WORLD RESOURCES INSTITUTE

ENVIRONMENTAL HEALTH NOTES

HEALTH, ENVIRONMENT AND DEVELOPMENT PROGRAM

# URBAN AIR POLLUTION RISKS TO CHILDREN: A GLOBAL ENVIRONMENTAL HEALTH INDICATOR

Principal authors: Devra L. Davis, Ph.D., M.P.H., (devra@wri.org) Paulo H. N. Saldiva, M.D., Ph.D.

Contributing authors: A. Karim Ahmed, Ph.D., World Resources Institute, Joya Carreira, M.D., Simone Miraglia, M.S., University of Sao Paulo, Brazil, Ruchi Bandhari, M.A., M.B.A., Robin White, Ph.D., World Resources Institute, Nasir Khattak, M.S., Climate Institute, Changhua Wu, M.A., World Resources Institute, Shouzheng Xue, M.D., Shanghai Medical University, Bingheng Chen, M.D., School of Public Health, Shanghai Medical University, Charles Schmidt, M.S., Miranda Loh, B.A., World Resources Institute.

*Summary: This report assesses risks to children from urban outdoor air pollution based on 1993-95 levels. An earlier version of this analysis was presented to the annual meeting of the American Association for the Advancement of Science, in Anaheim, California, in January, 1999, and included 207 cities with a population over 1 million in 53 countries weighted for three air pollutants - Total Suspended Particulates (TSP), sulfur dioxide ($SO_2$), and nitrogen dioxide ($NO_2$). This report focuses on cities with a population over 9 million for which data were available. In order to assist policy makers in identifying priority areas for intervention, we present two distinct analyses: 1.) Cities with populations over 9 million—megacities— are ranked in terms of the annual average levels of three different pollutants; 2.) Megacities are identified where the greatest number of children face the highest risks from these 3 pollutants combined. Since 1995, a number of cities have substantially reduced their air pollution levels. As these areas continue to develop, comprehensive and accurate air quality monitoring and information management systems need to be implemented. It is now widely understood that the same activities that contribute to local and regional air pollution also threaten our climate and weather by producing persistent greenhouse gases. In this regard, adopting policies to mitigate the build up of these gases can also reduce health risks from pollution. Near term efforts to promote energy efficiency, especially in rapidly growing transport and energy sectors, will have collateral benefits of protecting the health of millions of children, and will also reduce the buildup of greenhouse gases in the long term.*

## I. INTRODUCTION

Most of the world's children today are growing up in rapidly expanding urban areas in the developing world where they regularly breathe dirty air. Each year, levels of air pollutants in these cities are often two to eight times above the recommended World Health Organization maximum guideline levels (WHO, 1995). As many as 85 percent of all children under the age of 15 live in developing countries, and roughly half of them live in cities (Cutter, 1995). The widespread exposure of large numbers of children to heavily polluted air in developing countries has skyrocketed and is a relatively new public health issue. Massive and unprecedented migrations of populations from rural to urban areas in the past few decades are fueling urban growth worldwide. In much of the developing world, more people now live in expanding urban and industrial zones than at any other time in history.

While generally associated with social and economic benefits, the growth of industries and cities is often accompanied by a serious degradation in air quality. The combination of poorly controlled industrial emissions and automobile exhausts has resulted in dangerously high levels of air pollution in many urban areas. When not well managed, development can also greatly increase exposures to potentially hazardous materials.

## Environmental Health Indicators

If societies are to move beyond the rhetoric of sustainable development, they must devise useful and clear systems for gauging progress and assessing current and future prospects. The tremendous growth of computerized information systems has generated new sources of material, which make it possible to assess and disseminate data on health and the environment in a way that was unimaginable a few years ago. A variety of metrics or indicators has been proposed for evaluating social policies and overall economic growth.

Over the past decade, World Resources Institute has pioneered in developing systems for assessing threats to both coastal and urban environments (Hammond et al., 1998). This report builds upon that work by assembling and displaying information from 1993-1995 on the risks of air pollution to children as an environmental health indicator (EHI). EHIs provide tools for decision and policy-makers that can be applied for gauging progress in environmental health, setting cross-sectoral priorities, and establishing goals for research and regulatory action. EHI is a concept elaborated recently by the World Health Organization, the Environmental Health Project of U.S. Agency for International Development, the U.S. Environmental Protection Agency, the World Resources Institute and researchers at several major international public health schools (WHO, 1996). Two basic types of environmental health indicators can be created:

* Exposure-based indicators estimate the percentage of the population potentially or actually exposed to physical, chemical, or biological pollutants, or other conditions known or suspected to affect health. These exposures are compared to existing standards expressed in compatible units, where feasible.

* Health or outcome-based indicators assess patterns in time and space of diseases which are either not known to be explained by established risk factors or are believed to result from environmental conditions.

## Developing Indicators of Air Pollution

How bad is air pollution today in cities? This depends on both the concentrations of the various pollutants and the sizes and vulnerability of populations generally exposed. In order to provide a systematic way of assessing the risks of air pollution for children throughout the world in major urban areas, we have combined information from 1993-1995 on yearly average levels of three commonly measured pollutants—Total Suspended Particulates (TSP), nitrogen dioxide ($NO_2$) and sulfur dioxide ($SO_2$).

This report assesses and compares the proportion of the population under age 5 in cities with populations of 9 million or more where levels of these three air pollutants exceed the WHO or EU guidelines (WHO, EEA 1997) (WHO Guidelines were revised in 1998). EU guidelines are the same as WHO's, excepting those for TSP. To create this indicator, we amassed information from numerous international and national agencies, a number of different national statistical yearbooks and the World Health Organization's Air Monitoring Information System (WHO AMIS) (see Box 1). The proportion of children under age 5 in a country was used to estimate the population under five in each of the cities in that country. Please see references at the end of this report for a complete list of sources. More detailed information on this combined indicator can be obtained from the web sites, www.wri.org, www.who.org, and www.eea.eu.int.

## II. Indicator Pollutants–The Study

Overall, air pollution concentration data were collected from 207 cities and metropolitan regions in 53 countries that reported average yearly levels of the three air pollutants for at least one year between 1993 and 1995. These pollutants, TSP, $NO_2$, and $SO_2$, are representative of the total burden of urban air pollution. Because data are not uniformly available, we did not include estimates of indoor air pollution or a number of important compounds, such as heavy metals, carbon monoxide, ozone and volatile organic compounds (see Box 2). We used the WHO annual guidelines in 1995 for $NO_2$ and $SO_2$ and the EU guideline for TSP, because WHO did

## Box 1 Difficulties Comparing Air Pollution Risks Among Cities

The indicator used in this study is based on average annual concentrations for each pollutant. We used data compiled from various sources, which obtained their data through differing means. Not all cities have the same number of monitoring sites, and not all sites are used in determining the annual concentration levels. For 1995, the World Health Organization's Air Monitoring Information System (WHO AMIS) uses five sites for Mexico City and three for Calcutta. Another database, such as OECD's, may use a different number of sites. Placement of the sites can have an impact on the resultant concentration average as some may be located in an area of higher pollution than others. The number of sites used and their location thus can cause discrepancies between two averages for the same pollutant and the same city for the same time, as evidenced by the following example:

In our examination of Mexico City, we encountered a substantial difference in average concentrations for 1994 data reported by the OECD, which we used in our comparative analysis, and the concentrations reported by the Mexican government for the same period. This difference arises from the fact that OECD used information gathered from five monitoring sites, and relied on peak values, whereas Mexico's averages provide annual estimates that come from 19 sites (26 for $SO_2$).

In Mexico, the government's automatic air quality monitoring network comprises 32 stations supported by 19 manual air monitoring stations. The city also provides hourly air quality information to the public through billboards sited next to major roads and radio stations. The monitoring network is verified by USEPA twice a year (Onursal and Gautam, 1997). Official data provided by the Mexico City Government (GDF) and by the National Institute of Ecology (INE/SEMARNAP) that includes all available monitoring stations in the Metropolitan Area, show the following annual averages of pollutants for 1995: $SO_2$ average of 26 monitoring stations 34.0 ug/m$^3$ (47.5 ug/m$^3$ the average of the station with the highest levels); $NO_2$ average of 19 monitoring stations 43.6 ug/m$^3$ (65.3 ug/m$^3$ the average of the highest station); TSP average of 19 stations 167 ug/m$^3$ (375 ug/m$^3$ the average of the highest station). Although these values are much lower than the ones used throughout the paper, the OECD and WHO data were employed in our analysis so that we would have a single, common source of information for all cities compared.

Because of these problems, the differences that arise in this analysis should be construed as qualitative indicators of the relative rankings of these cities, and should not be misconstrued as precise measures. The goal of this study is to identify high risk areas for which intervention will have the greatest effect in the shortest amount of time. (For more information on the sources of data used, please refer to the end of this report.)

