a relevant action considering that this material is a sink of hydrophobic compounds such as PAHs and Dioxins. Children and adults can be exposed to this material, by inhalation (indoor air particles), ingestion (dust particles) or direct dermal exposure. This work was a pilot study and although with the limitation in sample size, the improvement in exposure (1-0HP, and COHb) and effect (comet assay) was so homogeneous that the State Government of San Luis Potosi, using the precautionary principle has expanded the program to different communities. We are following our studies in these sites.

Cookstove dissemination programs are evolving from ''projects'' narrowly targeting stove construction and fuelwood savings to more integrated ''program'' approaches looking at providing a set of health, environmental and socio-economic benefits. For them to be successful, systemic and interdisciplinary approaches are needed, including work on technology innovation, users' needs and priorities, market development and innovative financing. Strong and sustained efforts need to be devoted to monitoring stove performance in the field and to ensure the sustainability of the achieved benefits. Being more complex and ambitious, the new approaches come with a new set of challenges. More than ever, an intense cross-fertilization among groups, both North-South and South-South, is urgently needed. Donors and governments need to realize that sustained and longterm efforts rather than the typical two- to three-year projects are needed for setting up the type of integrated approaches described above. There is a need to support continuous technology innovation, getting research institutions to work hand in hand with local organizations on new stove designs that are more robust, cost-effective and clean. Participatory research is also needed to better understand users' priorities and needs and also to better assess the dynamics of multiple fuel use. Innovative and creative financial mechanisms are required that help users

Fig. 5. Patsari wood-burning cookstove.

overcome the investment costs of improved cookstoves. Users – specifically women -- need to have a strong say in program design and implementation. Finally, to be successful in the medium and long term, cookstove programs need to look at the overall policy context and integrate cookstove programs within larger sustainable rural development strategies. The challenge is substantial, but fostering the current partnership and networks on household energy use and learning from each other's experience will surely pave the way to a larger number of success stories in the near future.

Characteristics of Patsari stoves: The Patsari is oriented to mass dissemination; it is built with the help of a mould, and includes several custom-made pieces. The size and geometry of the combustion chamber (primary furnace), the tunnels and the secondary furnaces are designed to increase heat transfer to the pot. Metal flat pans (or comales) are tightly adjusted to the furnaces to prevent smoke leakage. The stove comes with a metal chimney, which is inserted into the stove body with the help of a custom-made metal base built in the stove. Currently, two models of Patsari, one with a single entry for fuelwood and a second with two entries, are being disseminated. In the latter case, both a ceramic comal and a metal comal are used in the primary furnaces (Figure 6).

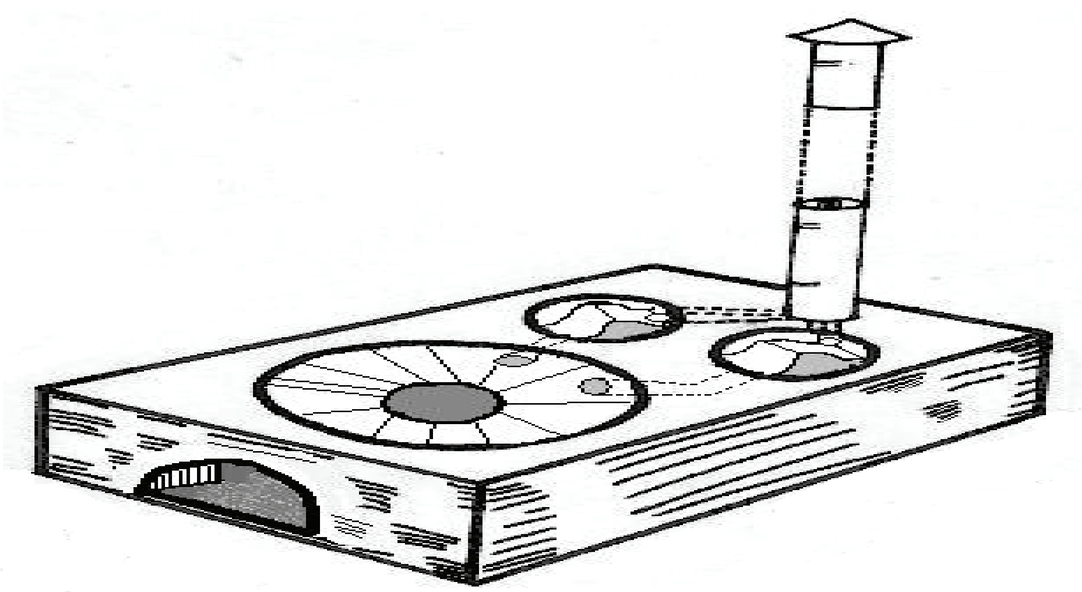


Fig. 6. Design of Patsari wood-burning cookstove.

