Improving Air Quality In Megacities: Mexico City Case Study

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Background.

One of the great challenges facing society in the 21st Century is to find practical ways to bring the benefits of economic growth to developing countries without damaging the environment. Mexico City, Sao Paulo, and Beijing all experience similar –and serious– environmental problems, including severe air and water pollution. As many cities in developing countries swell with people and automobiles, the number of cities with poor environmental quality continues to grow. There is an urgent need to address the interrelated issues and common obstacles experienced by these urban areas around the world and a need for a more complete understanding of the connections between air pollution, human health, and climate change.

The poor air quality in many urban areas is the result of both high emissions and unfavorable meteorological conditions such as stagnation and inversions, which tend to restrict the dispersion of the pollutants once emitted into the atmosphere. Sources of pollutants include emissions from the combustion of fossil fuels in motor vehicles and for industrial processes, energy production, domestic cooking and heating, and high dust levels due to local construction, unpaved roads and long-range transport from surrounding barren landscapes. Policy initiatives to address these problems effectively are urgently needed.

While many of the impacts of high air pollution levels are often centered in the urban areas, the impacts of urban activities are not confined within the city boundaries. The regional and global dispersion of pollutants generated locally has been well established in the case of acid deposition, climate change and stratospheric ozone depletion. Concerns for tropospheric ozone and particulate matter have heightened recently because long-range transport of these pollutants could influence air quality in regions far from their sources and because they also contribute to climate change. Furthermore, land use and land cover are changing rapidly all over the urban centers around the world. Increasing human population growth and human demands on ecosystems are changing the landscape with important atmospheric consequences.

Thus, rapid population growth, uncontrolled urban expansion, unsustained economic growth, increased energy consumption and increased motorization all translate into serious air pollution problems in cities throughout the world. A persistent and pervasive threat to health, air pollution does more than choke lungs, impair visibility and damage the ecosystems; it also poses a tremendous economic and social cost to society.

Mexico City Air Quality Program.

Over the past three years, a benchmark integrated assessment of air quality in the Mexico City Metropolitan Area (MCMA)—one of the world's largest megacities—has been undertaken by a

team of Mexican, U.S. and other international scientists and engineers, economists, political and social scientists. This case study of the Integrated Program on Urban, Regional and Global Air Pollution —a collaborative research and education program initiated at MIT— addresses in a coordinated and interdisciplinary manner the air pollution problems stemming from human activity in megacities. Moreover, the Program involves active collaboration with Mexican government officials and decision makers. Although the original research was focused on the MCMA, the goal was to develop method of integrated assessment applicable to other large urban centers throughout the world.

Mexico City epitomizes the types of environmental problems experienced by megacities around the world and the common obstacles to solving them. Although international attention has focused on global climate issues, most local decision makers do not take into account the relationships between urban, regional and global pollution in addressing the common causes—scientific, economic and social—that underlie these interrelated problems.

Through the integrated assessment approach, we have developed recommendations emphasizing the interaction between different disciplines. The approach required not just an understanding of air pollution science but also how to balance economic, social and technological factors, and how to make decisions in the presence of uncertainty and incomplete data. This research resulted in the publication of a book entitled "*The Air Quality in the Mexico Megacity: An Integrated Assessment*," (Kluwer Academic Publishers, 2002), which provides an overview of the current understanding of the air pollution problem, lessons learned from air quality management programs to date, and recommendations for research and institutional change so that cost-effective measures can be efficiently developed and implemented. The material presented in the book has provided the foundation for the strategic planning for the new ten-year air quality management program prepared by the Mexican authorities; some of the recommendations suggested by the Program have already been adopted and implemented.

Urban Growth in the Mexico City Metropolitan Area.

The Mexico City Metropolitan Area (19°25'N Latitude and 99°10'W Longitude) lies in an elevated basin at an altitude of 2240 m above mean sea level. The nearly flat floor of the basin covers about 5000 km^2 of the Mexican Plateau and is confined on three sides (east, south and west) by mountain ridges but with a broad opening to the north and a narrower gap to the south-southwest.