---

not establish a value for particulate matter. Recently, WHO Europe issued a risk guideline for particulate matter of diameter 10 microns or smaller based on linear relationships between particulate concentrations and health effects. Air pollutants comprise a complex mixture of materials that can occur as both gases and particles. Some pollutants, such as TSP, a generic term used to describe airborne particles that vary in size, origin, and chemical composition, have the capacity to be buoyant over long distances and times, depending upon their size. TSP originates mainly from coal-fired power plants, although auto and diesel exhausts are also major contributors, especially in crowded urban areas.

More recent assessments have focused on the role of PM10 and PM2.5, particulate matter with an aerodynamic diameter of less than 10 and 2.5 microns, respectively. A single micron is 50 times smaller than a human hair. Typical fine air particulates (PM2.5) cannot be seen and are most hazardous to human health because they penetrate more deeply into the lung. Once there, some of these minute particles can remain highly reactive and cause a variety of respiratory problems (Wilson and Spengler, 1996). About 1.1 billion people around the world are exposed to high levels of TSP (Schwela, 1996).

Particles can attract to their surface a variety of volatile materials and heavy metals, such as lead, that enhance the toxicity of particulate matter. Fine particles, such as those found in smoke from the Indonesia and southern Mexico forest fires of 1998, can remain suspended in the air for days and even weeks, enabling them to cause health prob-

Table 1 Index Pollutants

| Air Pollutant | Sources | Adverse Affects | 1995 Annual Guidelines |
|---|---|---|---|
| Nitrogen Oxide | Automotive exhaust, gas stoves and heaters, by-product of burning fossil fuels | Respiratory tract damage and irritation, deaths | 50 ug/m$^3$ (WHO) |
| Sulfur Dioxide | Burning of fossil fuels in power plants, automotive exhausts, smelters, oil refineries and other industries | Worsening of asthma and other lung diseases, respiratory tract irritation, deaths | 50 ug/m$^3$ (WHO) |
| Total Suspended Particles | Burning of fossil fuels, natural and industrial dust and fumes, cigarettes | Respiratory tract damage and irritation, deaths | 80 ug/m$^3$ (EU) |

lems thousands of miles away. Ultra fine particles, smaller than half a micron, are believed to be quite toxic. The same physical properties that allow fine particles from fires to move great distances over long periods of time also permit them to be inhaled deeply into the lungs. Studies in experimental animals have found that only 3 days of exposure to concentrated amounts of particulate matter can kill rats that already have pneumonia or chemically damaged lungs. Healthy rats are not damaged by such exposure (Godleski et al., 1996).

$SO_2$, a product of fossil fuel combustion, is often found in association with airborne particulate matter. Because it causes a person's airways to constrict, $SO_2$ leads to a variety of respiratory ailments and aggravates pre-existing health conditions, such as asthma. Chronic exposure causes the mucus layer of the trachea to thicken, which may eventually lead to a reduction in the body's ability to remove foreign and infectious agents (Harte, 1991).

$NO_2$, a gaseous pollutant, is also critical to the formation of secondary particles and photochemical oxidants, which form smog and ozone. $NO_2$ levels tend to be elevated in regions where traffic density is high. This pollutant's effects on health include damage to the cells lining the lung, also contributing to greater difficulty in removing bacteria and other agents, thus increasing susceptibility to respiratory infections (Harte, 1991).

An active scientific debate continues to evolve about the precise mechanisms through which these air pollutants are linked to various health problems. Some studies indicate that the combined effects of these pollutants can be greater than merely additive; lung tissue damage from one pollutant can worsen effects of another (Hazucha et al., 1994). To address the implications of such cumulative harm, our indicator simply adds annual average levels of three selected pollutants.

## Changing Nature of Cities

In the 1950s, New York City was the only city in the world with a population greater than 10 million. By the turn of the century, more than 21 cities will be this size or greater, and 18 of them will be in the developing world, where urban growth is currently occurring about four times faster than that of rural areas (Cutter, 1995). The average age of the population in a great number of rapidly growing megacities in developing countries is under 16 years of age (WRI, 1998). High levels of air pollutants regularly occur in many urban zones, where development has progressed with little consideration for the need to control emissions.

Elevated pollution is not unique to the developing world. Developed countries have experienced life-threatening air pollution problems in the past — particularly during the industrial revolutions of the late nineteenth to mid-twentieth centuries. The mortality from the air inversions in Pennsylvania and London in the twentieth century illustrates the potential danger from pollution (see Box 3).

These lethal episodes in industrialized countries decades ago made clear that high levels of coal-based and other industrial air pollution can kill those who are vulnerable. However, they left uncharted the more difficult and important question of what regular, daily exposure to lower levels of polluted air mean for the health of the general population.

Recent studies have shown that chronic exposures to a number of common air pollutants can cause a variety of health problems, including increases in hospital admissions for respiratory problems, asthma, and impaired lung function (McMichael and Smith, 1999). WHO has determined that fine particulate pollution is responsible for 7 to 10 percent of all respiratory infections in European children, with the number rising to 21 percent in the most polluted cities (WHO, 1997).

Air pollution threatens public health in all regions of the world today, although the nature and extent of the risk varies. More developed regions continue to be faced with chronically elevated levels of some pollutants, especially in zones where traffic density is high or where poorly controlled coal is used to produce energy. The rate of pollution generated from transportation and energy has been much reduced, due to the expanded use of control technologies and increased efficiency. Despite this progress, levels of traffic-based pollutants in many regions often exceed WHO Guidelines (EEA, 1998). The developing world must contend with both newer hazards from growing traffic congestion, inefficient transportation and industrial systems, as well as older hazards linked with traditional energy and household patterns.

## Children at Increased Risk

No matter what the source, air pollution generally affects children more severely than adults. Already, air pollution in the developing world is responsible for at least 50 million cases of chronic cough in those under age 14 (World Bank, 1992). Respiratory disease is now the leading cause of death in children worldwide (WHO, 1997). As urbanization expands, more children will be exposed to hazardous pollutants in the air, driving the proportion with serious respiratory illness upward.

Children are at enhanced risk from air pollution for a number of important reasons. Physiologically, their organ systems continue to develop through their first few years of life.

### Box 2 Indoor Air Pollution

The indicator we devise does not assess air pollution from burning dirty fuels indoors, which remains a serious environmental hazard in many parts of the world for both urban and rural populations. A number of extensive and welcome changes such as the increased use of natural gas to reduce domestic coal burning in some urban areas - as is occurring in several large cities in China today - are improving the quality of indoor air. In many large cities today, no such progress is evident regarding the threat of polluted outdoor air, which continues to rise dramatically in the developing world.

Although monitoring information is often limited, data compiled by the World Health Organization indicate that indoor particulate concentrations are often found at levels 10 to 20 times higher than the WHO guidelines. Estimates produced by the WHO suggest that 2.5 million people including many children worldwide die annually from exposures to the combustion products of solid indoor fuels (WHO, 1997). Significant improvements in indoor air quality can be achieved by moving to cleaner and higher efficiency fuels, as well as to more efficient and renewable technologies. (Smith, 1996)

A child's lung, for example, grows most rapidly in the first two years of life (Nelson, 1996), and continues to grow until the late teen years. Developing organs can be extremely sensitive to the toxic effects of air pollutants. Children also tend to absorb pollutants more readily than adults, and retain them in the body for longer periods of time. Because they breathe at a higher rate than adults (both at rest and at play) children are exposed to greater levels of pollutants relative to their smaller body weight and are generally more sensitive to their effects (National Research Council, 1993) on a pound-for-pound basis. While the average active adult inhales about 10,000-20,000 liters of air per day, a 3-year-old child takes in twice the amount of an adult per unit body weight (WHO, EEA, 1997). That child therefore absorbs double the amount of pollutants for its weight than an adult. In a study of infant deaths in their first month of life and particulate air pollution in the US, those living in areas with greater PM10 exposure encounter a 45% higher risk of dying from respiratory illness than those living in less polluted areas (Woodruff, 1997).

## Box 3 History of Urban Air Pollution

In the autumn of 1948, a stagnant mass of heavily polluted air in Donora, Pennsylvania, a small steel town in the Monongahela Valley, caused 20 excess deaths in one week. Hills surrounding the town trapped hot factory fumes in a thermal inversion that sickened half the residents (Bates, 1994). In Donora, for more than a decade after the killer smog hit, elevated death rates occurred in the town.

In London, during one week in the winter of 1952 an inversion of coal- generated smoky black mist in the basin around the town caused 3,000 more deaths than normal (Bates, 1994). A similar episode in 1956 killed 1,000 more than would have been expected (Waldbott, 1978). Most of these deaths occurred in the elderly, many of whom had grown up during less polluted times. The relative role of fluoride, sulfur, and other gases, as well as particles in these events remains unresolved.