6. Conclusion

Indoor pollution will continue to be an essential field for health studies and interventions, because exposure to varied indoor substances will likely increase in coming years. Better studies dealing with genetic susceptibility to indoor pollutants, their carcinogenic effect and their impact on lung growth, lung development and, later on, lung aging, are also required. To answer several of these questions, longitudinal studies are required. A formal evaluation of improved stove programs from many viewpoints is also essential to improve guidance for countries and communities as they implement their own programs. Although local adaptation of programs will always be required, improved biomass stoves will likely be more common, with better community acceptance, reduced burden on forests, and increased spare time for homemakers.

7. Reference

Albalak, R. (2001). Indoor respirable particulate matter concentrations from an open fire, improved cookstove, and LPG/open fire combination in a rural Guatemalan community. Environ Sci Technol. 35:2650–5.

Arias, T.; & Cervantes, V. (1994). Las estufas de barro ahorradoras de leña ¿Una tecnología apropiada para la región de la Montaña de Guerrero?, Programa de Aprovechamiento Integral de Recursos (PAIR)-UNAM, México.

Barnes, B.; Mathee, A.; & Moiloa, K. (2005). Assessing child time-activity patterns in relation to indoor cooking fires in developing countries: a methodological comparison. Int J Hyg Environ Health. 208: 219–225.

Behera, D.; Dash, S.; & Malik, S. (1988). "Blood Carboxyhaemoglobin Levels Following Acute Exposure to Smoke of Biomass Fuel." Indian Journal of Medical Research 88: 522–524.

Boy, E.; Bruce, N.; Smith, K.R.; & Delgado, H. (2000). Fuel efficiency of an improved wood-burning stove in rural Guatemala: implication for health, environment and development. Energy Sustain Dev. 2:21–29.

Brauer, M.; Bartlett, K.; Regalado-Pineda, J.; & Pérez-Padilla, R. (1996). Assessment of particulate concentrations from domestic biomass combustion in rural Mexico. Environ.Sci. Tech, 30(1): 104-109.

Bruce, N.; Pérez-Padilla, R.; & Albalak, R. (2000). ''Indoor air pollution in developing countries: a major environmental and public health challenge''. Bulletin of the World Health Organization, 78(9): 1078-1092.

Bruce, N. G.; Bates E.; Nguti, R.; Gitonga, S.; Kithinji, J.; & Doig, A. (2002). "Reducing Indoor Air Pollution through Participatory Development in Rural Kenya." In Proceedings of 9th International Conference on Indoor Air Quality and Climate, Monterey, CA, 590–95.

Cayetano, H. (1997). Curso taller de promoción y construcción de estufas rurales en la comunidad de Santa Cecilia Lalana, Asesoría Técnica a Comunidades Oaxaqueñas (ASETECO), Oaxaca, Oax., Mexico.

Chapman, R.S.; He, X.; Blair, A.E.; & Lan, Q. (2005). Improvement in household stoves and risk of chronic obstructive pulmonary disease in Xuanwei, China: retrospective cohort study. BMJ. 331:1050–1056.

Dutt, G.S.; Navia, J.; & Sheinbaum, C. (1989). Cheranátzicurin: tecnología apropiada para cocinar con leña. Ciencias. 15: 43-47.

EPA, U. S. Environmental Protection Agency. (2000). Air quality criteria for carbon monoxide. EPA 600/P-99/001F. Washington, D.C. Office of Research and Development, U. S. Environmental Protection Agency.

Estrella, B.; Estrella, R.; Oviedo, J.; Narváez, X.; Reyes, M.T.; Gutiérrez, M.; & Naumova, E.N. (2005). Acute respiratory diseases and carboxyhemoglobin status in school children of Quito, Ecuador. Environ Health Perspect. 113:607–611.