Fifty years ago, Mexico City had fewer than 3 million inhabitants. In the year 2000, the population is 6 times higher, with more than 18 million people. Today, the MCMA is the second largest populated city in the world, exceeded only by the metropolitan area of Tokyo, with 26 million inhabitants. As the site of the nation's capital, the MCMA is home to the national political institutions, the greatest concentration of economic investments, and most of the country's industrial and financial infrastructure.

During the Twentieth Century, the MCMA has undergone a massive transformation in urban areas and demographics. The MCMA has attracted migrants from other parts of the country and

stimulated economic growth as the nation began industrialization. The population grew rapidly and continually occupying land further away from the historic center of the Federal District. In the last half century alone, the urbanized area of the region has increased more than ten times, from just 120 km^2 in 1940 to 1,500 km^2 by 1995. The expansion pushed the city beyond the Federal District and into other municipalities of the State of Mexico and other neighboring states.

Sources and Trends of Air Pollutants in the Mexico City Metropolitan Area.

The topography and meteorology of the MCMA contribute substantially to the problem of air pollution. The mountains, together with frequent thermal inversions, trap pollutants within the MCMA basin. The high elevation and intense sunlight also contribute to photochemical processes which drive the formation of ozone. In this geographical setting, the metropolitan area's almost 20 million residents, 3.5 million vehicles, and 35,000 industries and services together consume more than 40 million liters of fuel per day, producing emissions of thousands of tons of pollutants, which can react in the atmosphere to generate other pollutants that can be more dangerous to health than the original pollutants. Air pollution is generally worst in the winter, when rain is less common and thermal inversions are more frequent.

Both the Mexican government and citizens have recognized air pollution as a major social concern since the mid-1980s. In the 1990s, there were successful reductions in the concentrations of some pollutants such as lead, carbon monoxide and sulfur dioxide. Comprehensive air quality management programs were developed and carried out. The monitoring and evaluation of air pollution were improved. The government strengthened and began to enforce a vehicle inspection and maintenance program. Natural gas in industry and the power sector replaced fuel oil. Among other measures, specific actions reduced volatile emission from gasoline stations and storage tanks in industry, as well as removal of lead from gasoline and the implementation of catalytic converters in automobiles. In addition, programs such as “No driving day” (*Hoy No Circula*) have been used as incentives to modernize the vehicle fleet and to help insure the proper maintenance of vehicles.

As a result of the above control measures, important reductions in ambient concentrations of lead, sulfur dioxide and carbon monoxide were achieved recently. However, serious air pollution problems still persist. Lack of financial resources, as well as lack of information and inadequate follow up, have meant that some measures have not fully been put into practice. MCMA residents remain exposed to unhealthy concentrations of air-borne pollutants, especially particulate matter and ozone, the two most important pollutants from the standpoint of public health.

Today, ozone and PM_{10} are the air quality standards most frequently violated, while other pollutants are usually below the air quality standard. In the case of ozone, the standard is violated on about 80% of days, and this has happened every year since 1988. The peak ozone concentrations —nearly 300 ppb— that occur a few times a year, are comparable to those in the city of Los Angeles in the 1970s and are higher than those observed in any city in the U.S. With respect to PM_{10}, the daily standard has been exceeded on more than 40% of the days in some years (although since 1999 the standard was exceeded on less than 10% of the days). On the

other hand, the annual average concentrations have exceeded the maximum levels established by the air quality standard since 1995.

These problems will worsen, causing increasingly adverse health effects as the population continues to increase and development and fuel use also rise, unless intervention takes place. No single "silver bullet" will fix this tenacious problem. To have a substantial impact, an array of appropriate strategies must be identified and deployed to enhance air quality.

The severe air pollution problem has spurred significant research and action in Mexico City, making it an ideal case study for learning about current challenges in air quality research, management and policy. Mexico City has begun to take action to improve air quality, and is looking to current scientific and policy research to help it continue to solve its air quality problems. The research resulting from Mexico City can also help solve air quality problems in other large cities world-wide.