Children living in megacities in rapidly developing countries are also at double jeopardy from poverty and degraded environments. Many children do not have access to basic health care, and therefore are not immunized (WHO, 1997). Moreover, a significant number of them suffer from malnutrition and infectious diseases. Environmental pollution only adds to the burden of food deprivation, microbial diseases, and lack of preventive care or medical treatment that many children face in the developing world. It has long been known that air pollution can aggravate illnesses such as bronchitis, asthma, and chronic obstructive pulmonary disease (World Bank, 1997). Children with diets deficient in vitamins, minerals, and protein are especially vulnerable to toxic effects of chemicals. When their immunity is reduced, they cannot transform pollutants easily to more benign substances in their bodies and tend to retain toxic materials for longer periods of time (Amdur et al., 1991).

Scientists do not know the lifetime consequences of so many young people growing up breathing such polluted air on a regular basis. Nearly nine out of every ten of the world's children live in developing countries; half of them reside in urban areas (WRI, 1998). The proportion of these populations exposed to heavy pollution is without precedent. Children will live more years of life than adults under these conditions. Those exposed to air pollution when young will have more time for the effects of pollutants to accumulate and to develop health problems triggered by such early environmental exposures.

Damage that occurs during the growing years can have a greater impact than in later years. While the full social and economic impacts of air pollution related damage to children's health cannot be precisely gauged at this time, the long-term impacts are likely to be considerable. These include diminished productivity stemming from shortened life-spans and reduced lung capacity, increased numbers of sick days, greater incidence of a variety of age-related chronic diseases, and a reduced overall quality of life. In addition, toxic pollutants, such as lead, which can be carried on airborne particles, have a detrimental effect on children's physical and neurological development.

### Ranking of Cities Based on $SO_2$, TSP, and $NO_2$, 1995

*Cities with a population of 1 million or more*

In order to identify the locations with the greatest number of people facing the highest annual levels of air pollution for 1995, we began by ranking cities with populations of 1 million or more where information was available on all 3 pollutants.

Looking at all the cities over 1 million in populations for which we have data, the highest recorded levels of TSP were found in Lanzhou, a Chinese city with a population of 1.7 million in 1995. Lanzhou's annual concentrations were 9 times above the EU's mean annual guideline of 80 micrograms per cubic meter. The capital city of Gansu Province in Northwest China, Lanzhou lies at the heart of a major petrochemical industry and oil-refining center that has experienced massive growth and development in recent years. Low-lying mountains to the east of the city prevent dispersion of heavily polluted air, and temperature inversions frequently hold TSP and other pollutants at ground level for days at a time (WRI, 1998).

Air pollution controls in recent years have helped to reduce the growth rate of TSP emissions in many cities in China since the early 1980s. Despite this welcome progress, increases in ambient $SO_2$ levels continue to parallel China's yearly coal consumption rates, which are expected to rise from 0.99 billion metric tons in 1990, to 1.5 billion metric tons annually by the year 2000 (Li et al., 1995). For example, the average annual $SO_2$ concentrations for the two worst cities are found in China — Guiyang and Chongqing, with ambient air concentrations of 420 and 340 micrograms per cubic meter, respectively. These levels are about 7 to 8 times above the WHO annual guideline of 50 micrograms per cubic meter. With respect to $NO_2$, Milan, Italy, which sits in a basin surrounded by hills, had the highest levels reported in our system in 1995.

*Cities with a population over 9 million*

This analysis focuses principally on megacities and finds that that TSP and $SO_2$ levels are highest in areas where extensive coal burning occurs, including China, and India (see Figures 1 and 2). Rio de Janeiro tops the list for $SO_2$ alone, where the sulfur content of its diesel fuels and gasoline is very high. With respect to megacities in our system, Delhi reported the highest levels of TSP in 1995, followed by Beijing, Calcutta, Tianjin and Mexico (Figure 1).

With respect to $NO_2$, a number of cities in developed regions have annual levels of this pollutant that are from 2 to 4 times the WHO guidelines. New York, Los Angeles, Tokyo, and Paris also had yearly levels exceeding WHO 1995 guidelines (see Figure 3). Cities, where highly polluting motorcycles, and inefficient, older cars, trucks and buses are in common use, have much higher levels of nitrogen compounds in the air.

The growth of automotive transport in much of the developing world has been exponential within the past decade. The World Bank reported that emissions from motor vehicles can be especially hazardous, because they include a number of toxic and extremely small-sized particles (Onursal and Gautam, 1997).

Figure 1 Annual TSP Concentrations in Cities Over 9 Million, 1995

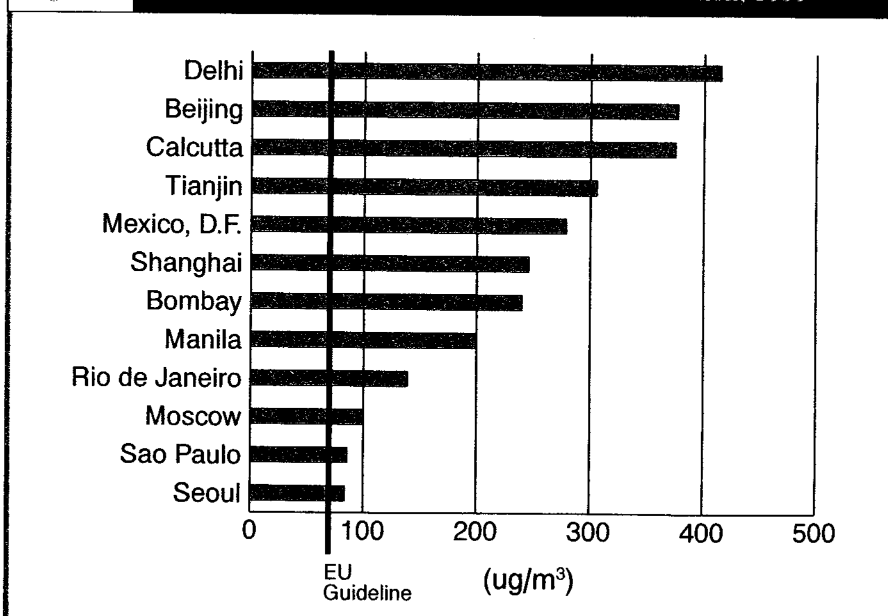
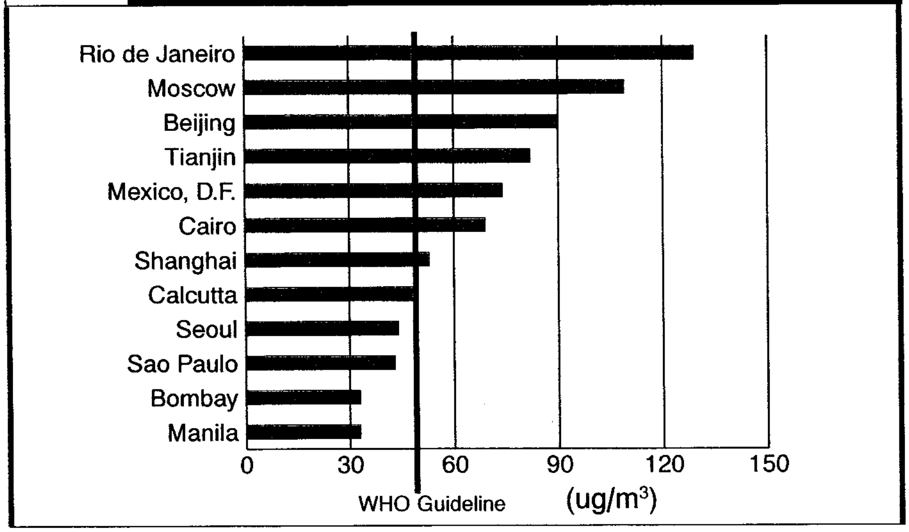


Figure 2 Annual $SO_2$ Concentrations in Cities Over 9 Million, 1995




Highly polluting, inefficient engines comprise much of the growing fleet in rapidly growing urban regions in India and several other nations.

## Combined Air Pollution Indicators in Megacities and Exposed Children

The estimated number of children under age 5 in 1995 in cities with populations of 9 million or more was linked to the annual levels of air pollution reported for our 3 indicator pollutants for 1995. All 3 pollutants are combined into a single indicator, weighted by a city's population age 5 or younger. The largest urban centers with the highest risks to children were in Latin America, China and India, in 1995.

The graphs in this report rely on OECD data, which has been superceded by improved analyses and reporting from the Mexican government. Mexico City, due to its large population of children must reinforce and increase efforts undertaken regarding environmental policies, in order to maintain the present air pollution reduction trends. Mexico is the country where most young children live in cities rather than in rural areas. The remaining cities in the list are also grappling with dangerously high levels of urban air pollution.