Jacob, J.; & Seidel, A. (2002). Biomonitoring of polycyclic aromatic hydrocarbons in human urine. J Chromatogr B Analyt Technol Biomed Life Sci 778:31–47.

Jenkins, BM.; Jones, A.D.; Turn, S.Q.; & Williams, R.B. (1996). Emission factors for polycyclic aromatic hydrocarbons from biomass burning. Environ Sci Technol. 30:2462–2469.

Jongeneelen, F.J. (2001) Benchmark guideline for urinary 1-hydroxypyrene as biomarker of occupational exposure to polycyclic aromatic hydrocarbons. Ann Occup Hyg. 45:3–13

Jonker, MT.; Hawthorne, S.B.; & Koelmans, A.A. (2005). Extremely slowly desorbing polycyclic aromatic hydrocarbons from soot and soot-like materials: evidence by supercritical fluid extraction. Environ Sci Techno. 39: 7889–7895.

Jonker, M.T.; & Koelmans, A.A. (2002a) Sorption of polycyclic aromatic hydrocarbons and polychlorinated biphenyls to soot and soot-like materials in the aqueous environment: mechanistic considerations. Environ Sci Technol. 36: 3725–3734.

Jonker, M.T.; & Koelmans, A.A. (2002b). Extraction of polycyclic aromatic hydrocarbons from soot and sediment: solvent evaluation and implications for sorption mechanism. Environ Sci Technol. 36: 4107–4113.

Khushk, W.A.; Fatmi, Z.; White, F.; & Kadir, M.M. (2005). Health and social impacts of improved stoves on rural women: a pilot intervention in Sindh, Pakistan. Indoor Air. 15: 311–316.

Kleinman, M.T. (2000). Carbon monoxide: evaluation of current California air quality standards with respect to protection of children. Prepared for California Air Resources Board, California Office of Environmental Health Hazard Assessment. Irvine, CA: University of California Irvine; [Departament of Community and Environmental Medicine].

Levine, J.O. (1995). First international workshop on hydroxypyrene as a biomarker for PAHexposure inman—summary and conclusions. Sci Total Environ. 163:164–168.

McCracken, J.P.; Smith, K.R.; Diaz, A.; Mittleman, M.A.; & Schwartz J. (2007). Chimney stove intervention to reduce long-term wood smoke exposure lowers blood pressure among Guatemalan women. Environ Health Perspect. 115: 996–1001.

Martínez-Salinas, R.I.; Leal, M.E.; Batres-Esquivel, L.E.; Domínguez-Cortinas, G.; Calderón, J.; Díaz-Barriga, F.; & Pérez-Maldonado, I.N. (2010). Exposure of children to polycyclic aromatic hydrocarbons in Mexico: assessment of multiple sources. Int Arch Occup Environ Health. 83:617–623.

Masera, O. (1996a). Deforestación y degradación forestal en México. Documentos de trabajo N°19, Grupo Intrediciplinario de Tecnología Rural Apropiada (GIRA A.C.) Pátzcuaro, México.

Masera, O. (1996b). Uso y Conservación de Energía en el Sector Rural: El caso de la leña. Documentos de Trabajo N°21, Grupo Interdisciplinario de Tecnología Rural Apropiada (GIRA A.C.). Pátzcuaro, México.

Masera, O.; Navia, J.; Arias, T.; & Riegelhaupt, E. (1997). Patrones de Consumo de Leña en Tres Micro-regiones de México: Síntesis de Resultados. Proyecto FAO/MEX/TCP/4553(A). Grupo Intrediciplinario de Tecnología Rural Apropiada (GIRA A.C.). Pátzcuaro, México.

Masera, O.R; Drigo, R.; & Trossero, M.A. (2003). Woodfuels integrated supply/demand overview mapping. Universidad Autónoma de México, FAO-EC Partnership Programme. Food and Agriculture Organization of the United Nations.

Masera, O.; Edwards, R.; Armendáriz-Arnez, C.; Burrueta, V.; Johnson, M.; Rojas-Bracho, L.; Riojas-Rodríguez H.; & Smith, KR. (2007). Impact of Patsari improved cookstove on indoor air quality in Michoacán, México. Energy Sustain Dev. 9:25–36.