In the following sections, we described some of the key findings and the actions taken by the government authorities of the MCMA recently to reduce transport-related emissions, the largest source of pollutants that are harmful to the health of the population.

Health Impacts of Air Pollution.

Human health is the major concern over air pollution and the major driver for policy actions in the MCMA. However, the Mexico City Case Study also considers effects of air pollution on ecosystems, as well as the linkage with global warming. Mexico, like other countries in the world, contributes to global warming and is likely to be affected by it. In this paper, we will discuss only the impact on health.

Air pollution has a range of impacts on health and imposes potentially substantial economic costs to society. Much of our knowledge of the health effects of air pollution comes from studies of the daily fluctuations in deaths, hospital admissions, and respiratory symptoms in response to daily fluctuations in the levels of pollution in Mexico City and other cities throughout the world. These time-series (or "acute") mortality and morbidity studies have revealed the effects of various pollutants (generally PM_{10}, ozone, CO, NO_2, and SO_2).

A health effects sub-team—led by the Harvard School of Public Health in collaboration with Mexican scientists from the Environmental Health Office of the Health Ministry and the Autonomous Metropolitan University—has assessed health risks posed by current and anticipated levels of air pollution in the MCMA. It has also estimated the economic implications of Mexico City's air quality. The study focused on exposure to the pollutants, mainly PM_{10} (particulate matter smaller than 10 μm in diameter) and ozone.

The team found that in 1998 the average population exposure to PM_{10} was comparable to those in several of the largest cities in the world (about 90 $\mu g/m^3$). Studies in various cities around the world, including Mexico City, show a correlation between daily fluctuations in deaths and daily fluctuations in air pollution levels. It is estimated that for each 10 $\mu g/m^3$ increase in daily levels

of PM_{10}, an increase in daily mortality on the order of one percent may be expected. Most of these are cardiovascular deaths, perhaps of relatively elderly people already suffering from coronary heart disease. However, some recent evidence suggests that some of the premature deaths in the MCMA may be among infants. In a population as large as Mexico City (close to 20 million people), these health effects studies suggest that a ten percent reduction in PM_{10} concentrations could reduce the number of premature deaths in the MCMA by approximately 1000 per year. The effect could be several times larger if one considers longer-term responses to particulate matter exposure.

PM_{10} concentrations have also been associated with nonfatal health outcomes including increased cases of chronic bronchitis, hospital admissions for respiratory or cardiovascular cases, visits to the emergency room for respiratory or cardiovascular problems, asthma attacks, symptoms in the upper airways, and restricted activity days.

Ozone levels have received much attention in Mexico City, as the one-hour air quality standard of 110 ppb is being exceeded more than 300 days every year. Although the effect on mortality is not as striking as that of particulate matter, ozone has significant effects on respiratory function and on hospital admissions for respiratory conditions such as asthma.

The economic value of the health benefits expected from air pollution control is difficult to estimate because of the uncertainties in assigning monetary values to the reduction of health risks. Most estimates of the monetary value of reductions in mortality risks are derived by using estimates of society's willingness to pay for such improvements. The first study of this kind in Mexico is being conducted as part of the Mexico City Case Study. Past estimates were extrapolated using values derived from studies conducted in the US and other developed countries.

Recent research suggests that the most important factor for human health involves the presence of fine particles ($PM_{2.5}$). For this reason, measurements of the chemical composition of $PM_{2.5}$, the development of an emission inventory, and the design of control strategies aimed at reducing the levels of $PM_{2.5}$, are considered as high priority activities for the Project. One of the recommendations coming out of our studies is to monitor $PM_{2.5}$ and to develop an emissions inventory for $PM_{2.5.}$ In August 2003, the Mexico City government formally inaugurated the $PM_{2.5}$ network, which consists of 8 automatic and 6 manual monitoring stations. The data obtained from this network will be very important in designing strategies for the abatement and control of this pollutant.