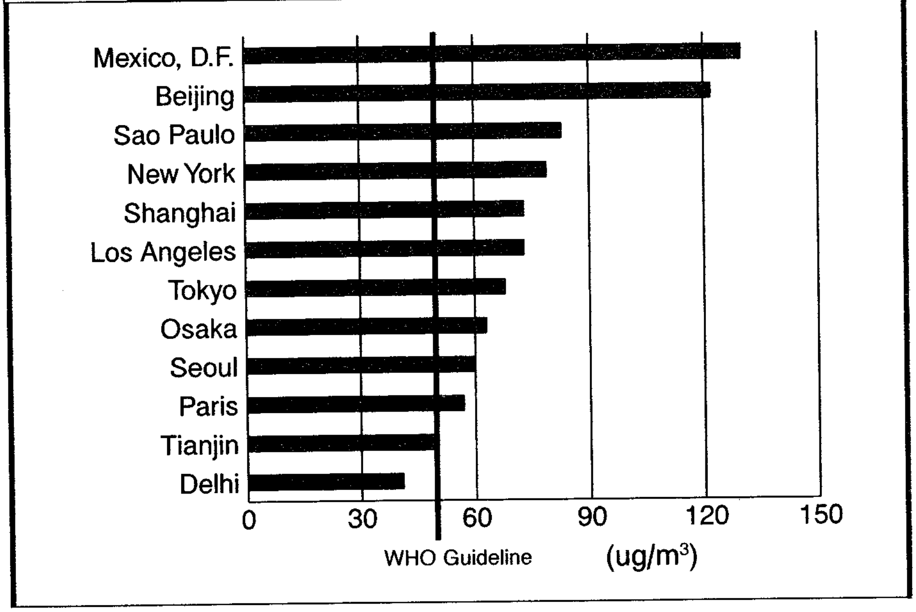
It is important to note that the work described here measures the potential for children in major urban areas in 1995 to be exposed to three 'conventional' air pollutants in terms of annual concentrations levels deemed unhealthy by WHO and other public health bodies. In other words, this analysis indicates populations at risk, based on current scientific understanding of the impacts of these air pollutants. An average child in Mexico City will be exposed to less pollution than her counterpart in Beijing. Because the population in Mexico City is much younger, they will have more life years of exposure to pollution. Figure 4 illustrates this point by juxtaposing the total concentration of all three pollutants with the population of children under age five.

Similar to other cities where vehicles are the primary source of urban air pollution, the mean annual concentration of $NO_2$ for 1995 from the OECD system we used, was high in Mexico City. This pollutant is key in the formation of ozone, which is the main environmental problem in Mexico City. Studies conducted in Mexico City indicate that short-term increases in ozone and particulate matter diminish lung function in urban children, suggesting that longer chronic exposures may lead to sustained pulmonary damage (Gold et al., 1999).

With almost half of the population under the age of 15, the need to address environmental quality in Mexico is self-evident. Since 1995, reported levels of some pollution, such as TSP, have dropped. Efforts are underway to devise broad policies to provide additional improvements (Onursal and Gautam, 1997) (see Box 4).

Any region where fossil fuels are used in industry and transportation systems have relatively outdated control technologies will have high ambient levels of fine particles and other air pollutants. In Sao Paulo, Brazil, the death rate of adults living in more polluted zones was 13% higher during periods when PM 10 was highest, compared to periods when it was relatively low (Saldiva et al., 1995). Similar results have been reported in a number of US and other cities (Wilson and Spengler, 1996). An earlier study in Sao Paulo found that children under age 5 exposed to $NO_2$ levels about twice as high as the WHO guideline also had elevated death rates (Saldiva et al., 1994). In a separate study, experi-

Figure 3 Annual NO2 Concentrations in Cities Over 9 Million, 1995




mental rats breathing the polluted air of Sao Paulo (as compared to a cleaner region) developed lungs marked with damage typical of heavy cigarette smoking (Saldiva et al., 1992). More recently, late fetal deaths (where pregnancy ends after 7-8 months) were clearly shown to be related to increased air pollution in Sao Paulo (as measured by an indicator that combined exposures to $NO_2$, $SO_2$ and CO) (Pereira et al., 1995).

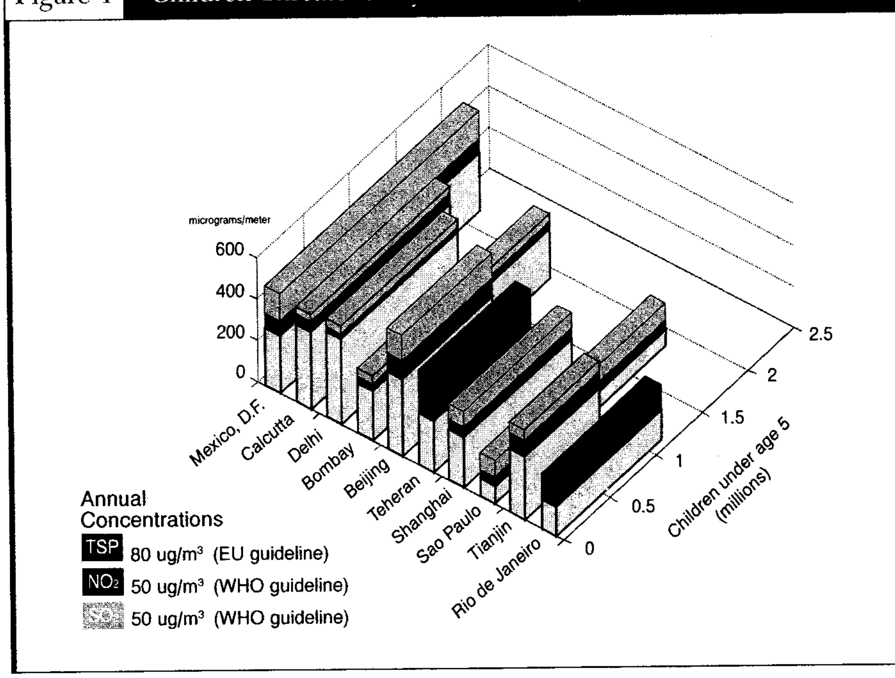
### Other Air Pollutants

While pollutants such as lead, carbon monoxide, hydrocarbons and ozone are important, they are excluded here solely because we could not obtain data on them in all the cities. For similar reasons, we do not include information on indoor air exposures, an especially important source of pollution in rural areas.
Despite the absence of a comparison of airborne lead levels, it is important to note that lead from industry and gasoline remains a major threat to public health worldwide. Since 1997, Mexico City began phasing out leaded gasoline. Beijing and Shanghai have recently begun to phase it out. But nearly 100 countries still use this well-known hazard in their gasoline (World Resources Report, 1998). Recent studies of children hospitalized in Dhaka, Bangladesh, showed blood lead levels ranging between 93 and 200 micrograms per deciliter, which are 4 to 8 times greater than WHO's guidelines (Reuter's News Service, 1999).

## III. An Environmental Crisis Unfolding

In the developed world, industrialization and urbanization took place over a period of a century or more. In many rapidly developing countries today, particularly in cities and major urban centers, the same growth is taking place in a highly compressed period of a few decades. Increased urbanization and rapid industrialization in these regions is already contributing to an epidemic of air pollution-related diseases in many of the world's young children. The World Health Organization has reported that more than 80 percent of all deaths attributable to air

Figure 4 Children Threatened by Air Pollution, 1995



pollution-induced lung infections occur in children in developing countries younger than 5 years of age (World Bank, 1992). Rising levels of air pollution in urban areas only intensify this already substantial environmental crisis.

For air pollutants, the nature of risk depends on the source of the pollution, its physical characteristics and chemical composition, and the extent of exposure. In areas where industry and domestic coal consumption are the largest sources of air pollutants, for example in China and India, health risks derive primarily from particulate matter and $SO_2$ from coal and fuel burning. But in wealthier areas, where many more cars and motorbikes are in use, such as Mexico City and Sao Paulo, vehicle exhausts comprise the largest source of air pollutant exposure. In these places, oxides of nitrogen (such as $NO_2$) and fine particles are more important hazardous agents.

All three pollutants add substantially to the burden of disease, which is compounded by the lack of access to health care for those living in these urban areas. Respiratory deaths rank among the top causes of disability and early years of life lost, according to the World Health Organization (Murray and Lopez, 1996).

As populations become increasingly concentrated in large metropolitan areas, an unprecedented public health crisis is unfolding whereby more children than ever are being exposed to dangerously high levels of air pollutants. In many areas, these concentrations approach those encountered during the 1948 killer fog in Donora, Pennsylvania. Many cities in the rapidly growing world also are located in valleys or other zones where local meteorological conditions can trap air pollutants. If temporary increases in the death rate can be tied with air pollution in cities such as London in the past decade, one can only guess as to how much more dangerous and often these events occur in places where pollution levels are sometimes greater and public health monitoring not as comprehensive.

The 3 billion people expected to live in cities by the first quarter of the next century face a double jeopardy. Because population density in many mega-cities will remain truly unparalleled, a greater proportion of people in any given area can be exposed to hazardous materials than in the past. Environmental threats can be particularly damaging to rapidly urbanizing populations at risk from poor living conditions, inadequate health care and malnutrition, including some of the 2.5 billion residents of overcrowded cities (UN, 1995; WRI, 1996). Pollution can directly injure their health, and may also weaken their immune systems, making them more vulnerable to both infectious and chronic disease.