Mcdonald, J.D.; Zielinska, B.; Fujita, E.M.; Sagebiel, J.C.; Chow, J.C.; & Watson, J,G. (2000). Fine particle and gaseous emission rates from residential wood combustion. Environ Sci Technol. 34:2080–2091.

Mishra, V. (2003). Effect of indoor air pollution from biomass combustion on prevalence of asthma in the elderly. Environ Health Perspect. 111:71–78.

Naeher, L.P.; Smith, K.R.; Leaderer, B.P.; Mage, D.; & Grajeda, R. (2000). Indoor and outdoor PM2.5 and CO in high- and low-density Guatemalan villages. J Expo Anal Environ Epidemiol. 10: 544–551.

Navia, J. (1992). Estufas mejoradas, programa de difusión en Cheran Atzícurin, Primera Reunión Internacional sobre energía y medio ambiente en el sector residencial mexicano, comp. J. Quintanilla.

Olguín, E. (1994). 'Evaluación y optimización del uso de la leña a nivel familiar y de pequeñas industrias rurales. Instituto de Ecología, A.C. Jalapa, Veracruz, Mexico.

Raub, J.A.; & Benignus, V.A. (2002). Carbon monoxide and the nervous system.Neurosci Biobehav Rev. 26:925–940.

Red de Tecnologías Apropiadas (RETA). (2004). Memorias del Taller de Intercambio de experiencias sobre estufas ahorradoras de leña, San Cristóbal de Las Casas, Chiapas, México, 11 pp.

Reddy, AKN.; Williams, RH.; Johansson TB. (1997) Energy after Rio: prospects and challenges. New York: United Nations Development Programme.

Regalado, J.; Perez-Padilla, R.; Sansores, R.; Paramo Ramirez, J.I.; Brauer, M.; Pare, P.; & Vedal, S. (2006). The Effect of Biomass Burning on Respiratory Symptoms and Lung Function in Rural Mexican Women. Am. J. Resp. Crit. Care Med. 174: 901-905.

Riojas, R.H.; Romano, P.; Santosburgoa, C.; &Smith, K.R. (2001). Household firewood use and the health of children and women of Indian communities in Chiapas, México. Int J Occup Environ Health, 7(1): 44-53.

Romieu I.; Riojas-Rodrıguez, H.; Marron-Mares, A.T.; Schilmann, A.; Perez-Padilla, R. & Masera, O. (2009). Improved Biomass Stove Intervention in Rural Mexico. Impact on the Respiratory Health of Women. Am. J. Resp. Crit. Care Med. 180: 649-656.

Saksena, S.; Thompson, L.; & Smith, K.R. (2004). "Indoor Air Pollution and Exposure Database: Household Measurements in Developing Countries." http://ehs.sph.berkeley.edu/hem/page.asp?id=33.

Secretaría de Energía (SE). (1998). Balance Nacional de Energía. Gobierno de México, Secretaría de Energía, México D.F.

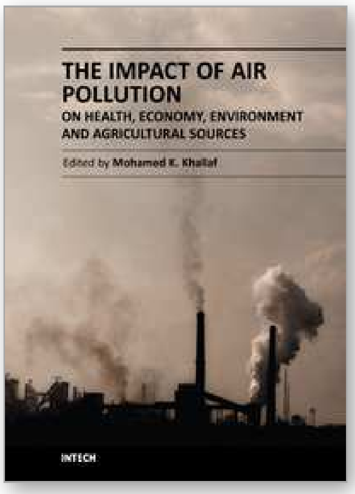
Secretariat of Health in Mexico (SSA). (2005). Children Health and the Environment in North America. A First Report on Aviable Indicators and Measures.

Available in http://www.cec.org/Storage/27/1802_CountryReport-Mexico-CHE_en.pdf. Accessed on 18-03-2011.

Smith KR. (1987). Biofuels, air pollution, and health: a global review. New York: Plenum Press.

Smith, K.; Mehta, S.; & Maeusezahl-Feuz, M. (2004). Indoor air pollution from household use of solid fuels. In: Ezzati M, Lopez A, Rodgers A, Murray C, eds. Comparative quantifi cation of health risks. Global and regional burden of disease attributable to s elected major risk factors. Geneva, Switzerland: World Health Organization. pp 1435–1493.