In the spring of 2003, the MIT-led multinational team of experts conducted an intensive, five-week field campaign in the Mexico City Metropolitan Area. The overall goal of this effort —funded by the Mexican government and other international agencies—is to contribute to the understanding of the air quality problem in megacities by conducting measurements and modeling studies of atmospheric pollutants in the MCMA. Such an understanding will help provide a scientific base for devising effective emissions control strategies to reduce exposure to harmful pollutants in the MCMA and also provide insights to air pollution science in other megacities, including large urban centers in the US.

Transportation System: Mobility and Air Pollution.

Transportation is a critical enabler of economic activity and beneficial social interactions. Yet the transportation sector is also a major source of air pollution in the MCMA, estimated to account for nearly all of carbon monoxide (CO), more than 80% of nitrogen oxides (NO_x), 40% of volatile organic compounds (VOC), 20% of sulfur dioxide (SO_2), and 35% of PM_{10} in 1998. The growing problems of congestion, accidents, and lack of security are also very worrisome. The key question, therefore, is how to reduce the adverse environmental impacts and other negative effects of transportation without giving up the benefits of mobility.

This dilemma becomes most pressing under conditions of rapid urban growth, which is likely to increase travel demand significantly. Given current trends, by 2020 the MCMA population will reach 26 million—with the largest growth in the State of Mexico rather than in the Federal District. Including the nearby cities of Puebla, Tlaxcala, Cuernavaca, Toluca and Pachuca, the entire megalopolis will contain some 36 million people.

Although in some scenarios, the projected rate of population increase may be reduced, even moderate population growth is likely to lead to substantial increases in both passenger and freight travel demand in the region. The increasing geographic dispersion of the metropolitan population is also likely to increase aggregate transportation demand, since the greater number of trips will also be longer and public transport will be less efficient and universal.

As the population has increased and the residential areas have decentralized, patterns of passenger trip mode choice in the MCMA have also shifted dramatically: The number of private automobiles has increased significantly, by most estimates at a rate of six percent annually in recent years. Moreover, for the following decade an average annual rate of economic growth of between three and five percent is expected. (However, very recent estimates are much more modest, with a projected growth rate of between one to three percent due to the downturn in global economy.) This could mean a higher number of vehicles in circulation, a higher ratio of vehicles per inhabitant, and the possibility that the trips and the distances traveled will increase even more as a result of the escalation of economic and social activities.

Meanwhile, the percentage of total trips made by large, fixed-route buses has declined precipitously as a result of the emergence and growing predominance of other transport systems, e.g., the *colectivos*, competing for patronage on the same routes, frequently under conditions of cut-throat competition and limited regulation. The percentage of total trips made on the Metro system has also declined, despite increases in system capacity and substantial government subsidies.

In contrast, the *colectivo* service (mainly minibuses) has increased dramatically, becoming the dominant mode of mass transportation. Even at higher fares, these vehicles offer superior service and convenience, making them increasingly attractive compared to the Metro and relatively inflexible fixed-route buses. However, intense competition among thousands of proprietors/operators of minibuses generates chaos, excess pollution, and accidents in the absence of an effective regulation. Furthermore, the *colectivo* fleet is getting older and more polluting.

Overall, travelers are using high-occupancy modes of transport less frequently (e.g., buses and rail transit) and increasingly using low occupancy mass transit vehicles (particularly *colectivos*) and private autos. To a substantial degree, these changes have occurred because the existing transportation system has not adequately adapted to the changing population distribution, economic changes, and resulting new travel patterns. Due to weak development planning and land use controls, low-income housing is constructed in locations that lack adequate road capacity and mass transportation options, and new commercial development occurs with inadequate roadway construction and transit access.