Air pollution constitutes a singularly important threat to public health in many rapidly growing regions. According to WHO, 460,000 avoidable deaths occur annually due to exposure to suspended particulate matter (Schwela, 1996). Exposure to pollutants early in life not only affects a child's development, but may also increase the risk of developing cancer. One study reported that the risk of childhood cancer was 2 to 5 times greater for children growing up in areas of high traffic density in the US (Savitz and Feingold, 1989). Another study found that deaths from childhood leukemia and cancer in Great Britain from 1953-1980 were significantly higher in children who lived near major industrial sources of air pollution when compared to children who did not live near such sources.

**Box 4** **Evolution in Air Quality Improvement: Mexico City**

Mexico has recently achieved several important successes in its air quality improvement. One of these is the marked reduction in ambient lead levels. The annual average lead concentrations in Mexico City dropped from 1.3 ug/m3 to 0.2 ug/m$^3$. A key contributor to this decrease is the initiative the Mexican government has taken in phasing out the use of lead in gasoline. In 1986, the lead content of gasoline was reduced from 0.9 g/L to 0.09 g/L. Then in 1991, unleaded gasoline became available, with its use increasing until mid-1997, when leaded gasoline was eliminated from Mexico City (Dirección 1996). Blood lead levels fell by 66 % in children between 1991 and 1994 - 17.5 ug/dl to 6.0 ug/dl of blood (CMPCCA, 1995).

The earlier in life that exposure occurred, the greater the risk of cancer (Knox and Gilman, 1997).

Devastating levels of air pollution stalk many rapidly developing countries, where they can insidiously damage the respiratory and neurological systems of millions of children and adults. The developing world's 18 mega-cities today are plagued by gross air pollution levels that greatly exceed recommended limits from the World Health Organization. To meet the needs of their populations, newly industrializing countries are exploring ways of improving energy efficiency and the use of renewable technologies so that future pollution burdens will be reduced as their economies continue to grow.

## IV. Limits To This Assessment

This project was undertaken in order to identify those cities where the most children face the highest levels of exposure from these pollutants. It should be noted at the outset that there are many limits to this assessment. A study of this magnitude is subject to limitations regarding data quality and consistency. We only assessed one period of time. Our analysis cannot indicate such changes as increased industrialization or improvements in pollution control. In addition, because we use an exposure-based indicator, we could not factor in variation in the underlying conditions of children in different countries, such as differences in life expectancy, disease patterns, and nutrition. All these aspects contribute to the state of health.

We relied mostly on international data collections, which may be several degrees removed from their sources. There is a tremendous range in the quality of information available, the number and location of monitors regularly assessed, the method of data collection, and in the types of pollutants surveyed in different cities today. Moreover, there are no internationally accepted standards for internationally accepted standards for assuring the quality of air pollution measurements, although there are a number of efforts underway to improve standardization. This systemization will improve the ability to compare data and lead to the development of more effective and far-reaching policy-making tools, such as environmental health indicators. As air quality is both a local and global issue, the need for increased coordination and transfer of knowledge remains crucial. From our experience, for some highly polluted urban zones, no reliable information on air pollutants during this time period was available, including Karachi, Pakistan, Dhaka, Bangladesh, and Bangkok, Thailand. For some other cities including Cairo, Istanbul, Teheran, Jakarta, Moscow and Manila, key information is missing.

Information extracted from 1993-1995 cannot accurately reflect current patterns. In fact, our estimates may significantly understate the overall impact on the exposed population. As such, this work should not be construed as providing definitive, quantitative assessment of the harmful effects of air pollution on children's health. Since 1995, situations around the world may have changed. Risks may have increased or decreased depending on the rate of growth and industrialization as well as the effect of recent environmental initiatives.

One other major limit merits mention. By combining information on where the most children face the greatest risks, we are necessarily pointing to cities where much of the population is young. Pollution levels may well be higher in cities

### Box 5 Smog Threatens Modern-day London – 1991

Pollution still affects developed countries dramatically. In December of 1991, London recorded well above average hourly concentrations of $NO_2$ for four days. Certain monitoring sites registered the highest average concentrations in London's recorded history, with significant increases in deaths (Anderson, 1995). This contributed to 160 more deaths than would have normally occurred. When compared with the same time period in the previous year, deaths from respiratory disease were 22% higher, while deaths from cardiovascular disease were 14% higher (WHO, EEA, 1997) (Anderson, et al.,1995).

with generally older populations. Despite these clear limits, the combined indicator of children at risk from air pollution provides a simple metric, or environmental health indicator. There are considerable benefits of reducing air pollution both in the near and long-term. In cities where a large proportion of the population is young there are significant opportunities to reduce exposures and enhance the health of future generations.

## Air Quality Assessment, Management and Monitoring in Europe

Although proportionally fewer children live in Europe's cities, the majority of them live in urban areas. In this region, infants and young children are at high risk for respiratory illnesses, decrease in pulmonary function, and chronic obstructive pulmonary disease. A study in the Czech Republic found an increase in infant respiratory deaths associated with PM10 (Bobak and Leon, 1992). Between 4-6 million children are believed to have illnesses of the lower respiratory tract each year (WHO, 1995a). A WHO coordinated tri-national study from Switzerland, Austria and France estimated that current levels of air pollution in these countries are tied with more than 40,000 deaths each year, and that more than half of these are linked directly with traffic-related pollution (Kunzli et al., 1999).

Part of the concern over air pollution also stems from fact that pollutants do not remain within national boundaries. Europe has created regional initiatives to address this problem. The Framework Council Directive on Ambient Air Quality (EC Directive 96/62/EC), drafted in 1996, provides a basic strategy for setting common assessment criteria, pollutant limit values, and alert thresholds, which are levels above which the risk to health from a brief exposure requires action by the member state. The first pollutants to fall under the regional framework are SO2, NO2, fine particulate matter, suspended particulate matter, and lead. Other compounds include benzene, carbon monoxide, polyaromatic hydrocarbons, cadmium, arsenic, nickel, and mercury (Ariel Research, 1996).

Studies of the health effects of this report's pollutants are contributing to an increasing understanding of the problem. Two major regional studies are "Air Quality in Major European Cities" and WHO's "Concern for Europe's Tomorrow." The latter study by WHO determined that almost half of Europe's residents live in polluted urban areas (WHO, 1995a). According to "Concern for Europe's Tomorrow," nearly 6 out of every 10 people are exposed to average concentrations of particulate matter above the guideline value of 120 ug/m$^3$ (WHO, 1995a). For $NO_2$, nearly 7 out of every 10 urban residents are annually exposed to levels that exceed the guideline value of 40-50 ug/m$^3$, according to EEA. For Europe, areas of highest exposure fall mostly in eastern and southern Europe (EEA, 1998). In a study conducted by the EEA, only a few cities had fully verified data which had been checked for quality assurance and quality control (EEA, 1998).

Consistency in data is further compromised by various factors, including the location of monitoring sites, the techniques used, and the statistical analysis and reported values. For example, in measuring suspended particulate matter, three different types of sampling are used in Europe. TSP monitoring, the most commonly used method, consists of particle collection on a filter and calculation of atmospheric concentration from the determination of collected mass and air flow. Some cities' TSP sampling equipment may only allow particles under a certain diameter to pass through, but this varies from place to place. Another method for sampling is comparing visual evidence of darkness of a stained filter against some standard set for pitch-black smoke. The darkness of the stain depends on the emission sources. The preferred means of monitoring involves collection of PM10 and PM 2.5 particles, for which the health effects are of greatest concern (EEA, 1998).

Such inconsistencies in monitoring have led the EEA to recommend efforts to improve comparability of monitoring methods and data reporting. Cooperation between countries on unifying air quality assessment will foster greater accuracy in managing air pollution. In addition to the sharing of expertise between nations, information dissemination and public warnings and awareness of air quality have increased in recent years. Some cities post information on air monitoring on public monitors, or on WEB sites that can easily be accessed (www.imeca.com.mx). Amendments to EU legislation have increased the availability of recent air quality data (EEA, 1998).