Smith-Sivertsen, T.; Diaz, E.; Bruce, N.; Diaz, A.; Khalakdina, A.; Schei, M.A. et al. (2004). Reducing indoor air pollution with a randomized intervention design—a presentation of the stove intervention study in the Guatemala Highlands. Nor Epidemiol. 14: 137–143.
Saatkamp, B.D.; Masera, O.; & Kammen, D.M. (1999). Energy and health transitions in development: fuel use, stove technology, and morbidity in Jarácuaro, Mexico. Energy for Sustainable Development. IV(2): 7-16.
Torres-Dosal A, Pérez-Maldonado IN, Jasso-Pineda Y, Martínez Salinas RI, Alegría-Torres JA, Díaz-Barriga F (2008) Indoor air pollution in a Mexican indigenous community: evaluation of risk reduction program using biomarkers of exposure and eVect. Sci Total Environ 390:362–368
Vargas, F. (1990). Breve diagnóstico sobre el proyecto de estufas rurales en México, Secretaria de Agricultura y Recursos Hidraúlicos (SARH), Mecanografiado, 8 pp.
Viau, C.; Hakizimana, M.; & Bouchard, M. (2000). Indoor exposure to polycyclic aromatic hydrocarbons and carbon monoxide in traditional houses in Burundi. Int Arch Occup Environ Health. 73:331–338.
World Health Organization. (WHO. 1997). Health and environment in sustainable development. Geneva, Switzerland: World Health Organization.
World Health Organization. (WHO. 1999). Environmental health criteria 213, carbon monoxide. IPCS, International Programme on Chemical Safety. Second Ed.Geneva, Switzerland: World Health Organization; 1999.
World Health Organization. (WHO. 2007). Indoor air pollution from solid fuels and risk of low birth weight and stillbirth: report from a symposium held at the Annual Conference of the International Society for Environmental Epidemiology (ISEE), September 2005, Johannesburg. Geneva, Switzerland.
Zhang, J. (1999). Smith KR. Emissions of carbonyl compounds from various cookstoves in China. Environ Sci Technol. 33:2311–2320.
Zhang, H.B.; Luo, Y.M.; Wong, M.H.; Zhao, Q.G.; & Zhang, G.L. (2006). Distribution and concentrations of PAHs in Hong Kong soils. Environ Pollut. 141:107–114.
Zhao, Z.H.; Quan,W.Y.; Tian, D.H. (1992). The relationship between polynuclear aromatic hydrocarbons in ambient air and 1-hydroxypyrene in human urine. J Environ Sci Health. A27:1949–1966.
Zuk, M.; Rojas, L.; Blanco, S.; Serrano, P.; Cruz, J.; Angeles, F.; Tzintzun, G.; Armendariz, C.; Edwards, R.D.; Johnson, M.; Riojas-Rodriguez, H.; Masera, O. (2007). The impact of improved wood-burning stoves on fine particulate matter concentrations in rural Mexican homes. J Expo Sci Environ Epidemiol. 17:224–232.



The Impact of Air Pollution on Health, Economy, Environment and Agricultural Sources
Edited by Dr. Mohamed Khallaf

ISBN 978-953-307-528-0
Hard cover, 444 pages
Publisher InTech
Published online 26, September, 2011
Published in print edition September, 2011

This book aims to strengthen the knowledge base dealing with Air Pollution. The book consists of 21 chapters dealing with Air Pollution and its effects in the fields of Health, Environment, Economy and Agricultural Sources. It is divided into four sections. The first one deals with effect of air pollution on health and human body organs. The second section includes the Impact of air pollution on plants and agricultural sources and methods of resistance. The third section includes environmental changes, geographic and climatic conditions due to air pollution. The fourth section includes case studies concerning of the impact of air pollution in the economy and development goals, such as, indoor air pollution in México, indoor air pollution and millennium development goals in Bangladesh, epidemiologic and economic impact of natural gas on indoor air pollution in Colombia and economic growth and air pollution in Iran during development programs. In this book the authors explain the definition of air pollution, the most important pollutants and their different sources and effects on humans and various fields of life. The authors offer different solutions to the problems resulting from air pollution.