Freight transport has a special relevance because of its high polluting emissions, the excessive antiquity of the fleet and the effect that it has on the traffic conditions in the MCMA. The concentration of economic activity in the MCMA makes it an important shipping destination. There is substantial intra-city truck traffic; furthermore, much inter-city trucking travels through Mexico City on route to other destinations, lacking adequate circumferential routes.

Population and economic growth, increasing travel demand, metropolitan dispersion, and inadequate expansion of road and rail transit infrastructure in the areas of greatest growth have combined to produce increasingly severe traffic congestion throughout the MCMA. This increasing congestion results in inefficient vehicle operation creating higher levels of pollution per kilometer traveled.

Our transportation team has provided recommendations in which the MCMA can work to create a sustainable transportation/mobility/environmental system. As mentioned above, some of the recommendations have been incorporated in the Air Quality Management Plan. Over the past two years, the government authorities in the MCMA have taken major steps to implement some of the recommendations to reduce transport-related emissions and to enhance mobility. Most notably:

- Impose progressively tougher new car emission control standards;
- Improve fuel quality by reducing the sulfur content of both gasoline and diesel fuel so that new vehicle technologies can be introduced.
- Enforce an increasingly strict and technically sophisticated Vehicle Verification Program for semi-annual inspection of vehicle emission control systems.
- Increase the use of high-capacity public transportation by extending the metro lines, introducing bus rapid transit, improving service quality and personal security and facilitating inter-modal transfers.
- Provide low-interest loan for taxi substitution.
- Construction of roadway and other infrastructure.

Metropolitan Coordination and Citizenship Participation.

One of the major obstacles to the implementation of anti-pollution measures in the MCMA is the lack of a powerful metropolitan institutional structure. The Metropolitan Environmental Commission (CAM)—an interagency that consists of environmental authorities from the federal

government, the State of Mexico and the Federal District— was created in 1996 to coordinate the policies and programs that are implemented in the metropolitan area. However, CAM does not have a specific budget for its own operation, nor does it have a defined operative organizational structure. Furthermore, the constant change of personnel according to political winds, its lack of independent budget, and its lack of power to enforce regulations have a negative influence on the functioning of this agency. To ensure continuity in the implementation of long-term action plans, we recommend that the CAM should be significantly restructured and should be empowered to carry out the planning, integration and implementation of metropolitan environmental policies.

During the design of the new air quality management program, the CAM increased its efforts to encourage public participation and stakeholder input by forming working groups consisting of representatives from academia, NGOs and industries.

The Mexico City Case Study has also implemented several activities including workshops and symposia, distinguished visiting faculty and scientists, and air quality management courses for professionals, policy makers and environmental leaders from non-governmental organizations, media and industry. The outreach activities currently underway involve stakeholder education and participation. The awareness of the population and the active and informed participation of stakeholders are necessary to ensure public acceptance of pollution control policies.

Summary.

The pressing environmental issues of urban pollution, land degradation, and climate change are closely linked problems sharing common causes and solutions. The fact that air pollutants and greenhouse gases arise largely from combustion (fossil, biofuel, and biomass), and that particulate matter play key roles in air quality, climate change and ecosystem perturbations are illustrative examples. Clearly there is a need to pursue and coordinate studies that can support environmental policies that achieve multiple benefits.

The Mexico City Case Study brings together health, transportation, administration, and many other interdisciplinary approaches to understanding and defeating air pollution. Although we have focused on the Mexico City area, the work carried out under this Case Study has significance for developing nations generally. Policies to reduce air pollution must be based on the best available scientific knowledge; however, political will and capacity must transform this knowledge into action. What is learned from this Mexico City Case Study will provide insights on the challenges and opportunity facing other megacities of the world.

In summary, the solution of the air pollution problem in the MCMA requires a great deal of effort that must be maintained in the long term. The development and effective implementation of solutions is not a luxury, but a necessity to guarantee the health of the inhabitants of the MCMA and the welfare of society. For this, it is necessary to have the active and informed participation of society, the private sector, the academic community, social organizations, and the government, since dealing with pollution requires the implementation of different specific strategies in multiple fields of action.