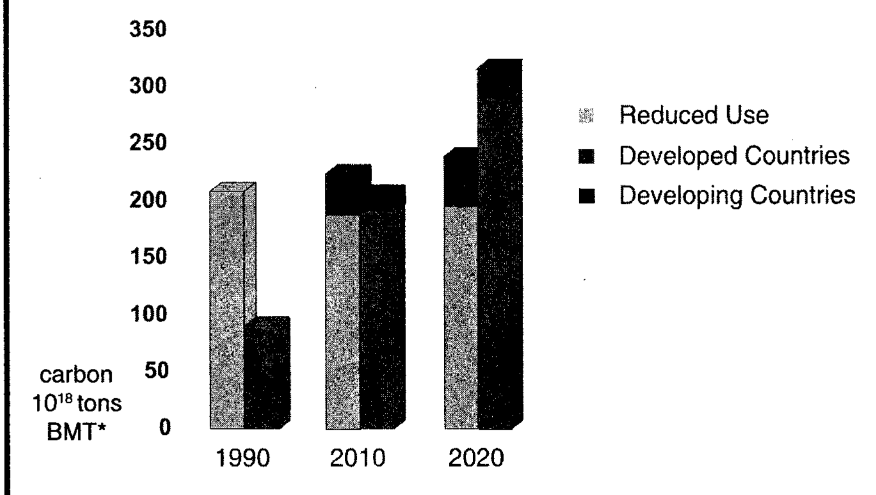
An ongoing collaborative project, Air Pollution on Health: European Approach (APHEA), may revise current air quality guidelines. This is a cross-Europe study on short-term effects of pollution. Preliminary results indicate that levels around or even below current guideline values may still be harmful to health (Katsouyanni et al., 1995). The APHEA analysis will include epidemiological time-series data, monitored air pollution levels, and information on confounding variables, which will be based on standardized methodologies. This effort illustrates the increasingly holistic approach to air pollution control that will prove vital in the next century.

## V. Air Pollution and Climate Policy

This report has addressed the increasing threat of pollution in a rapidly growing world and the consequent importance of coordinating regional air pollution management programs. Solutions to these issues must be based on a global consensus on common targets and the future direction of air policy and implementation. One means of achieving such an agreement lies in climate policy.

Much of the debate over various energy and climate scenarios misses one basic point: the same activities that create inefficiencies in transport, commerce, industry and other sectors also directly impact human health. As a consequence, policies aimed at reducing local and regional air pollution can also yield joint benefits, insofar as they reduce the buildup of greenhouse gases (GHG) as well as ambient air pollution.

Figure 5 Total Fossil Fuel Use Under Current Policies and With Reduced Use



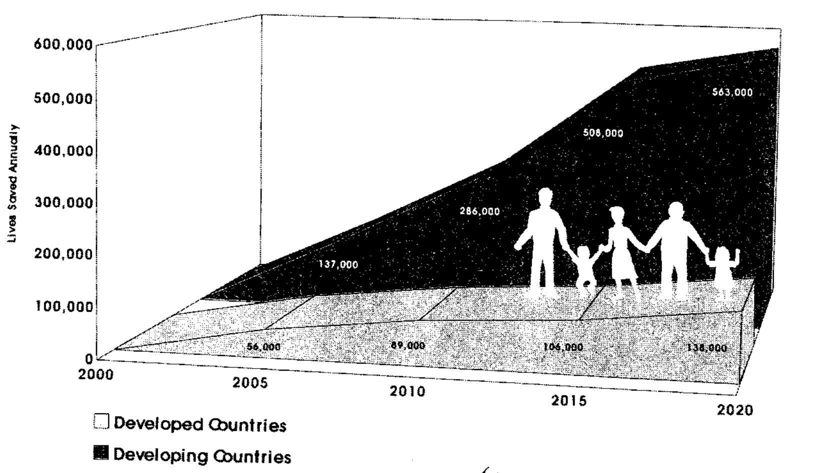
(Lancet, 1997)

Fossil fuel combustion for energy uses in transportation, industrial, agricultural, residential, and commercial sectors not only generates carbon dioxide and other greenhouse gases, it also produces pollutants, such as particulate matter (PM), sulfate, and ozone, which are detrimental to human health. In a 1997 study by the Working Group on Public Health and Fossil-Fuel Combustion, PM was used as a representative of these harmful pollutants because of its association with the combustion of fossil fuels. The study found that efforts to reduce the use of fossil fuels in the short-term would have tremendous impacts on public health, and would also decrease the buildup of greenhouse gases.

This study estimated likely emissions from 4 major sectors: transportation, industry, energy and household and residential uses. Relying on atmospheric dispersion models that were adjusted for temperature and humidity, the authors estimated the likely change in total particulates that would occur if a modest reduction in carbon was achieved globally in both developed and developing countries.

Two scenarios of the future were modeled: business-as-usual (BAU), referring to what would happen if no change in pollution policy is implemented; and the implementation of a hypothesized climate policy, which involves a reduction by developed countries of energy-related $CO_2$ emissions to 15% below 1990 levels by year 2010, and a decrease by developing countries of their emissions to 10% below the levels of greenhouse-gas emissions anticipated to be released by these countries in 2010 (see Figure 5). Both scenarios assume that total energy use and efficiencies in developing countries will continue increasing to

Figure 6 Lives Potentially Saved Annually from Reductions in Air Pollution from Fossil Fuels



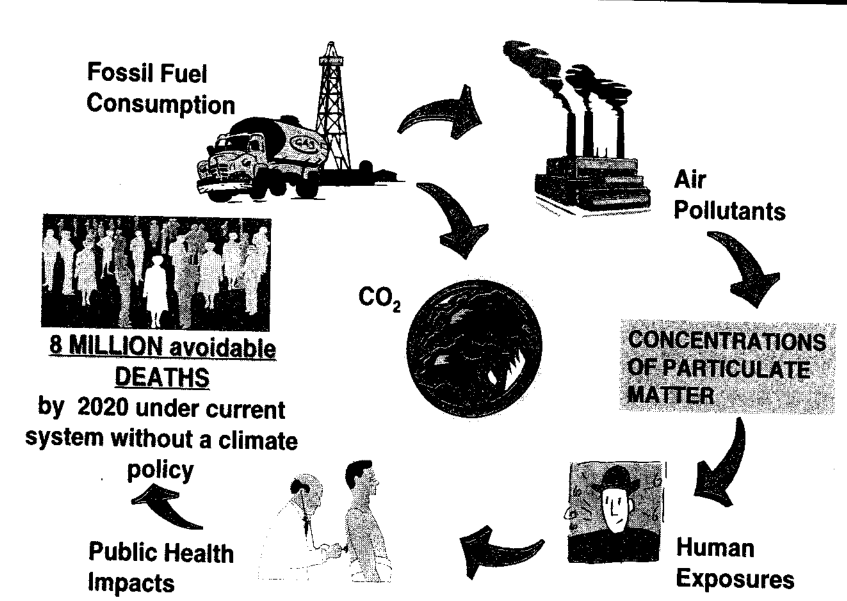

(Lancet, 1997)

meet the demands of economic growth (Working Group on Public Health, 1997).

Adoption of the climate policy scenario could avoid at least 700,000 premature deaths annually by 2020 from reduced particulate matter concentrations (see Figure 6). The cumulative savings of lives could be up to 8 million globally, with 6.3 million in developing countries and 1.7 million in developed countries. In the US alone, at least 33,000 deaths a year could be avoided, which is on the order of the number of deaths in the US in 1995 from traffic crashes or HIV- related illnesses (Working Group on Public Health, 1997). By 2020, respiratory-related diseases are estimated to become one of the top ten causes of death (Ostro, 1996). Although the number of lives saved is greater in developing countries, the marginal benefit from reducing particulate air pollution may also be large in developed countries, where populations face fewer health problems, such as malnutrition and infectious diseases.

While this study focused on potential health impacts from reducing particulates, the benefits of adopting climate policies would be much more far-reaching. Significant reductions would be achieved in other hazardous pollutants, including organic compounds and heavy metals. As Figure 7 summarizes, a global commitment to reducing fossil fuel use will have broad-ranging effects on both environment and health.

Figure 7 Global Impact of Current Fossil Fuel Use on Public Health




### The Potential of New Energy and Transport Technologies

This report's examination of the risks of air pollution to human health demonstrates the importance and urgency of effective air pollution interventions. For developing countries, control of pollution and clean production should be incorporated into their development strategies. Even in developed countries air pollution continues to take its toll on human health. In the US, 3 out of 4 adolescents recently tested in Harlem had evidence of exposure to diesel exhausts in their urine (Northridge et al., July 1999).

## Box 6 Looking to the Future – India, China, and Mexico

India faces some especiallyprob-lematic challenges. Its urban population has quadrupled in half a century. Nearly half of all vehicles in the country are in 3 cities: Delhi, Calcutta, and Mumbai (Bombay). Diesel fuel and inefficient two-stroke gasoline engines, which are highly polluting, power most vehicles in the country. A study by Maureen Cropper and World Bank colleagues calculated that the country loses 57,000 person years annually from particulate pollution alone (Cropper et al., 1997). Recognizing the problems posed by these vehicles, the Delhi government proposed that, by April 2000, all vehicles must meet stringent control standards (Dieselnet, 1999). Similar policies are under development in Mexico and China.

In Mexico City, about half of its 3.5 million vehicles have advanced pollution controls. Pre-1991 models generate more than 80 percent of the total emissions produced by automobiles. Even in 1991 and 1992, when unleaded gasoline became available in Mexico City, the Car Manufacturers Association was reluctant to introduce cleaner vehicles, despite the fact that they had been exporting cleaner cars made in Mexico to the US for many years. It was only after the introduction of the 1999 model-year and a year of negotiations, that the government persuaded all car manufacturers to meet Mexico's emission standards, which are similar to US EPA TIER I standards.

Recent reports from Mexico show that the number of days when ozone levels triggered major public disruptions have begun to decline. A "contingency" declaration brings normal life to a halt across several sectors: "Hoy no circula" bans on non-emergency vehicles; mandatory restrictions on industrial emissions; bans on street repairs and other public works; and an alert to schools to keep the children indoors. The Air Quality Monitoring Network of the Mexico City's Government reported that half as many declarations were issued in 1998 as in 1995.

More stringent emission standards for vehicles along with the introduction of unleaded gasoline would contribute to major reductions in most cities: mobile sources. Disallowing the sale and manufacture of older model vehicles will further bring down mobile emissions. In Mexico City, most of the pollution from cars comes from pre-1990 models. It was not until recently that cars manufactured in Mexico meet with Mexican emission standards.

Countries like China also face twin perils from poorly managed growth of transportation and energy. Coal provides nearly 75 percent of China's primary energy, while the number of vehicles has been growing at an annual rate of 15 percent in the last two decades. Beijing has ten times more vehicles now than it had 10 years ago. Given these conditions, it is not surprising that respiratory diseases are the leading cause of death in China today (World Bank, 1996). According to a 1997 World Bank study, if current rates of fossil fuel consumption remain constant, the health costs will rise from $32 billion in 1995 to $98 billion in 2020. Per year, this increase includes health costs amounting up to 600,000 premature deaths, 5.5 million cases of chronic bronchitis, 5 billion restricted activity days, and 20 million cases of respiratory illness (World Bank, 1997).

---

Diesel fuel is known to emit fine particulates and $NO_2$.

In a world where population and living standards are expected to grow for a long time to come, investing in improved technology offers one of the most promising routes for reducing the health threats to children from air pollution.
The energy choices made today have direct, short- and long-term impacts on public health and the environment. New transport and energy technologies are emerging that will reduce the public health impacts of fossil fuels, while preventing global warming and enhancing environmental and national security (MacKenzie, 1997). In particular, innovations in the transportation sector are important because mobile sources are the major contributors to urban air pollution.

Development partners are beginning to realize that it is in their best interests to encourage improvements in energy and air quality management. With support from the Global Environment Facility, the World Bank is currently undertaking a US $1.1 billion, decade-long program to fund investments in cleaner energy and transportation in Mexico City, spurred by the reality that air quality in the region requires improvement. This program will also provide for refinements in air quality and public health monitoring.

The acquisition of more efficient

## Box 7 Cleaner Alternatives

There is strong support for the use of renewable energy alternatives in China and many other developing countries. Already, a natural gas pipeline from Shaanxi province to Beijing has completed the first phase of its construction. The substitution of natural gas for coal may lower the air pollution index by approximately 15 percent (China Environment Reporter ,1997). Boilers in downtown Beijing will also use natural gas. Levels of particulate matter and sulfur dioxide are expected to be reduced by almost 25% (China Environment Reporter, 1997). China now has nearly 7,000 small-hydro power plants. It also operates 6 million square meters of fixed solar panels, 40,000 square meters of solar heated greenhouses and 140,000 solar heated stoves. Wind energy projects in remote agricultural regions, mountainous areas and along the coast generate a combined capacity of 50,000 kilowatts. Linhai, the largest wind power station in south China, located on the coast of Zhejiang province, supplies electricity to the southern reaches of greater Shanghai.

India is also embarking on major efforts to use solar and other renewable energy (Climate Institute, 1997). Brazil is actively promoting the development of less polluting forms of transit and energy (Reid and Goldemberg, 1997). India is phasing out filling stations that provide fuel for highly polluting two stroke engines in Delhi (Parivesh, 1999).

transport systems, the use of renewable energy, and the building of more efficient and renewable power plants will have significancant and immediate effects on public health worldwide. The expanded use of less carbon intensive energy will also ultimately reduce the buildup of greenhouse gases associated with fossil fuel patterns. Indeed, China, India and Brazil have already started to take actions to reduce sulfur, particles and carbon emissions. Technological advances in industrial equipment have greatly improved China's energy efficiency since the mid-seventies when China's production sector was among the most technically and economically inefficient in the world (Reid and Goldemberg, 1997). Had China's energy intensity remained constant at 1977 levels, the country would now be consuming more than twice as much energy - and emitting twice as much carbon and twice as many particles into the atmosphere - than it currently does (Baumert et al., 1999).

## VI. Conclusion

Given the projected growth of cities and the relatively young average age of their populations, the opportunity to promote energy efficiency and reduce pollution in urban areas today must be understood as a fundamental challenge to public health. An expanded focus on the issue of children's health in urban environments will become increasingly acute and pressing in the years to come. A broad array of available technologies can improve efficiency, lessen GHG buildup, and reduce the threat of air pollution today. If sustainable development requires protecting the rights of future generations, that commitment must manifest itself foremost with our children.

## NOTES


**Amdur,** M., J. O' Doull, C. Klaassen, and D. Curtis (eds.), 1991*: Casarett and Doull's Toxicology: The Basic Science of Poisons.* Pergamon Press, New York, pp. 118-119.

**Anderson,** H.R., E.S. Limb, J.M. Bland, A. Ponce de Leon, D.P. Strachan, J. S. Bower, 1995: Health Effects of an Air Pollution Episode in London, December 1991. *Thorax.* 50: pp. 1188-1193.

**Ariel Research Corporation**, 1996: EU Issues Directive on Ambient Air Quality Assessment and Management. *Euro Chemicals Report.* Ed. Willem Dicke.

**Bates,** D., 1994*: Environmental Health Risks and Public Policy: Decision Making in Free Societies.* University of Washington Press, Seattle.

**Bobak,** M., Leon, D.A., 1992: Air Pollution and Infant Mortality in the Czech Republic, 1986-1988. *Lancet*, 340: pp. 1010-1014.

**China Environment Reporter,** 1997: Beijing to Meet Pollution Standards, Oct. 27.

**China Environment Reporter,** 1997: Natural Gas Aids Beijing, Oct. 27.

**Climate Institute,** January - February, 1997: Climate Alert. 10(1); p. 7-9.

**Cropper,** M., N. Simon, A Alberini, S. Arora, and P.K. Sharma, 1997: The Health Benefits of Air Pollution Control in Delhi. *American Journal of Agricultural Economics*, 79(5), pp. 1625-1929.

**Cutter,** S.L., 1995: The Forgotten Casualties: Women, Children, and Environmental Change.
Global Environmental Change, 5(3), pp. 181-194.

**Departamento del Distrito Federal,** 1996: *Compendio Estadístico 1986-1995. Red Automática de Monitoreo Atmosférico de la Ciudad de México.* Dirección General de Prevención y Control de la Contaminación, 1st edition. pp. 74

**Dieselnet,** "India introduces car emission standards," Ecopoint Inc., www.dieselnet.com.

**Dockery,** D.W. and C.A. Pope, 1996: Epidemiology of Acute Health Effects: Summary of Time-Series Studies. In *Particles in Our Air, Concentrations and Health Effects.* R. Wilson and J. Spengler (eds.), Harvard University Press, Cambridge, MA, pp. 123-149.

**Godleski,** J., C. Sioutas, M. Katler, M. Catalano., and P. Koutrakis, 1996: Death from Inhalation of Concentrated Ambient Air Particles in Animal Models of Pulmonary Disease. In *Proceedings: Colloquium on Air Pollution and Human Health.* J. Lee and R. Phalen (eds.), pp. 136-143.

**Gold,** D.R., A.I. Damokosh, C.A. Pope, D. Dockery, W.F. McDonnell, P. Serrano, A. Retama, M. Castellejos, 1999: Particulates and Ozone Pollutant Effects on the Respiratory Function of Children in Southwest Mexico City. *Epidemiology*, 10(1), pp. 8-17.

**Hammond,** A., 1998: *Which World? Scenarios for the 21st Century: Global Destinies, Regional Choices.* Island Press/ Shearwater Books, Washington, DC.

**Harte,** J., C. Holdren, R. Schneider, C. Shirley, 1991. *Toxics A to Z: A Guide to Everyday Pollution Hazards.* Berkeley: University of California Press.

**Hazucha,** M.J., L.J. Folinsbee, E. Seal, P.A. Bromberg, 1994: Lung Function Response of Health Women after Sequential Exposures to NO2 and O3. *American Journal of Respiratory Critical Care and Medicine*, 150, pp. 642-47.

**Howes,** J.E., W.L. Mounir, Z. Safar, and H. El-Manakhly, 1996: Development of a Lead Emission Inventory for the Greater Cairo Area, World Bank Report.

**James,** P. Bruce, Hoesung Lee, and Erik F. Haites (eds), 1996: *Economic and Social Dimensions of Climate Change.* Cambridge University Press, Cambridge, UK.

**Junfeng,** Li et al., *Energy Demand in China: Overview Report, Issues and Options in Greenhouse Gas Emissions Control Subreport Number 2* (The World Bank, Washington, D.C., 1995), p. 43.

**Katsouyanni,** K., Zmirou, D., Spix, C., Sunyer, J., Schouten, J.P., Ponka, A., Anderson, H.R., Le Moullec, Y., Wojtynak, B., Vigotti, M.A., Bacharova, L., 1995: Short Term Effects of Air Pollution on Health: A European Approach Using Epidemiological Time-scale Data. *European Respiration Journal,* 8, pp. 1030-1038.

**Knox,** E.G., and E.A. Gilman. 1997: Hazard Proximities of Childhood Cancers in Great Britain from 1953-1980. *Journal of Epidemiology and Community Health,* 51, pp. 151-159.

**Kunzli,** N, R. Kaiser, S. Medina, M. Studnicka, G. Oberfeld, F. Horak, 1999: Air Pollution Attributable Cases: Health Costs due to Road Traffic Related Air Pollution prepared for the WHO Ministerial Conference on Environment and Health, London, June 1999. World Health Organization, Regional Office for Europe.

**MacKenzie,** J., 1997: Climate Protection and the National Interest: The Links Among Climate Change, Air Pollution, and Energy Security. *Climate Protection Initiative.* World Resources Institute, Washington, D.C.

**McMichael,** Anthony, and Kirk, R. Smith, 1999: Seeking a Global Perspective on Air Pollution. *Epidemiology*, 10(1), pp. 1-4.

**Murray** C, A. Lopez, 1996: *A Global Burden of Disease.* Harvard University Press, Cambridge, MA.

**National Research Council,** 1993: *Pesticides in the Diets of Infants and Children.* National Academy Press, Washington, D.C.

**Natural Resources Defense Council,** 1997: Our Children at Risk: The Five Worst Environmental Threats to Their Health. *American Journal of Respiratory Critical Care and Medicine.*

**Nicholas,** D., 1997: Across Asia, A Pollution Disaster Hovers. *The New York Times,* November 28, 1997 pp. A14.

**Northridge,** M.E., J. Yankura, P.L. Kinney, R.M. Santella, P. Shepard, Y. Riojas, M. Aggarwal, P. Strickland, and the Earth Crew, 1999. Diesel Exhaust Exposure Among Adolescents in Harlem: A Community-Driven Study. *American Journal of Public Health,* 89(7), pp. 98-1002.

**Onursal,** B. and S. Gautam, 1997: *Vehicular Air Pollution: Experiences from Seven Latin American Urban Centers.* In World Bank Technical Paper, no. 373. The World Bank, Washington, D.C.

**Ostro,** Bart, 1994: *Estimating the Health Effects of Air Pollutants: A Method with an Application to Jakarta.* In World Bank Policy Research Working Paper, No. 1301. The World Bank, Washington D.C., pp. 48-49.

**Parivesh Newsletter,** Central Pollution Control Board, Delhi, India, Volume 6 (1), June, 1999.

**Pereira,** L.A.A., D. Loomis, G.M.S. Conceicao, A.L.F. Braga, R.M. Arcas, H.S. Kishi, J.M. Singer, G.M. Bohm, and P.H.N. Saldiva, 1998: Association Between Air Pollution and Intrauterine Mortality in Sao Paulo, Brazil. *Environmental Health Perspectives,* 106, pp. 325 - 329.

**Pereira,** P.M., P.H.N. Saldiva, R.S. Sakae, G.M. Bohm, and M.A. Martins, 1995: Urban Levels of Air Pollution Increase Lung Responsiveness in Rats. *Environmental Research,* 69, pp. 96 - 101.

**Reid, W.** and J. Goldemberg, 1997: Are Developing Countries Already Doing as Much as Industrialized Countries to Slow Climate Change? In Climate Notes. World Resources Institute, Washington D.C., July, pp. 1-6.

**Reuter's News Service,** 1999. Report of Study conducted by Dhaka University and the Bangladesh Atomic Energy Commission, as reported by, January 15, 1999.

**Richter,** Dorothee A. U., W.P. Williams, 1998: *Assessment and Management of Urban Air Quality in Europe.* EEA Monograph No. 5, EEA, Copenhagen.

**Saldiva,** P.H.N., M. King, V.L.C. Delmonte, M. Macchione, M.A.C. Parada, M.L. Daliberto, R.S. Sakae, P.M.P. Criado, P.L.P. Silvereia, W.A. Zin, and G.M. Bohm, 1992: Respiratory Alternations Due to Urban Air pollution: An Experimental Study in Rats. *Environmental Research,* 57, pp. 19-33.

**Saldiva,** P.H.N., A.J.F.C. Lichtenfels, P.S.O. Paiva, I.A. Barone, M.A. Martins, E. Massad, J.C.R. Pereira, V.P. Xavier, J.M. Singer, G.M. Bohm, 1994: Association Between Air Pollution and Mortality Due to Respiratory Diseases in Children in Sao Paulo, Brazil: A Preliminary Report. *Environmental Research,* 65, pp. 218 - 225.

**Saldiva,** P.H.N., C.A. Pope, J. Schwartz, D.W. Dockery, A.J. Lichtenfels, J.M. Salge, I. Barone, and G.M. Bohm, 1995: Air Pollution and Mortality in Elderly People: A Time-Series Study in Sao Paulo, Brazil. *Archives of Environmental Health,* 50, pp. 159 - 163.

**Savitz,** D.A., and L. Feingold, 1989: Association of Childhood Cancer with Residential Traffic Density. *Scandinavian Journal of Work and Environmental Health,* 15, pp. 360-363.

**Schwela,** D., 1996: Exposure to Environmental Chemicals Relevant for Respiratory Hypersensitivity: Global Aspects. *Toxicology Letters,* 86, pp. 131-142.

**Smith,** K.R., 1996: Indoor Air Pollution in Developing Countries: Growing Evidence of its role in the Global Disease Burden. In Yoshizawa S et al., eds. (1996) *Indoor air '96: proceedings of the 7th International Conference on Indoor Air Quality and Climate,* Nagoya, Japan, 21-26 July 1996. Tokyo, Institute of Public Health.

**United Nations Population Division,** *World Urbanization Prospects: The 1994 Revision* (U.N., New York, 1995), p. 87.

**Waldbott,** G., 1978: *Health Effects of Environmental Pollutants.* The C.V. Mosby Company, St. Louis.

**Walsh,** M., 1998: Motor Vehicle Pollution Control in China. *Sinosphere,* 1(2). The Professional Association for China's Environment.

**Wilson,** R., and J. Spengler (eds.), 1996: *Particles in Our Air: Concentrations and Health Effects.* Harvard University Press, Cambridge, MA.

**Woodruff,** T., J. Grillo, K. Schoendorf, 1997: The Relationship between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States. *Environmental Health Perspectives,* 105(6), pp. 608-612.

**Working Group on Public Health Fossil Fuel Combustion,** 1997: Short-term Improvements in Public Health from Global-Climate Policies on Fossil-Fuel Combustion: An Interim Report. *Lancet,* 350, pp.1341-1349.

**The World Bank,** 1992. *World Development Report: Development and the Environment.* Oxford University Press, New York, p. 52.

**The World Bank,** 1996. "China: Chongqing Industrial Pollution Control and Reform Project." Staff Appraisal Report. Washington, D.C.

**The World Bank,** 1997: *Clear Water, Blue Skies: China's Environment in the New Century.* Washington D.C. World Bank, Washington D.C.

**World Health Organization (WHO),** 1995: *Environmental Indicators.* World Health Organization, Geneva.

The World Resources Institute (WRI) is an independent center for policy research and technical assistance on global environmental and development issues. WRI's mission is to move human society to live in ways that protect Earth's environment and its capacity to provide for the needs and aspirations of current and future generations. Because people are inspired by ideas, empowered by knowledge, and moved to change by greater understanding, the Institute provides - and helps other institutions provide - objective information and practical proposals for policy and institutional change that will foster environmentally sound, socially equitable development. WRI's particular concerns are with globally significant environmental problems and their interaction with economic development and social equity at all levels.

WRI works with institutions in more than 50 countries to bring the insights of scientific research, economic analysis, and practical experience to political, business, and non-governmental organization leaders around the world. Research collaboration was provided by experts working with the European Environmental Agency, World Health Organization, the University of Sao Paulo Medical School, the Shanghai University Medical School, and the Climate Institute.

Anonymous reviewers provided critical comments on earlier drafts of this work as did colleagues at our home institutions. Our work on Health, Environment, and Development has been supported by the Goldman Fund, Jennifer Altman, W. Alton Jones, the Rockefeller Brothers, Wallace Global, Rockefeller Financial Services, the U.S. Department of Energy, Environmental Protection Agency, and the World Bank.

WORLD RESOURCES INSTITUTE

10 G Street, NE, Suite 800
Washington, DC 20002
**http://www.wri.org**

ISBN: 1-56973-427-5